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CONTENTS
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INTEGRATION OF LANDSAT 8 IMAGERY AND CART MODEL FOR ESTIMATING SOIL ORGANIC CARBON IN DAK LAK PROVINCE

Duong Dang Khoi
Hanoi University of Natural Resources and Environment, Vietnam

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Abstract

The storage potential of Soil Organic Matter (SOM) is critical for reducing CO_2 emissions. Recent advancements in remote sensing and machine learning have enabled significantly more precise prediction of SOM compared to traditional soil surveys. This study aims to examine the integration of Landsat 8 imagery and Classification And Regression Tree (CART) in estimating SOM in Dak Lak province. Landsat 8 imagery is utilized to extract spectral indices covariables that relate to SOM. The CART model was then applied to estimate SOM based on the covariables. A representative dataset of soil samples from various sites across the province was divided into training and validation subsets to evaluate the performance of the CART-based prediction. The validation result of the CART indicates that the RMSE and standard error of the model are 1.323 and 0.165, respectively. The estimation result indicates that the total amount of soil organic carbon is approximately 70.22 million tonnes of carbon in the topsoil of the province. The study provides baseline information for future estimates and carbon monitoring efforts in the topsoil of the province.

Keywords: Soil Organic Carbon (SOC); Classification And Regression Tree (CART); Landsat 8; Dak Lak.

Corresponding author, Email: ddkhoi@hunre.edu.vn

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1. Introduction

Soil organic carbon (SOC), also known as soil organic matter (SOM), refers to the carbon stored in the topsoil. It plays a crucial role in mitigating climate change by reducing atmospheric carbon dioxide levels [11]. However, SOM can be released into the atmosphere through natural processes like decomposition and wildfire, as well as human activities such as logging and land use change. The storage of carbon in topsoil is estimated to be about 680 billion tonnes [7], highlighting significant carbon reservoirs in soil. In addition to its role in climate regulation, SOM is vital for soil health [12, 15]. The pattern of SOM largely varies across landscapes due to various factors, including parent material, topography, climate, vegetation, land use, and management practices [9].

Several methods are available for mapping SOM, which are categorized into field-based and remote sensing-based approaches [4, 18]. In the field-based method, soil samples are collected from various sites and analyzed in the laboratory. Geostatistical techniques are then applied to map the SOM. Although this method is considered a standard approach, it can be labor-intensive and time-consuming

The remote sensing-based method employs reflectance values obtained from satellite or airborne sensors, or derived vegetation indices, to map SOM. Reflectance in the short-wave infrared (SWIR) and near-infrared (NIR) regions has been shown to be sensitive to SOM, with reflectance decreasing as SOM increases [2]. Spectral indices derived from SWIR and NIR reflectance have been developed to detect change in SOM [14, 16]. Both the field-based and remote sensing-based methods rely on regression analysis (RA) or machine learning (ML) algorithms. The RA uses soil samples collected at specific locations to predict SOM levels at other sites. However, the accuracy of these predictions can be limited by the representativeness of the sample locations and the availability of soil samples. RA models may also be sensitive to the selection of explanatory variables used in model development. On the other hand, ML models can be a useful tool for mapping SOM. ML methods do not rely on assumptions of normal distribution of samples, allowing for the quantification of complex relationships between SOM and covariates at large scales. This makes ML models particularly suitable for estimating SOM on a per-pixel basis [4].

Among ML algorithms, tree-based algorithms have been widely used and proven to perform well in improving accuracy and decreasing uncertainty when estimating soil properties at different scales [1, 3, 10, 13, 19]. The Classification and Regression Tree (CART) model is commonly used in soil property data analysis. The CART is a robust technique because it is easy to interpret and can be used for both categorical and continuous variables. It is a non-parametric statistical approach that utilizes decision tree models to analyze and predict complex relationships between covariables and response variables. Landsat 8 provides high-resolution multispectral imagery that captures a wide range of spectral information relevant to soil characteristics. The combination of the CART model's robustness in predictive analysis and Landsat 8's detailed spectral data enables accurate and reliable SOM estimation. Additionally, the availability and cost-effectiveness of Landsat 8 data facilitate large-scale and long-term monitoring of soil organic carbon, contributing to better soil quality management.

