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INTEGRATING AHP ANALYSIS TECHNIQUES AND GIS TECHNOLOGY TO ESTABLISH THE DRY MAP OF HA TINH PROVINCE

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Abstract

Drought is a complex natural phenomenon that develops slowly and causes serious impacts on people's living environment and production activities. Researching technologies that can assess the current situation while also providing early warnings or predicting drought risks is essential. To date, numerous methods and approaches for assessing, monitoring, and forecasting drought have been researched and applied. Notably, research has focused on developing and calculating drought indices derived from remote sensing images, which offer many advantages in assessing drought levels over large areas. In this study, five component indices (TCI, SAVI, VCI, WSVI, TVDI) are classified into different levels of importance, extracted from Landsat 8 data, and assigned weights based on their level of influence according to the direction of the index using the Analytical Hierarchy Method (AHP). The results have established a drought risk map for Ha Tinh province with five levels: No drought, low drought, moderate drought, high drought and very high drought. The findings indicate that the majority of Ha Tinh province is at non-drought and low drought levels (accounting for 88.59 % of the province's natural area). Moderate, high and very high drought levels make up 11.41 % of the province's natural area. Specifically, the area at moderate drought level accounts for 8.82 %, concentrated in Huong Son, Huong Khe, Cam Xuyen districts, as well as in the coastal communes of Thach Ha, Can Loc and Ky Anh districts. Areas affected by high and very high drought levels account for about 2.59 % of the province's natural area, appearing locally at some parts of Ky Anh, Nghi Xuan and Cam Xuyen districts.

Keywords: Drought; Ha Tinh; TCI; SAVI; VCI; WSVI; TVDI.

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1. Introduction

Drought is a natural phenomenon that seriously affects people's living environment and production activities. It is considered the third damaging disaster after floods and storms and has become increasingly intense and harder to control due to the impacts of climate change [1]. Therefore, quantifying the impacts of droughts, as well as monitoring and reporting its developments, is especially important for countries that have been, are currently, or will be severely affected by climate change.

In Vietnam, drought occurs throughout the country at different levels and durations, with the Central region being especially severe. On average in the past 10 years, the drought-affected area in the Central region reached 140,000 hectares and nearly 50,000 hectares were lost. Prolonged drought has seriously affected life as well as agricultural production and increased the risk of forest fires [8].

Ha Tinh is a province in the North Central region with diverse and complex terrain, often affected by various natural disasters. In recent years, the effects of climate change in Ha Tinh province have become increasingly evident, with noticeable changes such as rising temperatures over time. Additionally, rainfall distribution has changed significantly. Although total rainfall remained relatively consistent over the years, it is often concentrated in short periods and primarily during the rainy season. This has led to increasingly severe local droughts, accelerated desertification of arable land, and significant reductions in plant cover due to forest fires and water resource depletion.

Drought assessment and monitoring methods typically rely on rainfall data, which is limited because it is costly to place monitoring stations densely and challenging to obtain in near real-time. Meanwhile, satellite imagery is abundant, readily available, and can be used to identify the occurrence, duration, and intensity of droughts [15]. Numerous studies worldwide have shown that remote sensing data plays an important role in monitoring, evaluating, and zoning droughts. For example, studies using MODIS products have investigated soil moisture changes based on the Temperature Vegetation Dryness Index (TVDI) [12] [. Agricultural drought trends have been assessed using vegetation indices obtained from remote sensing data, including NDVI, VCI, and the Vegetation Temperature Condition Index VTCI [6, 18]. Additionally, Landsat and Sentinel satellite images have been applied in drought monitoring.

In Vietnam, remote sensing data has also been widely used in various drought studies, including monitoring and assessing drought levels through the Temperature Vegetation Dryness Index (TVDI) [10, 17]; Evaluating drought impacts on agricultural land [9]; Developing drought and agricultural drought zoning maps [11]; Establishing composite drought maps [5] and researching agricultural drought conditions on the Google Earth Engine platform [11].

