Spatial-Temporal Assessment of Drought in Hoa Vang district, Da Nang City, Vietnam Using Remote Sensing and Google Earth Engine

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Abstract. The objective of this research was to map the drought risk in Hoa Vang district, Da Nang city, and analyze the variability of drought events from 1991 to 2020 using remote sensing imagery. To achieve this, remote sensing and GIS methods were utilized to gather information on land surface temperature and the Normalized Difference Vegetation Index (NDVI). The study effectively employed the Google Earth Engine which is a cloud-based computing platform to analyze image sequences from Landsat 5 and OLI sensors spanning the period from 1991 to 2020. This analysis aimed to extract the remote sensing indices and applied them for drought assessment and monitoring. The study employed land surface temperature (LST) and Normalized Difference Vegetation Index (NDVI) to derive the Temperature Condition Index (TCI), Vegetation Condition Index (VCI), and Vegetation Health Index (VHI). These indices were utilized to assess drought conditions in Hoa Vang district, Da Nang city, over the period from 1991 to 2020. The research findings reveal that the drought values in Hoa Vang district exhibited variations throughout the studied period. Notably, regions at risk of drought during the later periods exhibited an increasing trend compared to the initial periods. This suggests a potential escalation in drought severity in the study area over time. The outcomes of this study provide essential background for evaluating the impacts of drought on agricultural production in Hoa Vang district, Da Nang city.

Keywords: Drought, Google Earth Engine, Hoa Vang, temperature, Vegetation Health Index.

1. Introduction

Drought is indeed a widespread natural disaster that has been increasing in severity in recent decades [1]. The United Nations Office for Disaster Risk Reduction estimates that drought has affected 1.5 billion people since the beginning of the century and caused economic losses of over $124 billion globally [2]. Drought occurs when there is a prolonged period of below-average rainfall, resulting in reduced river and stream flows, lowered water levels in lakes and reservoirs, and depleted groundwater resources. These conditions have significant implications for water availability, agricultural production, and overall ecosystem health [3].

In addressing the challenges posed by drought, Geographic Information System (GIS) and remote sensing play a vital role. Remote sensing provides timely and up-to-date information across different spatial and temporal scales, which would be time-consuming to obtain through traditional methods like field surveys [4]. Google Earth Engine (GEE) is a powerful tool that offers a wide range of capabilities for assessing drought hazard and conducting geospatial analysis. It provides access to extensive collections of satellite imagery and other geospatial data, allowing researchers to analyze large-scale datasets with global coverage. The GEE code editor enables users to implement various analysis algorithms and data processing techniques to generate maps and perform complex computations. This includes the ability to calculate drought indices, such as the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST), which are essential for drought assessment and monitoring.

The climatological community has indeed classified drought into four types: meteorological drought, hydrological drought, agricultural drought, and socioeconomic drought. In the context of agricultural drought research, the Vegetation Health Index (VHI) is widely used as an indicator of drought severity [5-8]. The VHI assesses drought by considering the health condition of vegetation and the impact of temperature on crop conditions [6, 9]. The VHI is calculated based on two primary components: the Land Surface Temperature (LST) and the Normalized Difference Vegetation Index (NDVI). The NDVI is used to determine the Vegetation Condition Index (VCI), which reflects the health and vigor of vegetation. On the other hand, the LST is used to determine the Temperature Condition Index (TCI), which indicates the thermal stress experienced by vegetation [10]. By combining these indices, the VHI provides a comprehensive assessment of drought stress on the vegetation canopy [11].
Hoa Vang district covers a significant portion approximately 78% of Da Nang city, Vietnam [12]. The district experiences a dry season from May to August each year, during which drought events often occur. These droughts lead to water shortages for rice production, impacting the yield, output, and income of local residents who rely on agriculture for their livelihoods. Given the importance of agriculture in Hoa Vang district and the significant impact of drought on rice production, it is crucial to understand and address the challenges posed by water scarcity and drought events in this study area.
This study aims to assess drought conditions in Hoa Vang district, Da Nang city over the period from 1991 to 2020. By establishing the VCI, TCI, and VHI maps, the study provides valuable insights into the temporal variations of drought severity and its impact on vegetation health in study area. These maps serve as important tools for assessing and monitoring drought conditions, aiding in the management of agriculture and water resources in the region.

2. Methodology

2.1. Study areas and Data processing

The study area is Hoa Vang district, Da Nang city, with an area of 73317 ha [12]. Hoa Vang is located in a typical tropical monsoon climate zone in Da Nang city which is in the Central Region of Vietnam. Hoa Vang has a diverse and complex terrain, spanning all three regions: mountainous, midland, and plain. There are two distinct seasons each year: a prolonged rainy season from September to December and a dry season from January to August. In particular, drought often occurs in the dry season from May to August in the study area. This is the time with the highest temperature and lowest rainfall in Hoa Vang district.