Soil carbon sequestration brings significant benefits for provinces specializing in agricultural production because it contributes to improving soil health and supports climate change mitigation. However, quantifying soil carbon storage potential in the area has been unknown in Dak Lak province. The aim of this study is to evaluate carbon sequestration in soils of the province. This assessment will provide valuable insights for climate change mitigation efforts. Moreover, the study will establish a baseline for the spatial distribution of soil carbon storage in forested and cultivated areas for future analysis in the province.

2. Materials and methods

2.1. Study area

Dak Lak province is situated in the Central highlands of Vietnam (Figure 1). With a total area of approximately 13,125 square kilometers, Dak Lak is one of the largest provinces in the country. The province is bordered by Gia Lai province to the North, Lam Dong province to the South, and Cambodia to the West. It is characterized by diverse topography, encompassing plateaus, mountains, and river valleys. The terrain is generally flat to gently sloping, with elevations ranging from 400 to 700 meters above sea level. The climate in Dak Lak is characterized by distinct wet and dry seasons. The rainy season lasts from May to October, while the dry season extends from November to April. The annual mean temperature ranges from 23 °C to 28 °C, with humidity varying between 78 % and 85 %. The agricultural sector is a major part of Dak Lak's economy because the province is a major producer of coffee, rubber, and pepper in Vietnam.

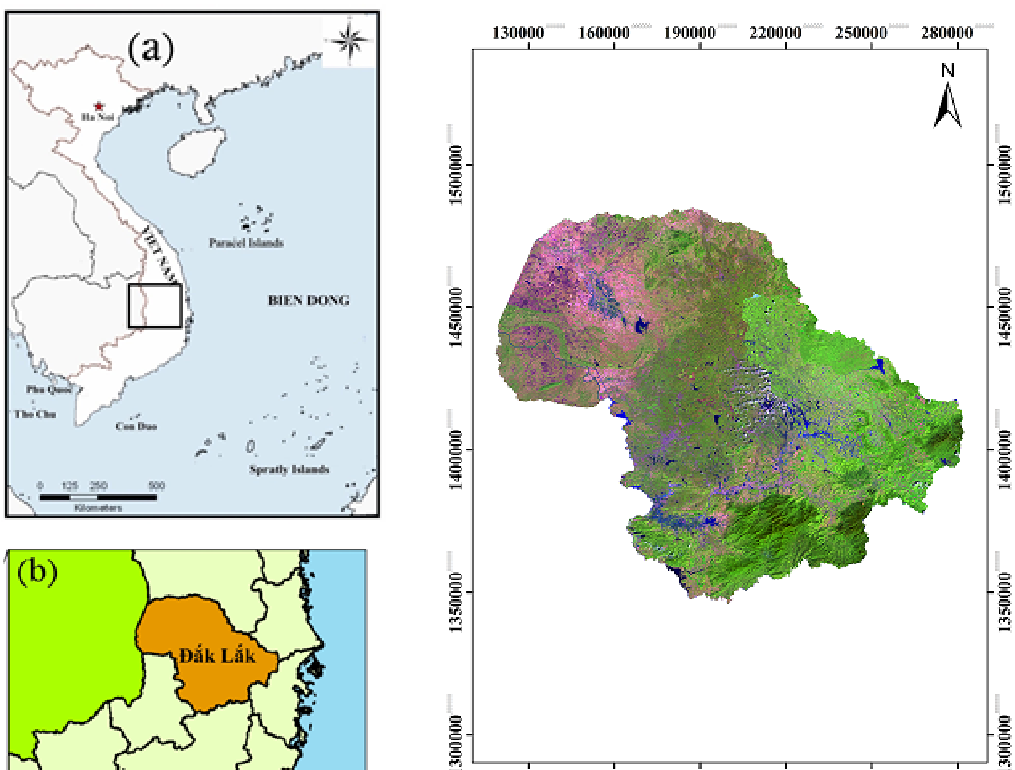


Figure 1: The site of the study area

With its extensive area, Dak Lak plays a crucial role in carbon sequestration and in soil health conservation. The province's soils possess a significant capacity for carbon storage, contributing to climate change mitigation by capturing carbon dioxide from the atmosphere and storing it in the soil. Dak Lak is known for its diverse and fertile soils, including Fluvisols, Ferralsols, and Gleysols [5, 6]. Overall, the soils of Dak Lak province hold immense importance due to their carbon storage potential and suitability for various crops, supporting both climate change mitigation efforts and the livelihoods of local communities.