In addition to remote sensing technology, which collects, measures and analyzes geospatial information on the Earth's surface, GIS technology offers functions for storing, analyzing, managing databases, as well as displaying geospatial data on map models. This functionality makes it easy to interact with spatial and attribute information about objects.

Additionally, with its ability to overlay thematic maps, GIS can identify areas at risk of natural disasters due to multiple influencing factors.

Based on the above analysis, this article presents a method for extracting and synthesizing weighted geospatial information from satellite imagery to create a drought risk zoning map of Ha Tinh province. This approach aims to identify areas with a high likelihood of drought, contributing to efforts to prevent and mitigate severe drought conditions in the province.

2. Data used and research methods

2.1. Research area

Ha Tinh is a province in the North Central coast region, located between 17°53’50” and 18°45’40” North latitude and 105°05’50” and 106°30’20” East longitude. The administrative boundaries of the province are as follows: To the North, it borders Nghe An province; To the South, it borders Quang Binh province; To the East, it borders the East Sea; To the West, it borders the Lao People’s Democratic Republic (Figure 1).

2.2. Data

Ha Tinh is one of the provinces with the harshest climates in Vietnam. Due to its terrain and geographical location, the weather in Ha Tinh exhibits characteristics of both the South and the North. According to a report on climate change in Ha Tinh province by the Institute of Natural Resources and Environmental Policy Strategy, the average annual temperature in Ha Tinh has increased by 0.7 to 1 °C over the past 40 to 50 years, and the number of dry days in dry season has increased by approximately 12 % [4]. In recent years, the effects of climate change in Ha Tinh have become increasingly clear and recognizable, with manifestations such as rising temperatures and prolonged heat waves, particularly severe ones that occur frequently. This has resulted in a shortage of rainfall in certain areas, leading to the risk of local water shortages in districts such as Huong Son, Huong Khe, Vu Quang, and Ky Anh. Additionally, downstream basins are on high alert for drought during the summer months.

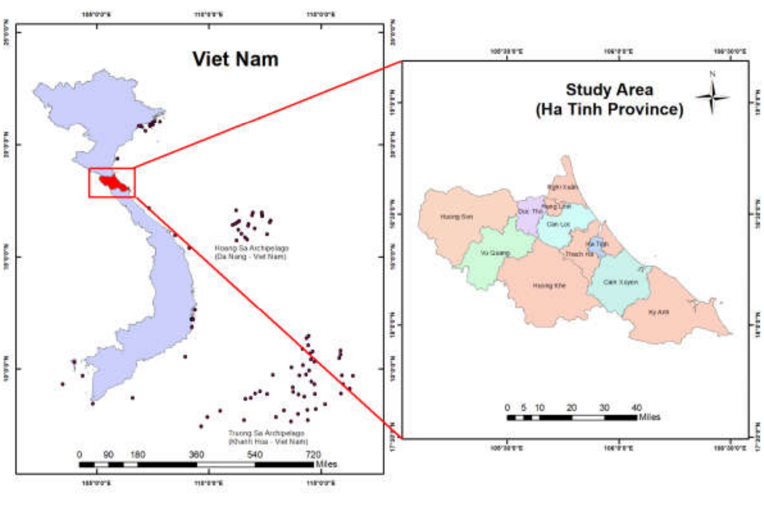

Figure 1: Geographical location of Ha Tinh province

The main data used in this study consists of Landsat 8 OLI_TIR remote sensing images downloaded from the United States Geological Service (USGS) website at https://earthexplorer.usgs.gov/. These images have an average spatial resolution of 30 meters in the multispectral channels, 60 to 120 meters in the thermal infrared channel, and 15 meters in the panchromatic channel. The area of Ha Tinh province encompasses three images, and the numbers corresponding to these images used in the study are as follows:

LC08_L1TP_126047_20230630_20230711_02_T1, taken June 30, 2023;

LC08_L1TP_126048_20230630_20230711_02_T1, taken June 30, 2023;

LC08_L1TP_127047_20230520_20230524_02_T1, taken May 20, 2023.