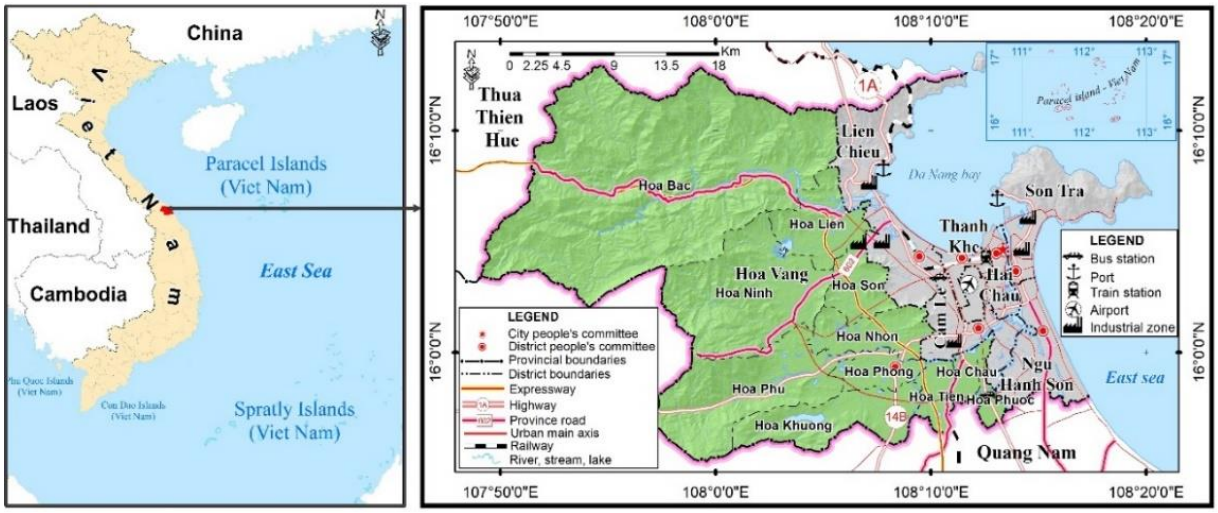

Figure 1. Location of Hoa Vang district, Da Nang city.

The average annual temperature in Hoa Vang district is 26.7°C, with the highest temperatures occurring in May, June, July, and August, averaging around 29-30°C, and the lowest temperatures in December, January, and February, averaging around 21-24°C. In the mountainous area of Ba Na at an altitude of nearly 1,500 meters, the average temperature is around 20°C. The average annual sunshine hours are 2,438 hours, with the most sunshine in May and June, ranging from 262 to 282 hours per month on average, and the least sunshine in December and January, ranging from 136 to 152 hours per month [12].

In Hoa Vang district, there is a river system including the Cu De River in the north and several rivers in the south such as the Tuy Loan River and Yen River, which are tributaries of the Ai Nghia River and Vu Gia River. The water regime of these rivers varies significantly with the seasons, leading to flooding during the rainy season and water scarcity during the dry season, contributing to drought conditions in Hoa Vang district.

In this study, Google Earth Engine platform was used to process a series number of Landsat images during the dry season from May to August in the period of 1991 to 2020. Accordingly, we conducted an analysis of 412 images of Landsat 5 TM and Landsat 8 OLI during the study period to calculate the average summer temperature. According to statistics, the highest temperature of Hoa Vang district, Da Nang city is in the period from May to August which is the hottest time of the year in Hoa Vang. The flowchart of data processing is presented in Figure 2 as below:

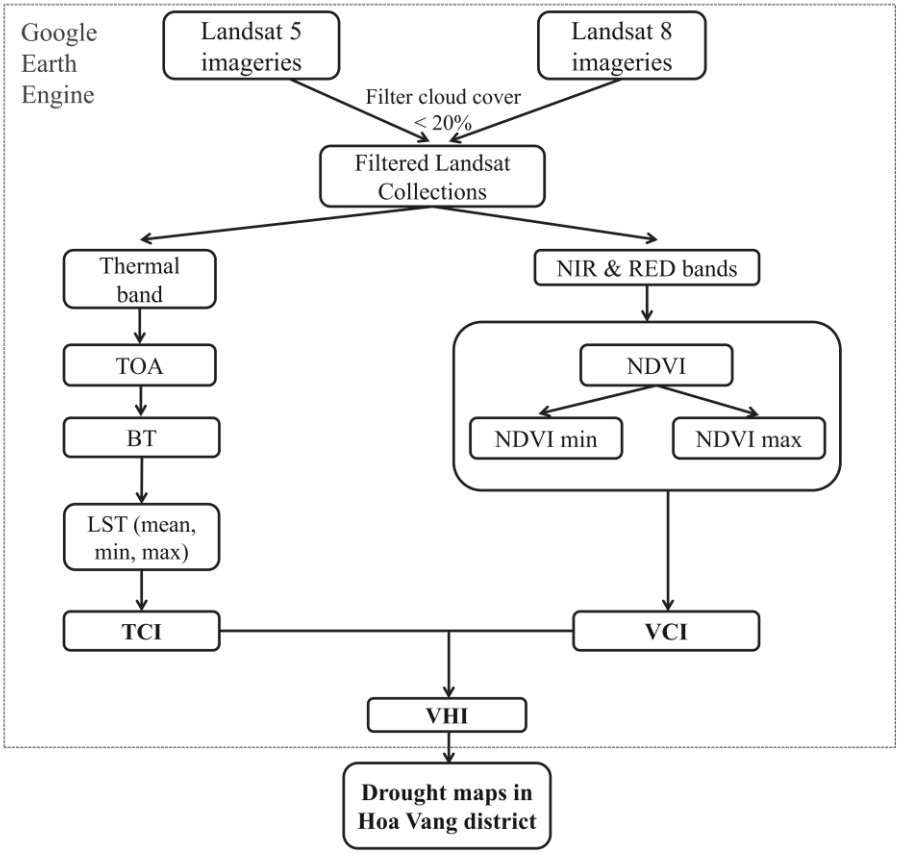

Figure 2. Flowchart of data processing.