2.2. Estimating soil organic matter

2.2.1. Preprocessing of Landsat 8 imagery

Applying CART involves data acquisition, preprocessing of Landsat 8 imagery, training and validation, and prediction (Figure 2). The first step is data acquisition, which involves gathering the necessary data for the model. This includes acquiring Landsat 8 imagery and obtaining an existing dataset of 677 SOM samples. The soil dataset was then divided into 478 training samples (70 %) and 199 validation samples (30 %). The Landsat 8 imagery was specifically acquired on January 20, 2020, a date typically experiencing dry weather with minimal cloud interference in the study area. The preprocessing of Landsat 8 imagery primarily involves employing the DOS (Dark Object Subtraction) technique for atmospheric correction. Atmospheric correction is an essential process in Landsat preprocessing that eliminates the atmospheric effects from the raw satellite data. To implement DOS, a dark object in the image, typically water or vegetation, which is expected to have a reflectance value of zero, is identified. The reflectance values of other objects in the image can then be adjusted accordingly based on the reflectance of the dark object.

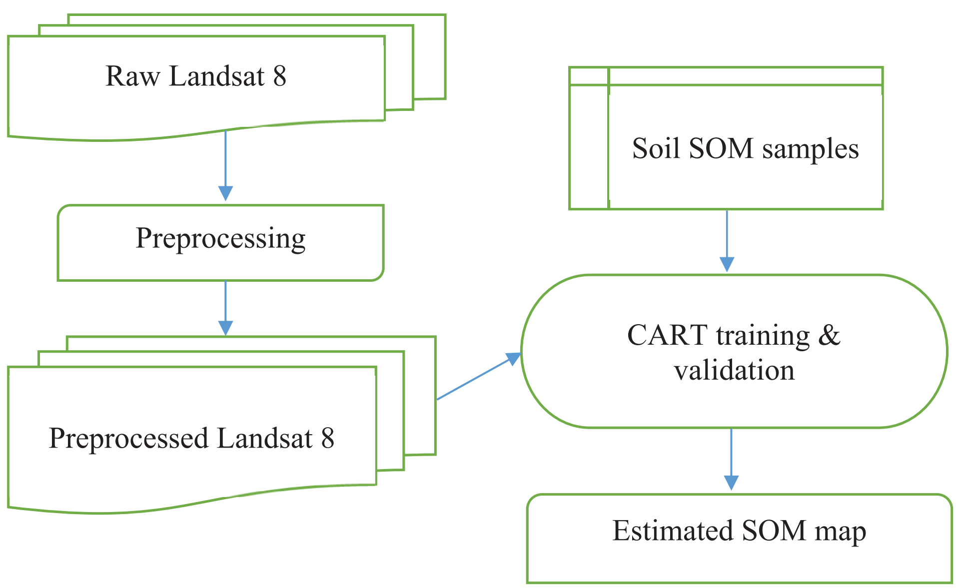


Figure 2: Flowchart of integrating Landsat 8 imagery and CART for soil organic matter estimation

2.2.2. Creation of covariables

From previous studies [2, 4, 14, 16], covariates consisting of spectral bands, NDVI, NDWI, and Clay Index have been widely chosen to estimate soil organic carbon.

NDVI is a measurement that quantifies the contrast between red and near-infrared (NIR) reflectance in vegetation. When vegetation is healthy, it tends to absorb more red light while reflecting more NIR light. The calculation of NDVI is as follows:

$$NDVI = (NIR - R)/(NIR + R) \quad (1)$$

In the Landsat 8, NDVI = (Band 5 - Band 4)/(Band 5 + Band 4).

NDWI, which stands for Normalized Difference Water Index, is a satellite-derived index that uses the near-infrared (NIR) and short-wave infrared (SWIR) bands. It compares the reflectance values of these bands to identify water bodies and assess water content in vegetation. The formula for calculating NDWI is as follows:

$$NDWI = (NIR - SWIR)/(NIR + SWIR) \quad (2)$$

In the formula [2], NIR represents the reflectance value in the near-infrared band (Band 5), and SWIR represents the reflectance value in the short-wave infrared band (Band 6). The resulting NDWI value ranges from -1 to 1, where higher values indicate a greater presence of water. Positive values suggest the presence of water, while negative values indicate the absence of water or the presence of other features such as bare soil or urban areas.