2.3. Research methods

2.3.1. Method for extracting indicators

Drought can be described in many different ways, so single indicators are often not suitable for decision-making. Therefore, multiple indicators and factors that contribute to drought phenomena should be considered simultaneously. Currently, the main factors typically examined when studying drought are rainfall and temperature. Research results applying drought indices built from these factors have shown promising outcomes. Consequently, in this study, five indices TCI, SAVI, VCI, WSVI and TVDI were selected to evaluate the severity of drought.

Accordingly, the indexes are calculated based on the proposed formulas as follows:

a. Temperature condition index (TCI)

TCI is an index used to identify temperature-related drought situations. This index assumes that during times of drought, soil moisture drops significantly and affects plants.

TCI is determined according to the formula:

$$TCI = 100 * \frac{LST_{max} - LST}{LST_{max} - LST_{min}} \quad (1)$$

in which:

LSTmax, LSTmin: Maximum and minimum surface temperature value.

TCI is a measure of the temperature distribution in an area expressed as a percentage (%). TCI value fluctuating around 50 % is the average temperature level, TCI > 50 %, the temperature begins to decrease and when TCI reaches close to 100 %, the temperature in that area is low. Therefore, low TCI values correspond to reduced plant vitality due to drought or harsh weather conditions caused by high temperatures.

b. Soil-Adjusted Vegetation Index (SAVI)

The Soil Adjusted Vegetation Index (SAVI) is designed to minimize the influence of ground reflections.

Formula of SAVI vegetation index [7]:

$$SAVI = \frac{NIR - RED}{NIR + RED + L}(L + 1) \quad (2)$$

in which: L is the correction factor. The value of L ranges from -1 to 1, depending on the density of green vegetation present in the area. To run image analysis of areas with high vegetation density, L is assigned the value 0 (in that case, the SAVI index value will be equal to NDVI);

While vegetation areas have low density, the value of L = 1.

c. Vegetation Condition Index (VCI)

The vegetation status index is considered a measure to evaluate the growth and development status of vegetation cover with the dimension of percentage (%).

The value of VCI measured as a percentage ranges from 0 to 100. According to Eskinder et al., (2018), high values of VCI indicate healthy vegetation conditions and the area is drought-free. VCI values fluctuate around 50 %: Plants grow normally, VCI > 50 %: Plants grow well, and when VCI reaches close to 100 %, plants grow best [2]. The VCI vegetation status index is determined according to the formula:

$$VCI = 100 * \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (3)$$

in which: NDVI- vegetation index; LST - surface temperature.

d. Temperature-vegetation drought index (TVDI)

After observing the relationship between NDVI and LST, to quantify the relationship between NDVI and LST, Sandholt (2002) proposed using the temperature-vegetation drought index TVDI (Temperature Vegetation Dryness Index) determined according to following formula [3]:

$$TVDI = \frac{LST - LST_{min}}{a + b.NDVI - LST_{max}} \quad (4)$$

in which: NDVI - vegetation index; LSTmin - minimum surface temperature corresponding to each value range of NDVI; LST - temperature at the pixel to be calculated; LSTmax - maximum surface temperature corresponding to each value range of NDVI; a, b - coefficients in the linear equation of LSTmax with NDVI vegetation index.

e. Water Supplying Vegetation Index (WSVI)

Water SupplyingVegetation Index (WSVI) is one of the indexes that combines NDVI vegetation index and LST surface temperature to determine soil moisture conditions. The formula for calculating the WSVI index was developed by Xiao et al., (1995) [4]:

$$\text{WSVI} = \frac{NDVI}{LST} \quad (5)$$

in which, WSVI: Water Supplying Vegetation Index; NDVI: Normalized Difference Vegetation Index; LST: Land Surface Temperature

In the study, ArcGIS Desktop software was used to process and extract index information from the main data: Landsat 8 OLI_TIR remote sensing images. Based on this information, component index maps were established, and the importance of these maps was determined by weighting the influencing factors.