Note:
TOA: Top of atmosphere; BT: brightness temperature; LST: land surface temperature; NDVI: normalized difference vegetation index; NIR: near infrared reflectance; VCI: Vegetation Condition Index; TCI: Temperature Condition Index; VHI: Vegetation Health Index.

2.2. Extraction of Normalized Difference Vegetation Index (NDVI) from Landsat imageries using Google Earth Engine

Normalized Difference Vegetation Index (NDVI) is widely used in global environmental and climate change studies [13]. NDVI is calculated as the normalized difference between the measured reflectance of vegetation in the red and near-infrared wavelengths [14]. Many researchers have used NDVI for vegetation monitoring purposes [15]. In drought studies, satellite-based NDVI data can be used to indicate precipitation deficits and assess both meteorological and agricultural drought conditions. NDVI is calculated using the formula:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR}-\mathrm{RED})}{(\mathrm{NIR}+\mathrm{RED})} \quad (1)$$

In which, RED and NIR represent the spectral reflectance measurements in the red and near-infrared regions of the electromagnetic spectrum, respectively. In this study, we computed NDVI values from 412 Landsat TM and OLI images for the period from 1991 to 2020 using the Google Earth Engine cloud computing platform (image.normalizedDifference function). Furthermore, we calculated the average NDVI values for the periods 1991-1995, 1996-2000, 2001-2005, 2006-2010, 2011-2015, and 2016-2020 using GIS software (QGIS).

2.3. Extraction of Land Surface Temperature from Landsat imageries using Google Earth Engine

Based on reviewing previous studies on LST extraction from remote sensing [16, 17] and integrating the usage of Google Earth Engine to process satellite imageries [18]. The steps are as follows:

(1) Calculation of spectral radiation (TOA); (2) Convert radiation values to temperature values (BT); (3) Calculate vegetation proportion (Pv); (4) Calculate emissivity (ε) and (5) Calculate land surface temperature (LST)

$$\mathrm{LST} = \frac{\mathrm{BT}}{(1+\left(0.00115 \times \frac{\mathrm{BT}}{1.4388}\right) \times \mathrm{Ln}(\varepsilon)} \quad (2)$$

The setting of formulas for calculating temperature is carried out on Google Earth Engine. On that basis, we calculated the temperature of 412 Landsat TM and OLI images for the period from 1991-2020. Continuing, we calculated the average temperature of the periods 1991-1995, 1996-2020, 2001-2005, 2006-2010, 2011-2015 and 2016-2020 on GIS software (QGIS).

2.4. Calculation of VCI, TCI and VHI using Landsat images on Google Earth Engine platform and GIS

2.4.1. Vegetation Condition Index (VCI). National Oceanic and Atmospheric Administration (NOAA) has designed a Vegetation Condition Index (VCI) based on data from the AVHRR sensor, which is highly useful for monitoring agricultural drought [19]. VCI compares the current NDVI value with the observed range of values during the same period in previous years and can detect vegetation development over time [20]. VCI is calculated using Equation (3) and provides information about the severity and extent of drought [19].

$$\mathrm{VCI} = \frac{(\mathrm{NDVI}-\mathrm{NDVI}_{\mathrm{min}})}{(\mathrm{NDVI}_{\mathrm{max}}-\mathrm{NDVI}_{\mathrm{min}})} \quad (3)$$

In which, NDVI, $\mathrm{NDVI}_{\mathrm{max}}$, and $\mathrm{NDVI}_{\mathrm{min}}$ represent the monthly average NDVI value, the absolute maximum value, and the minimum value over several years corresponding to the same month as the NDVI. NDVI is computed based on a series of Landsat images using the Google Earth Engine cloud computing platform for the period from 1991 to 2000. Both low and high VCI values indicate poor and good vegetation conditions, respectively.

2.4.2. Temperature Condition Index (TCI). TCI (Temperature Condition Index) is an index that measures the distribution of temperature within a region and is represented as a percentage (%). TCI

values range from 50% - the average temperature level, TCI > 50% - temperatures starting to decrease, and as TCI approaches 100%, the temperature in the area decreases.

$$\mathrm{TCI} = \frac{(\mathrm{LST_{max}} - \mathrm{LST})}{(\mathrm{LST_{max}} - \mathrm{LST_{min}})} \times 100 \quad (4)$$

Here, LST represents the value of a pixel at a specific time. LST_{min} and LST_{max} are the minimum and maximum values of LST for all pixels and the corresponding time period [21]. The TCI ranges from 0, indicating extremely unfavorable temperature conditions, to 1, indicating optimal temperature conditions.
Based on the calculated values of LST, LST_{min}, and LST_{max}, the study proceeds to compute the TCI values for different time periods. Subsequently, GIS software (QGIS) is used to calculate the average TCI values for the periods from 1991 to 2020 in Hoa Vang district, Da Nang city.

2.4.3. Vegetation Health Index (VHI). Vegetation Health Index (VHI) is one of the most commonly used indices for monitoring drought using remote sensing technology [22]. VHI consists of two components: the Vegetation Condition Index (VCI) and the Thermal Condition Index (TCI). VHI considers local biological and climatic conditions and can be used to monitor meteorological and agricultural drought conditions in different regions [22].