The Clay Index is determined by calculating the ratio between the Short-Wave Infrared 1 (SWIR1) and Short-Wave Infrared 2 (SWIR2) bands. It provides a measurement of the concentration of clay minerals present in the soil. In Landsat 8 imagery, the SWIR1 and SWIR2 bands are represented by bands 6 and 7, respectively.

$$Clay\ Index = SWIR1/SWIR2 \quad (3)$$

The Values to Point module in ArcGIS 10.3 was used to extract the spectral values of bands 2, 3, 4, 5, 6, 7, NDVI, NDWI, and Clay Index, along with the SOM content values of the sampled points. These variables were used as predictor variables, while the SOM content served as the dependent variable.

2.2.3. Training and validation

The next step involves training CART with a subset of the samples. In this step, the target variable (soil organic carbon) is estimated based on the values of band reflectance, NDVI, NDWI, and Clay Index. The data is divided into branches based on these predictor variable values, and decision rules are established. The model's performance is assessed using the Root Mean Square Error (RMSE) as follows:

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{n}} \quad (4)$$

where: $\hat{y}_i$ is the predicted value for the i^{th} observation in the dataset

y_i is the observed value for the i^{th} observation in the dataset

n is the sample size

2.2.4. Estimating SOM

In the final step, the calibrated CART model was used to predict the soil organic carbon content in new soil samples. This prediction was made using the spectral variables obtained from the Landsat 8 imagery. By utilizing the available data on soil bulk density for each soil unit in the topsoil and the extent of each soil unit, the total soil organic carbon stock across the entire province was estimated.

$$\text{Carbon Stock (tonnes)} = \text{SOM} \times 0.58 \times \text{A} \quad (5)$$

where SOM is soil organic matter (Mg/ha), the coefficient of 0.58 means 58 % of carbon content in SOM, and A is the area of each soil unit (ha).

3. Results

3.1. Descriptive summary of SOM content

The original dataset of samples has been divided into calibration and validation subsets. Both subsets show similar characteristics of the samples, indicating a reasonable division of the dataset. The calibration set consists of 478 samples, with an average value of 2.99 %. The minimum value in this set is 0.89 %, the maximum value is 7.47 %, and the standard deviation is 1.359. The validation set contains 199 samples, with a mean value of 2.96 %. The minimum value in this set is 0.83 %, the maximum value is 6.40 %, and the standard deviation is 1.348 %. The standard deviation reflects the spatial variability of SOM in the study area.

Table 1. Statistical description of SOM content

Set	Samples	Max (%)	Min (%)	Mean (%)	SD (%)
Whole set	677	7.47	0.83	2.98	1.355
Calibration set	478	7.47	0.89	2.99	1.359
Validation set	199	6.40	0.83	2.96	1.348

3.2. Reflectance analysis of Landsat 8 imagery

a) Calibrattion subset

Figure 3 presents the reflectance values of different bands (2, 3, 4, 5, 6, and 7) within a calibration subset derived from Landsat 8 imagery. A notable observation is the varied range of reflectance across the bands, suggesting varying degrees of electromagnetic radiation reflection from the Earth's surface.