2.3.2. AHP analytical hierarchy method

The importance of the component index maps is determined by assigning weights to the factors. In the study, the Analytical Hierarchy Process (AHP) was used to establish the weights. This is a decision-making technique, proposed by Thomas L.Saaty in 1980 [13]. The AHP analysis technique aids in selecting the most suitable option by identifying and analyzing influencing factors that impact the problem at hand. The importance of these factors is evaluated based on the opinions of experts using a priority of factors developed by Thomas L.Saaty as follows:

Table 1. Saaty's Scale of relative importance [13, 14]

Scale	Numerical Rating	Reciprocal
Extremely Preferred	9	1/9
Very strong to extremely	8	1/8
Very strongly preferred	7	1/7
Strongly to very strongly	6	1/6
Strongly preferred	5	1/5
Moderately to strongly	4	1/4
Moderately preferred	3	1/3
Equally to moderately	2	1/2
Equally preferred	1	1

When performing an assessment, the importance of the influencing factors depends on the subjective opinions of the decision-maker, making it difficult to ensure the objectivity of the evaluation. Therefore, to assess the consistency of the results, maintaining consistency in pairwise comparisons is essential. The Consistency Ratio (CR) is used to determine the level of inconsistency in the statements made during the AHP method. The process of calculating the consistency index is carried out through the following steps:

- Determine the total weight vector by multiplying the original pairwise comparison matrix by the weights of the previously determined factors.

- Calculate the consistency vector by dividing the total weight vector by the weights of the previously determined factors.

- Calculate the largest eigenvalue (λmax) by taking the average value of the consistency vector. The Consistency Index (CI) measures the degree of consistency deviation and is determined according to the following formula [13]:

$$CI = \frac{max-1}{n-1} \quad (6)$$

in which: λmax represents the average value of the consistency vector, and n is the number of criteria, the consistency ratio (CR) is calculated according to the following formula [13]:

$$CR = \frac{CI}{RI} \quad (7)$$

in which: RI is a random index, which depends on the number of factors being compared and is provided in Table 2.

Table 2. Stochastic index RI

N	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0,25	0,89	1,11	1,25	1,35	1,4	1,45	1,49	1,52	1,54

If the CR value is less than 10 %, the result is acceptable. However, if the CR is 10 % or greater, the previous steps must be reconsidered. After calculating the weights of the component drought indices, these values are aggregated to obtain the composite index for each drought component map.

Due to its advantages in determining weights and ranking indices, this method is used to calculate the weights of component drought indices. Specifically, the indices are compared pairwise based on their drought level indicators and actual local conditions, ensuring objectivity and accuracy.

2.3.3. Superposition of component indices using GIS techniques

After obtaining the weight of each index, the GIS tool is used to conduct a zoning assessment and calculate the total score by overlaying the component drought index maps. The synthetic drought map is created by overlaying the weighted component index maps TDVI, WSVI, VCI, SAVI, TCI using the weighted average method. The general formula is as follows:

$$P = \sum_{j=1}^{n} W_j W_{ij} \quad (8)$$

in which: P index of drought; W_j is the weight of the component index; is the weight of the ith layer in the drought index

Component indices must be standardized to a common scale for comparison. This process categorizes each parameter into five drought levels: no drought, mild drought, moderate drought, severe drought, and extreme drought. In principle, the rating scale for each indicator is determined using the AHP method.

3. Research results

3.1. Results of building component index maps

Drought is a type of natural disaster that causes widespread damage and lasts for many days, affecting the environment, economy, socio-politics and human health. Therefore, based on the type of natural disaster, intensity, scope of influence, research area and reference to regulations on natural disaster risk levels in Vietnam [16], the authors divided into 5 levels of drought risk. in Ha Tinh. Below are maps that classify 5 levels of drought risk according to indicators.