The basic principles of the Vegetation Health Index (VHI) are as follows: (1) low normalized vegetation index (NDVI) and high land surface temperature (LST) indicate poor vegetation health; and (2) the contributions of VCI and TCI to VHI are assumed to be equal, as there is no available data on the relative contributions of other conditions to vegetation health [22]. VHI is calculated using the following formula:

$$\mathrm{VHI} = \alpha \times \mathrm{VCI} + (1 - \alpha) \times \mathrm{TCI} \quad (5)$$

In which, the coefficient α determines the contribution of VCI and TCI to VHI, and it varies depending on the environment of the study area. Since the specific contributions of VCI and TCI to VHI are unknown, in this study, based on previuos research, we used α equals to 0.5 [9, 23-25]. The VHI values were validated using correlation tests using LST and NDVI as influencing factors. The VHI values were classified into four categories: Extreme drought (<10), Severe drought (10-20), Moderate drought (20-30), Mild drought (30-40), and No drought (>40) [21, 26, 27].

3. Results and Discussions

3.1. Variations of the Normalized Difference Vegetation Index in Hoa Vang district
In this study, we calculate NDVI values on Landsat TM and OLI images based on the Google Earth Engine cloud computing platform. Specifically, the study used 421 Landsat images from 1991 to 2020 and calculated the specific NDVI value of each image. Next, we calculate the average NDVI value for each year from 1991 - 2020. Finally, the study uses GIS software (QGIS) to calculate the average NDVI value and edit maps for each period. from 1991-2020. The results are shown in Figure 3.

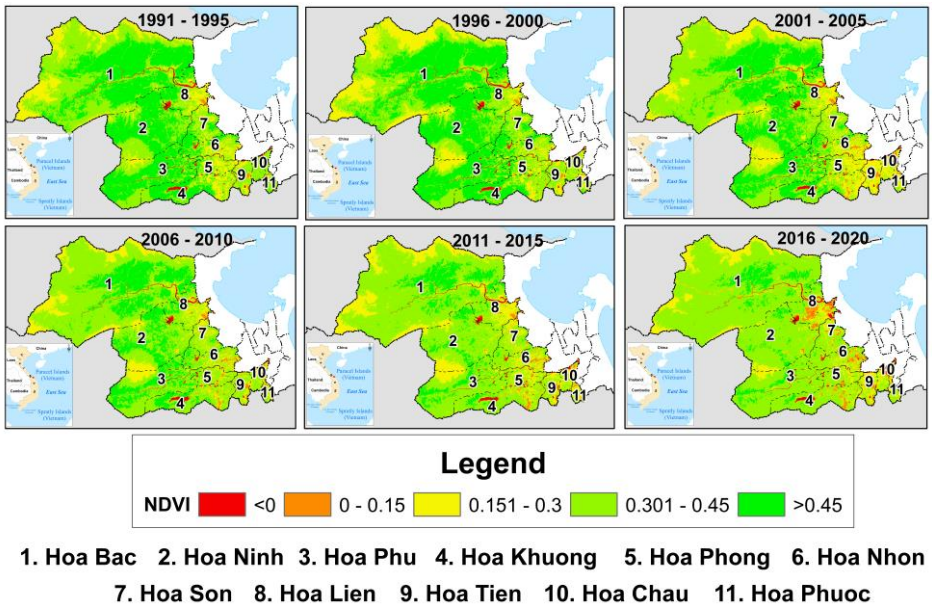

Figure 3. Map of NDVI in Hoa Vang district in the period of 1991-2020.

Table 1. NDVI values in Hoa Vang district in the period of 1991-2020.

Community	Stage						Average
	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	
Hoa Bac	0.412	0.404	0.399	0.392	0.372	0.368	**0.391**
Hoa Ninh	0.442	0.439	0.419	0.411	0.391	0.387	**0.415**
Hoa Son	0.372	0.377	0.355	0.344	0.324	0.316	**0.348**
Hoa Tien	0.307	0.296	0.233	0.287	0.267	0.256	**0.274**
Hoa Chau	0.330	0.296	0.236	0.260	0.240	0.238	**0.267**
Hoa Phuoc	0.339	0.305	0.251	0.270	0.250	0.255	**0.278**
Hoa Lien	0.348	0.353	0.328	0.327	0.307	0.265	**0.321**
Hoa Nhon	0.365	0.371	0.332	0.338	0.318	0.308	**0.339**
Hoa Phong	0.319	0.333	0.296	0.318	0.298	0.301	**0.311**
Hoa Khuong	0.387	0.390	0.360	0.365	0.345	0.338	**0.364**
Hoa Phu	0.443	0.441	0.422	0.413	0.393	0.389	**0.417**
Hoa Vang district	**0.405**	**0.401**	**0.384**	**0.381**	**0.361**	**0.355**	**0.381**

Based on Figure 3 and Table 1, we can see that the NDVI value in Hoa Vang district is relatively high. This proves that the area covered by vegetation still occupies a large area, especially mountainous communes such as Hoa Bac (0.391), Hoa Ninh (0.415) and Hoa Phu (0.417). Communes in the delta, where construction density is higher, have smaller NDVI values than average such as Hoa Chau (0.267), Hoa Tien (0.274) and Hoa Phuoc (0.278). Through Figure 3 and Table 1, we can also see that this NDVI value tends to decrease in the period 1991-2020, from 0.405 in the period 1991-1995 down to 0.355 in the period 2016-2020.

3.2. Results of land surface temperature mapping

Annual Land Surface Temperature (LST) values during dry season from 1991-2020 are calculated on Google Earth Engine. We then calculated the average temperature for each period on the GIS software. The results are shown in Figure 4.

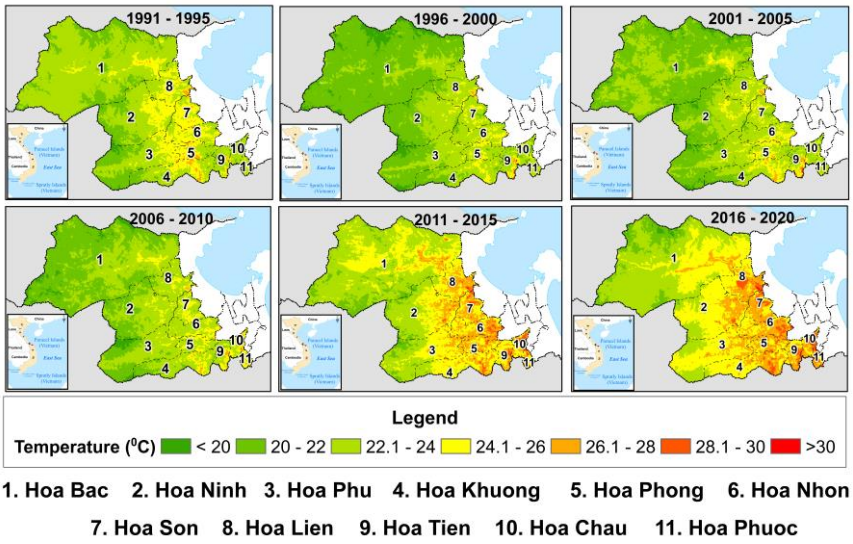

Figure 4. Average temperature (°C) in Hoa Vang district, Da Nang city from 5-8 months 1991-2020.

Based on Figure 4, we can see that the temperature of Hoa Vang district, Da Nang city has changed over the periods from 1991-2020. In general, temperatures in later stages are higher than in previous periods, in line with global temperature variability. High temperatures are concentrated in the high population density area, where there is a high density of construction, and high speed of urbanization.

Subsequently, we calculated the average temperature by districts in Hoa Vang district, Da Nang city, the results are shown in Table 2.

Table 2. Average temperature in Hoa Vang district, Da Nang City in the period 1991-2020.

Community	Stage						
	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	Average
Hoa Bac	22.64	21.12	21.75	21.67	23.46	23.30	22.32
Hoa Ninh	22.75	21.96	22.14	22.35	23.99	24.82	23.00
Hoa Son	24.65	23.47	23.46	23.75	26.29	26.66	24.71
Hoa Tien	23.20	23.48	23.87	23.64	25.92	26.52	24.44
Hoa Chau	22.80	23.06	23.07	23.95	26.43	27.06	24.40
Hoa Phuoc	23.18	23.28	23.24	24.78	26.81	27.36	24.78
Hoa Lien	24.09	22.98	23.19	23.25	25.88	26.40	24.30
Hoa Nhon	24.13	23.39	23.49	23.66	26.38	26.55	24.60
Hoa Phong	24.23	23.40	23.80	23.65	26.25	26.33	24.61
Hoa Khuong	23.41	22.62	23.08	22.91	25.20	25.84	23.84
Hoa Phu	22.53	21.79	22.02	22.13	23.88	24.85	22.87
Hoa Vang district	**22.94**	**21.83**	**21.91**	**22.28**	**24.22**	**24.50**	**22.95**

Based on Table 2, we can see that in general, the temperature of Hoa Vang district, Da Nang city tends to change in the direction of higher temperatures in the later period than in the previous period. In particular, the period from 2016-2020 had the highest average temperature (24.5 °C), followed by the period from 2011-2015 (24.22°C). Previous periods from 1991-2005 did not have a significant change in temperature. In terms of spatial distribution of temperature, Areas with high urbanization density during the period from 2016-2020 such as Hoa Phuoc (27.36 °C) and Hoa Chau (27.06 °C) have the highest

temperatures. On the contrary, areas with high vegetation density like Hoa Bac (23.3 ºC), Hoa Ninh (24.82 ºC) and Hoa Phu (24.85 ºC) communes have lower temperatures.

3.3. Generation of drought maps in Hoa Vang district

Based on the results of establishing temperature and NDVI maps of different periods, the study conducted to build maps related to drought index in Hoa Vang district, Da Nang city, which are TCI, VCI and VHI maps of different periods from 1991 - 2020. The results are shown in Figure 5 and Figure 6.