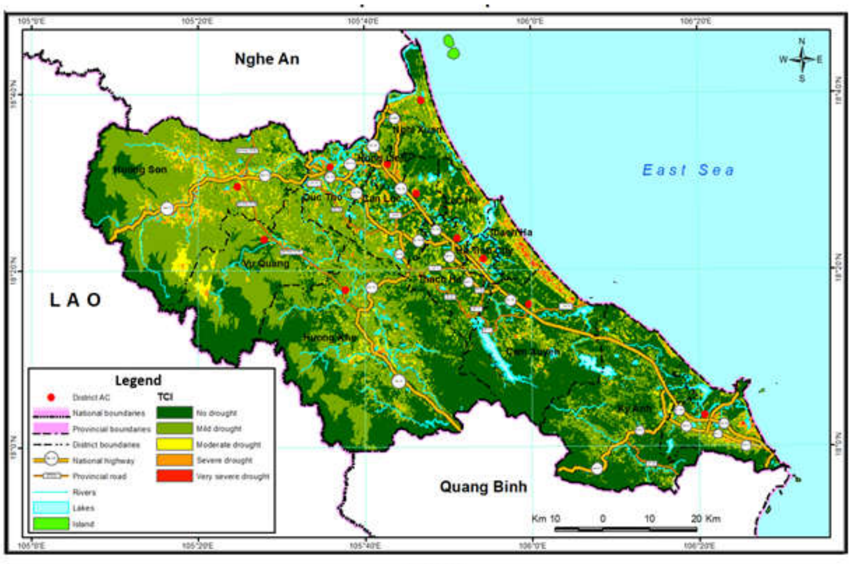

Figure 2: TCI index map of Ha Tinh province

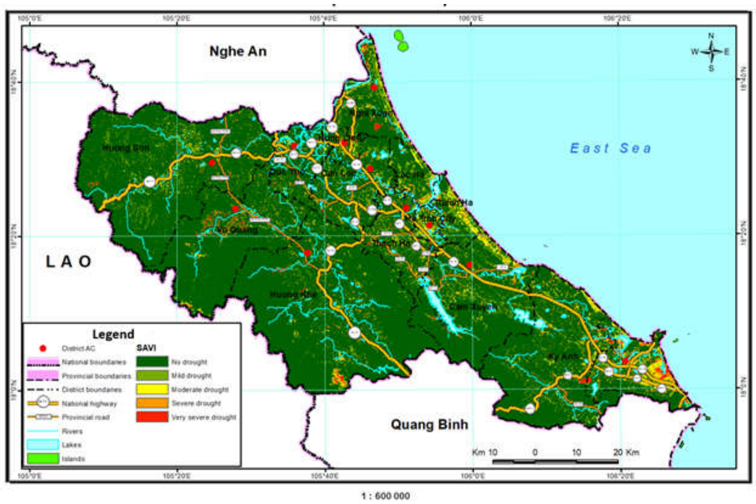

Figure 3: SAVI index map of Ha Tinh province

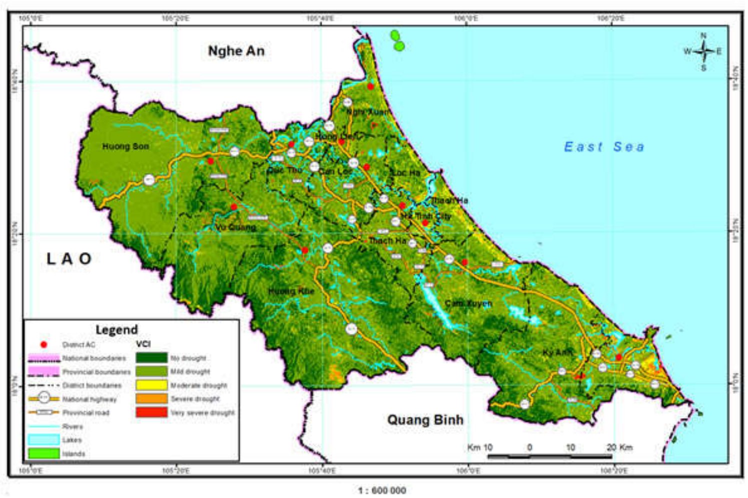

Figure 4: VCI index map of Ha Tinh province

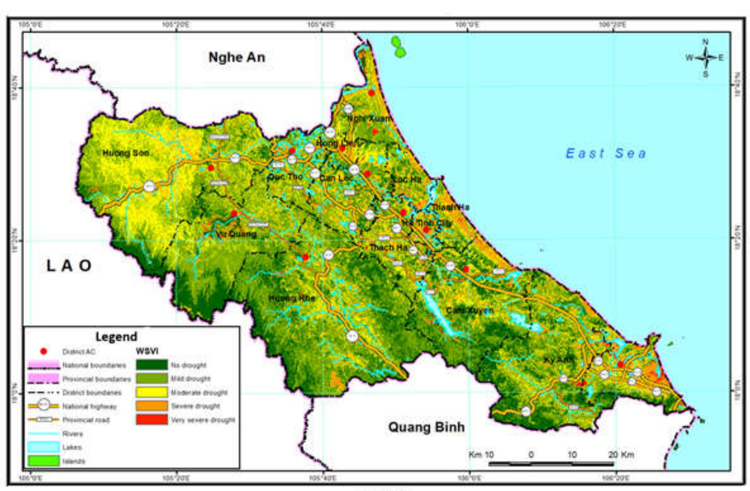

Figure 5: WSVI index map of Ha Tinh province

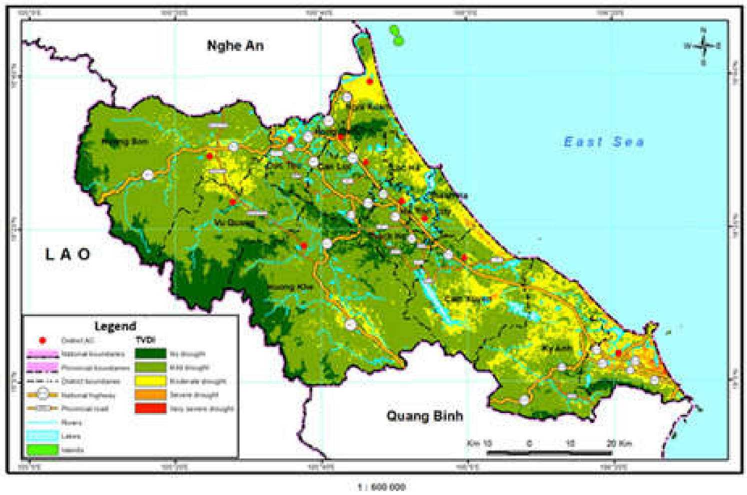

Figure 6: TVDI index map of Ha Tinh province

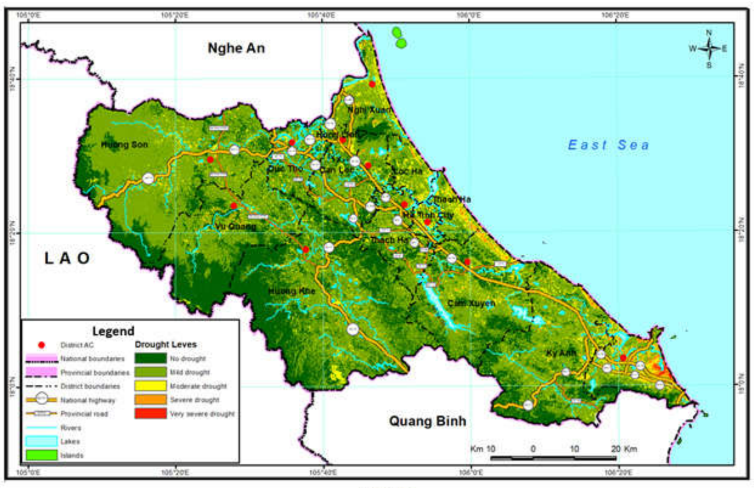

Figure 7: General drought map of Ha Tinh province

3.2. Determine the weight

The scoring scale for the indicators is established based on analysis, review of related research, and expert consultation through a questionnaire. Weight calculation is performed using the matrix normalization method. First, a priority matrix table is created for the five indicators - TDVI, WSVI, VCI, SAVI, TCI - then the matrix is standardized, and the indicators' weights are calculated. Based on expert opinions, a comparison matrix for the indicators is prepared. After calculating the consistency ratio (CR< 0.1), the final pairwise comparison table is synthesized and constructed.