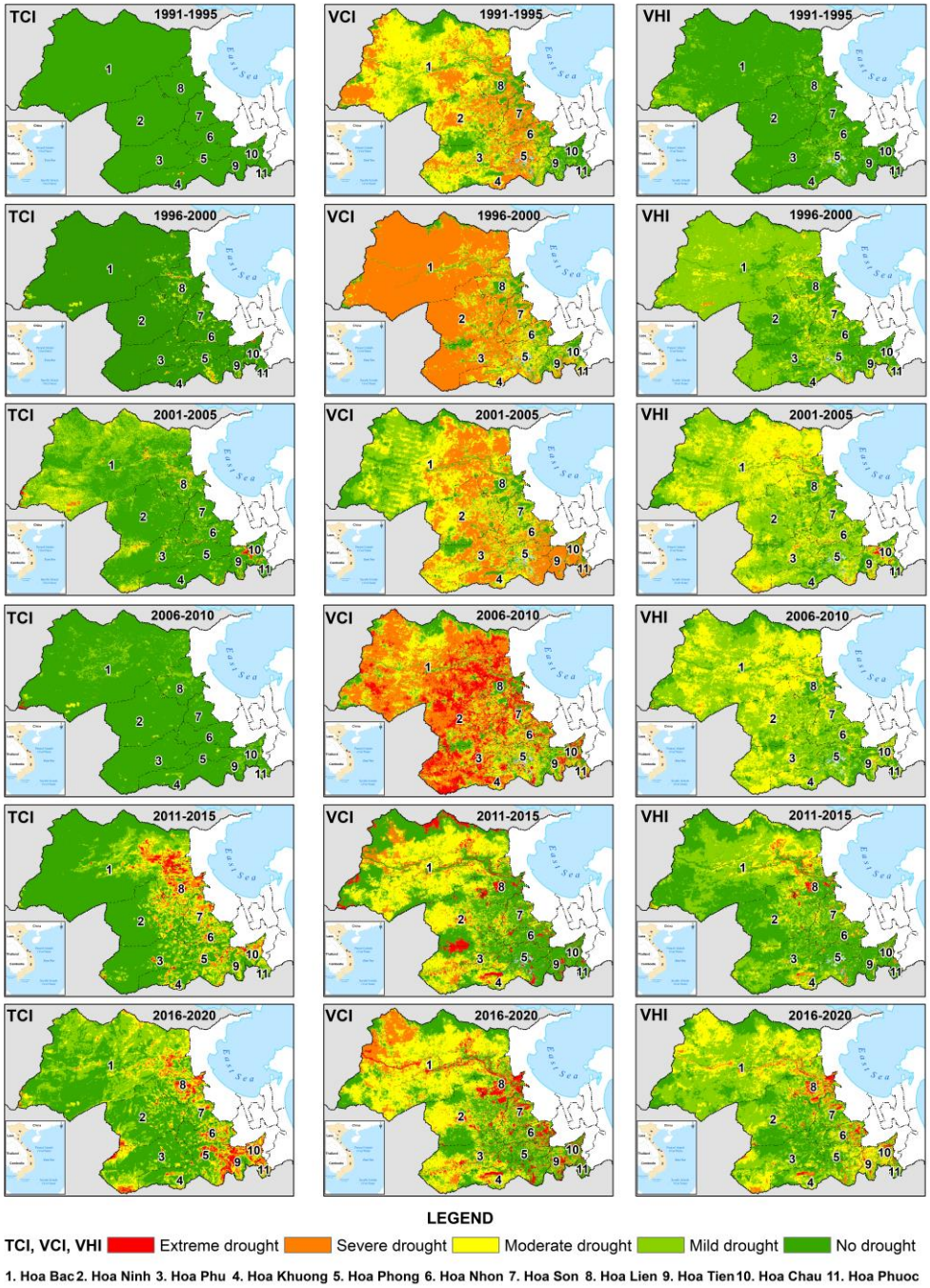

Figure 5. Map of TCI, VCI, VHI in Hoa Vang district in the period 1991-2020.

Within the scope of this paper, we assess the fluctuations of TCI, VCI and VHI indices in the period 2006-2020 in Hoa Vang district, Da Nang city. The statistics on the percentage (%) of drought area in Hoa Vang district are shown in Figure 8.