Accordingly, experts filled in information into the importance level matrices to compare 5 indicators; Create a priority matrix table of 5 indicators: TCI, SAVI, VCI, TVDI and WSVI, then normalize the matrix and calculate the weights of the 5 indicators. Based on the synthesis of experts' opinions, a comparison matrix was prepared for the component indexes. After calculating the CR index (CR< 0.1), it was found that the experts answered consistently.

Finally, synthesize and build the final pair comparison table (Table 3) according to the rule: the value in each cell is equal to the geometric average of the corresponding cell values in the experts' comparison tables.

Table 3. Index comparison matrix

Index	VCI	TCI	SAVI	WSVI	TVDI
VCI	1	3.302	2.520	0.731	0.275
TCI	0.303	1	0.682	0.422	0.317
SAVI	0.397	1.466	1	0.754	0.679
WSVI	1.368	2.371	1.326	1	0.565
TVDI	3.634	3.150	1.474	1.771	1
Total column	**6.702**	**11.289**	**7.002**	**4.678**	**2.836**

Table 4. Standardized matrix and weights of indicators

Index	VCI	TCI	SAVI	WSVI	TVDI	Total row	W weight
VCI	0.149	0.292	0.360	0.156	0.097	1.055	0.211
TCI	0.045	0.089	0.097	0.090	0.112	0.433	0.087
SAVI	0.059	0.130	0.143	0.161	0.239	0.732	0.146
WSVI	0.204	0.210	0.189	0.214	0.199	1.016	0.203
TVDI	0.542	0.279	0.210	0.379	0.353	1.763	0.353
Total column	**1**	**1**	**1**	**1**	**1**	**5**	**1**

λmax = 5.331; CI= (5.331 - 5)/4 = 0.083

Consistency Ratio CR = 0.064/1,11= 0.074 < 0.1

The pairwise comparison matrix is consistent, accepting a set of weights

Table 5. The vector calculation results are consistent

Index	VCI	TCI	SAVI	WSVI	TVDI	Total product of comparison matrix	W weight	Consistent vectors
VCI	0.211	0.347	0.293	0.169	0.118	1.138	0.211	5.392
TCI	0.053	0.087	0.098	0.152	0.071	0.460	0.087	5.309
SAVI	0.105	0.130	0.146	0.152	0.294	0.828	0.146	5.655
WSVI	0.253	0.116	0.195	0.203	0.212	0.979	0.203	4.815
TVDI	0.633	0.433	0.176	0.339	0.353	1.933	0.353	5.483
Total column	**1.255**	**1.112**	**0.908**	**1.016**	**1.046**	**5.338**	**1**	**5.331**

3.3. Overlay and merge component index maps

Based on the results from the index maps, the component factors were reclassified into five levels of drought, corresponding to the values of each index, taking into account previous studies and the geographical characteristics of the Ha Tinh province area. The weight values were determined (Table 3), and a synthetic drought map of Ha Tinh province was created.

Raster data layers will be overlaid using GIS tools according to the following model:

$$BDKH = TVDI \times 0.353 + WSVI \times 0.203 + VCI \times 0.211 + SAVI \times 0.146 + TCI \times 0.087$$

As a result of the calculation, the synthetic aridity map has a distribution value range from 0.854 to 5.0. The synthetic aridity zoning map is divided according to the following hierarchical value thresholds:

Value (BDKHmin) = 0.854

Value (BDKHmax) = 5

The point distance between levels is determined according to the formula:

$$\Delta = \frac{BDKH_{max} - BDKH_{min}}{n} = 0.829 \quad (9)$$

Accordingly, the resulting value range will be distributed from 0.854 to 5.0 and the drought zoning map is divided into 5 corresponding levels: No drought (0.854 - 1.683), Mild drought (1.683 - 2.512), Dry Moderate drought (2,512 - 3,342), Severe drought (3,342 - 4,172), Very severe drought (4,172 - 5.0).

3.4. Analyze and evaluate drought levels for drought monitoring and warning

The synthetic drought map of Ha Tinh province (Figure 8) combines both objective data and subjective data (expert opinions). The map of component factors will be scored, analyzed using AHP, and weighted. After calculation and statistical analysis, the results of the drought level zoning in Ha Tinh province are presented in the following table:

Table 6. Statistics of drought level zoning results in Ha Tinh province

No.	Degree of drought	Area (Km²)	Percentage
1	No drought	1745.31	29.28
2	Mild drought	3534.76	59.31
3	Moderate drought	525.68	8.82
4	Severe drought	147.28	2.47
5	Very severe drought	6.92	0.12
	Total	**5959.95**	**100**

According to the statistical table above, we can clearly see the dry areas corresponding to each level:

- *Non-drought:* The potential non-drought area is nearly 1,745.31 km², accounting for 29.28 % of the entire province.

- *Mild drought:* The area with a possibility of mild drought is about 3,534.76 km², representing the largest area at 59.31 % of the province.

- *Average drought:* The area with average drought potential is about 525.68 km², accounting for 8.82 % of the province.

- *Severe drought:* The area capable of severe drought is about 147.28 km², representing 2.47 % of the province.

- *Very severe drought:* The area with the possibility of very severe drought is nearly 6.92 km², accounting for 0.12 % of the province.

From this data, the corresponding ratios for each drought level are illustrated in the chart below:

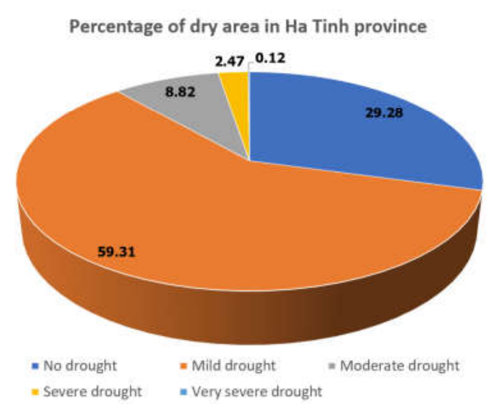

Figure 8: Dry zoning chart of Ha Tinh province

Analyzing the results indicates that the majority of Ha Tinh province is classified as having non-drought and mild drought levels, which together account for 88.59 % of the province's total area. Average, severe and very severe drought levels account for the remaining 11.41 %. Specifically, the area with an average drought level comprises 8.82 % and is concentrated in the districts of Huong Son, Huong Khe, Cam Xuyen, as well as in the coastal communes of Thach Ha, Can Loc and Ky Anh. The area affected by severe and very severe drought accounts for about 2.59 % of the natural area of the province, appearing locally at some points in Ky Anh, Nghi Xuan and Cam Xuyen districts.

In general, the drought phenomenon in Ha Tinh province tends to occur at localized points in certain districts. Although it does not increase sharply, it still significantly impacts people's living conditions and production activities. It is important to note that downstream basins are on high alert for drought during the summer months. The study results also highlight the important role of vegetation cover in reducing drought risk. In areas that have been newly greened with planted forests, the surface temperature is lower, resulting in a reduced level of drought. Conversely, populated areas with sparse greenery experience higher surface temperatures, which correlates with increased drought severity.

4. Conclusion

The combined approach of extracting geospatial information from remote sensing and GIS data can effectively identify arid areas based on several fundamental indicators. In this study, the degree of drought largely depends on temperature and vegetation indicators.

The results can be useful and rapid in identifying "drought risk" areas at the local level. This, in turn, can serve as a tool to address concerns about drought risk at more detailed levels (district and commune levels).

The calculation results of the relevant component factor index maps can be flexibly adjusted based on the provided data and the geographical characteristics of the study area, thereby increasing accuracy to meet the research needs. This is particularly important for studies related to natural disasters impacted by climate change.

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