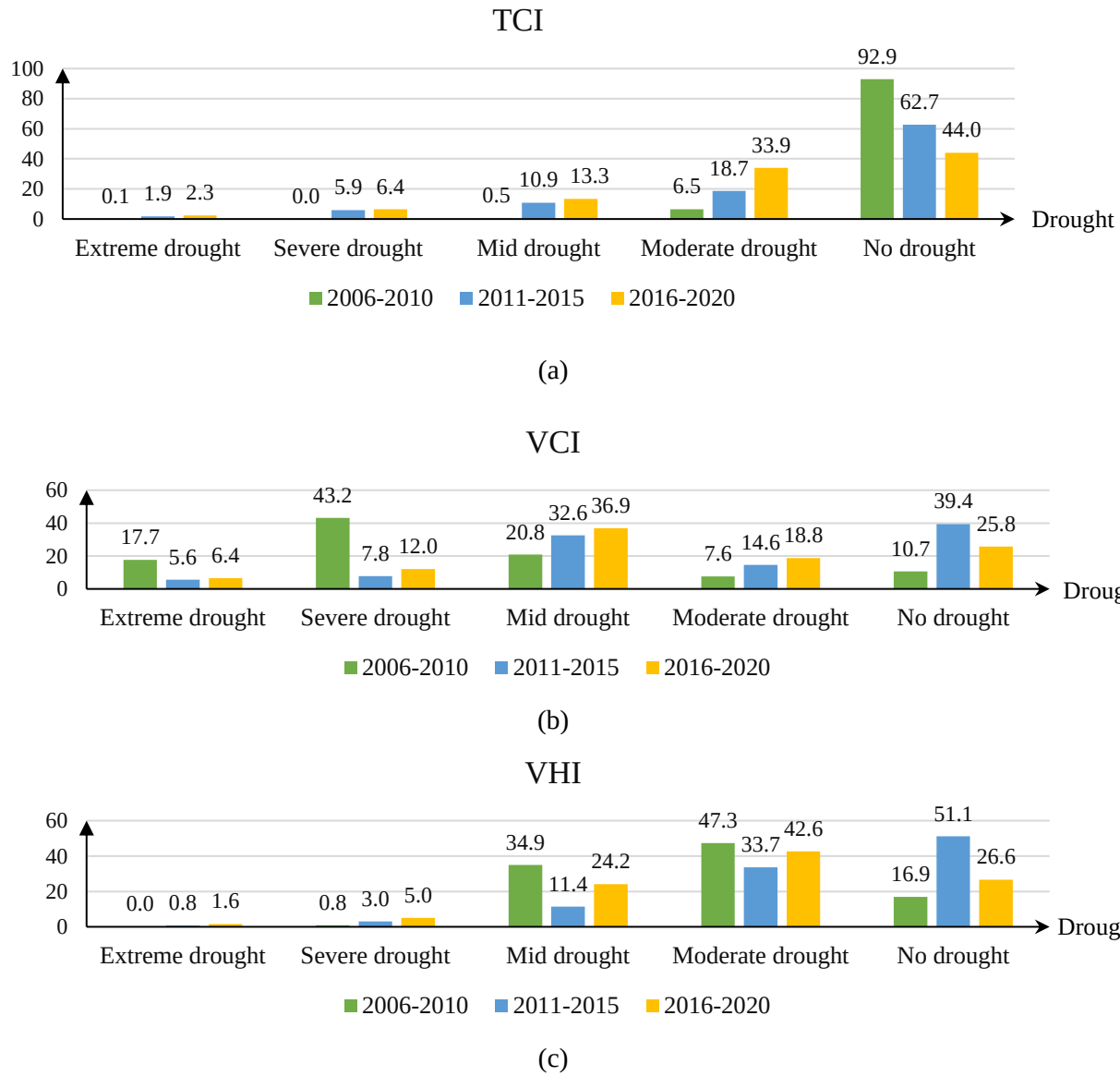

Figure 6. Chart of TCI (a), VCI (b) and VHI (c) values for the period from 2006 - 2020 in Hoa Vang district.

Based on Figure 5 and Figure 6, we can see the values of TCI, VCI and VHI changing over the periods from 2006 - 2020.

Regarding the TCI, we can see that the average dry, moderately dry and very dry values are increasing, while the proportion of non-arid area is decreasing. The reason is that the trend of increasing temperature in the period 2006 - 2020 has greatly affected the TCI. Accordingly, dry areas are increasingly expanding. This will greatly affect related fields, especially agricultural production in the District.

For the VCI, in the period 2006 - 2010, very dry and extremely dry values accounted for a large proportion of the area (about 61%). However, this value decreased sharply in the period 2011 - 2015 and 2016 - 2020. Meanwhile, for medium and light drought levels, the trend changes quite steadily over the periods. Accordingly, this value is increasing in area. For the medium drought level, the area ratio

increased from 20.8% in the period 2006 - 2010 to 36.9% in the period 2016 - 2020. Similarly, for the light drought level, the area ratio also changed in the same direction, from 7.6 % area ratio in the period 2006 - 2010 increased to 18.8% area in the period 2016 - 2020. These areas will significantly affect the agricultural production capacity of the District in the coming time.

As for the VHI, in general this index is increasing in the proportion of areas at risk of drought, especially at the extremely dry and very dry levels. Areas that previously had little drought occurrence in the period 2016 - 2020 have occupied a significant area of average or higher drought such as Hoa Tien, Hoa Chau and Hoa Phuoc communes. Therefore, agricultural production in these areas will be greatly affected in the coming time.

3.4. Assessing drought in Hoa Vang district, Da Nang city

In this study, we conducted a spatial assessment of drought by communes in Hoa Vang district, based on the VHI results of the most recent period from 2016 to 2020. The coverage area of each droght level were calculated by commune and the results are shown in Table 3 and Figure 7.

Table 3. Area and percentage coverage of drought levels by commune based on VHI in the period 2016-2020.

Commune	Drought severity										Total Area
	Extreme drought		Severe drought		Mid drought		Moderate drought		No drought		
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	
Hoa Bac	77.7	0.2	882.6	2.6	10147.8	29.5	17180.0	49.9	6121.6	17.8	**34409.7**
Hoa Chau	103.1	10.2	124.4	12.2	370.3	36.4	268.3	26.4	149.8	14.7	**1016.0**
Hoa Khuong	95.3	1.9	328.2	6.4	995.7	19.5	1974.7	38.8	1700.9	33.4	**5094.7**
Hoa Lien	429.8	10.8	861.2	21.7	952.0	24.0	1161.6	29.3	558.4	14.1	**3963.0**
Hoa Nhon	174.1	5.4	297.6	9.2	593.4	18.3	1010.5	31.1	1168.7	36.0	**3244.3**
Hoa Ninh	44.1	0.4	237.7	2.3	1017.8	9.8	4723.9	45.4	4384.7	42.1	**10408.1**
Hoa Phong	14.2	0.8	82.9	4.5	534.2	28.7	546.1	29.4	681.6	36.7	**1859.1**
Hoa Phu	6.5	0.1	318.1	3.5	1878.5	20.9	3138.2	35.0	3634.4	40.5	**8975.8**
Hoa Phuoc	67.8	9.1	55.9	7.5	129.5	17.4	237.8	31.9	253.5	34.1	**744.6**
Hoa Son	94.3	3.9	254.4	10.4	383.0	15.7	903.6	37.1	799.1	32.8	**2434.4**
Hoa Tien	69.4	4.7	194.4	13.3	765.9	52.4	309.3	21.1	123.5	8.4	**1462.4**
Sum	**1176.4**	**1.6**	**3637.5**	**4.9**	**17768.1**	**24.1**	**31453.9**	**42.7**	**19576.2**	**26.6**	**73612.1**

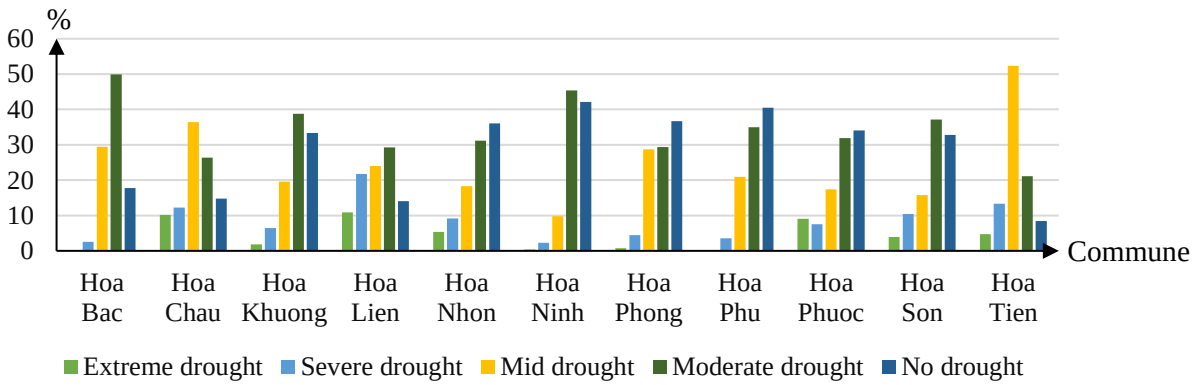

Figure 7. Percentage (%) areas according to drought levels (VHI) by communes in Hoa Vang district in the period 2016 - 2020.

Based on Table 3 and Figure 7, we can see that all levels of drought occur in communes of Hoa Vang district. However, the degree of impact of drought on these areas is different. In general, mild and moderate droughts account for a large proportion of localities, with an area of about 50,000 hectares, accounting for about 77% of the District's area.

Extremely severe drought is mainly distributed in Hoa Lien commune with an area of 429.8 hectares, accounting for 10.8% of the commune area, followed by Hoa Chau commune with 103.1 hectares, accounting for 10.2% of the area. Next is Hoa Phuoc commune with 67.8 hectares, accounting for 9.1% of the commune's area. The remaining communes have a smaller proportion of extremely severe drought areas.

For severe drought, concentrated in Hoa Lien commune (21.7%), Hoa Tien (13.3%), Hoa Chau (12.2%), Hoa Son (10.4%), Hoa Nhon (9.2%). The remaining communes account for a smaller percentage of severe drought area. It can be seen that Hoa Lien is the commune most strongly affected by drought in Hoa Vang district, with the total area of drought at two levels, extremely severe and severe, over 30% of the commune's area. This will have a significant impact on the commune's agricultural production activities.

When it comes to the moderate drought level, the analysis reveals noticeable disparities among the communes in the share of land affected. Specifically, Hoa Tien commune stands out as having the highest percentage of area impacted by average drought at 52.4% of its total land. Hoa Chau commune comes next with 36.4% of its area experiencing moderate drought during 2016-2020. Two other major rice growing communes - Hoa Bac and Hoa Phong - also saw over a quarter of their territory being under the influence of medium drought in the studied period, with the numbers being 29.5% and 28.7% respectively.

In general, moderate to extremely severe droughts are concentrated mainly in the main rice and annual crop growing areas in Hoa Vang district such as Hoa Lien, Hoa Tien, Hoa Chau, Hoa Phong communes. Therefore, to develop sustainable agriculture in these areas, we need to pay attention to drought prevention, especially ensuring water for irrigation in agricultural production areas during prolonged dry periods.

4. Conclusions

From the results of the assessment of drought fluctuations in Hoa Vang district, Da Nang city by remote sensing and Google Earth Engine, we have some conclusions:

- The use of Google Earth Engine in calculating temperatures is highly efficient, saving time and costs. In this study, we used 421 Landsat TM and Landsat OLI images to calculate NDVI value and average temperature for the period 1991-2020 in Hoa Vang district, Da Nang city.

- In general, the temperature of Hoa Vang district, Da Nang city tends to change in the direction of higher temperatures in the later period than in the previous period. In particular, the period from 2016-2020 had the highest average temperature (24.50 ^{o}C), followed by the period from 2011-2015 (24.22 ^{o}C). The results of the study showed that the average temperature of Hoa Vang district, Da Nang city was 22.95 ^{o}C. In the early stages from 1991-2005, the temperature did not fluctuate sharply, fluctuating in the temperature range of 22.93 ^{o}C. However, in the period from 2011-2020, the temperature increased sharply, reaching a value of 24.50 ^{o}C. Communes such as Hoa Phuoc (27.36 ^{o}C), Hoa Chau (27.06 ^{o}C) has the highest temperature value.

- Based on the calculation of LST and NDVI, the study has established VCI, TCI and VHI maps for the period from 1991 - 2020 in Hoa Vang district. Regarding the TCI, we can see that the average dry, moderately dry and very dry values are increasing, while the proportion of non-arid area is decreasing. Meanwhile, in the VCI in the period 2006 - 2010, the very dry and extremely dry values account for a large proportion of the area (about 61%). However, this value decreased sharply in the period 2011 - 2015 and 2016 - 2020. Finally, VHI in general is increasing in the proportion of areas at risk of drought, especially at the extreme drought level and very dry. Areas that previously had little drought occurrence

in the period 2016 - 2020 have occupied a significant area of average or higher drought such as Hoa Tien, Hoa Chau and Hoa Phuoc communes.

- Finally, the study conducted an assessment of drought fluctuations based on the VHI in communes of Hoa Vang district in the period 2016 - 2020 according to the percentage of area. In general, moderate to extremely severe droughts are concentrated mainly in the main rice and annual crop growing areas in Hoa Vang district such as Hoa Lien, Hoa Tien, Hoa Chau, Hoa Phong communes.

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