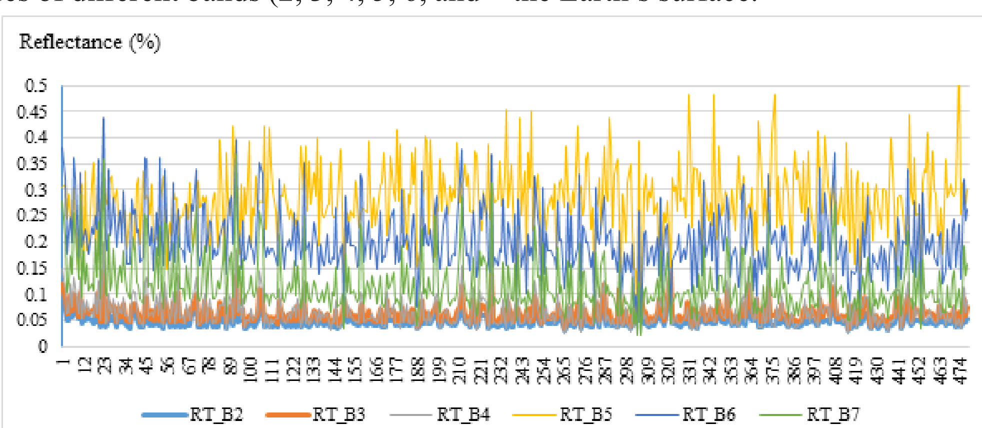


Figure 3: Reflectance of bands 2,3,4,5,6,7 of the calibration samples

Figure 4 shows the NDVI, NDWI, and Clay Index of the calibration samples. The graph illustrates the variability of the indices across the samples. The NDVI index, represented by the green line, shows a relatively stable range of values, suggesting consistent vegetation density within the calibration area. The NDWI index, depicted by the blue line, exhibits more fluctuation, indicating variation in water content. Interestingly, the Clay Index, shown in gray, presents a distinct pattern compared to the other two indices, which might be indicative of varying clay content in the soil.

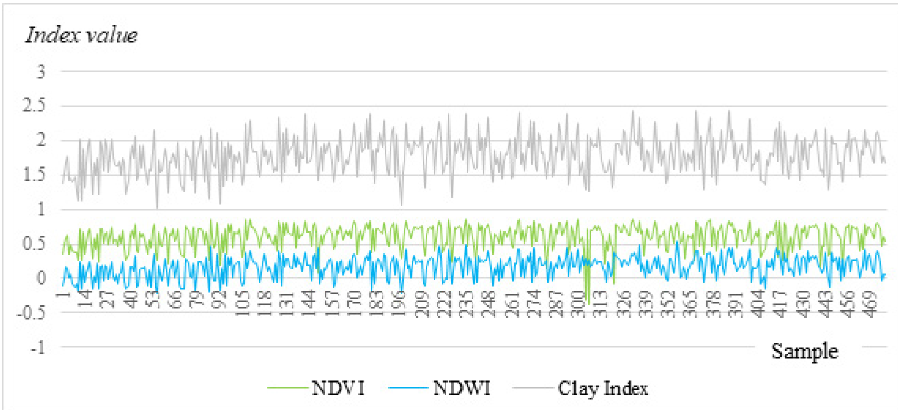


Figure 4: NDVI, NDWI and Clay Index of the calibration samples

b) Validation subset

Figure 5 presents the reflectance of a validation dataset, encompassing bands 2 to 7. The plot reveals substantial variability in reflectance across the spectral bands, suggesting heterogeneity within the validation samples. The spectral profiles of each band offer clues about the compositional properties of the materials present in the validation. The Figures 1 and 3 exhibit similar band reflectance trends. This indicates that the division of the original dataset into calibration and validation subsets is reasonable.

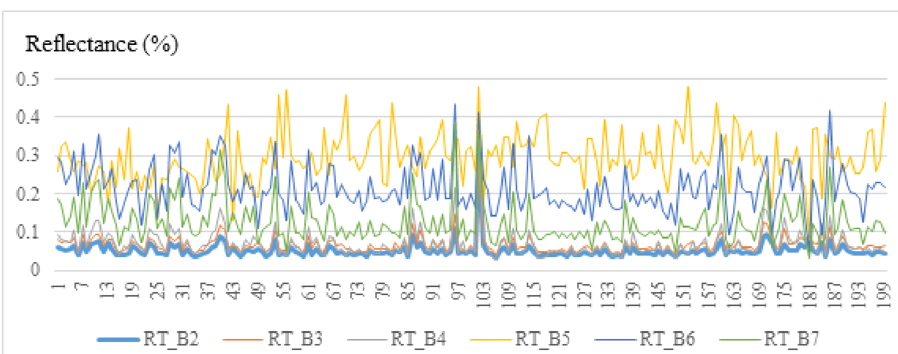


Figure 5: Reflectance of bands 2, 3, 4, 5, 6, 7 of validation samples

Figure 6 and Figure 4 indicate mostly similar trends in the NDVI, NDWI, and Clay Index of the validation samples. Over again, the graph demonstrates the variability of the indices across the samples. The NDVI index, represented by the green line, shows a quite stable range of values, suggesting consistent vegetation coverage within the validation area. The NDWI index, depicted by the blue line, exhibits more fluctuation, indicating variations in water content. Remarkably, the Clay Index, shown in gray, presents a distinct pattern compared to the other two indices, which might be indicative of varying clay content in the soil.

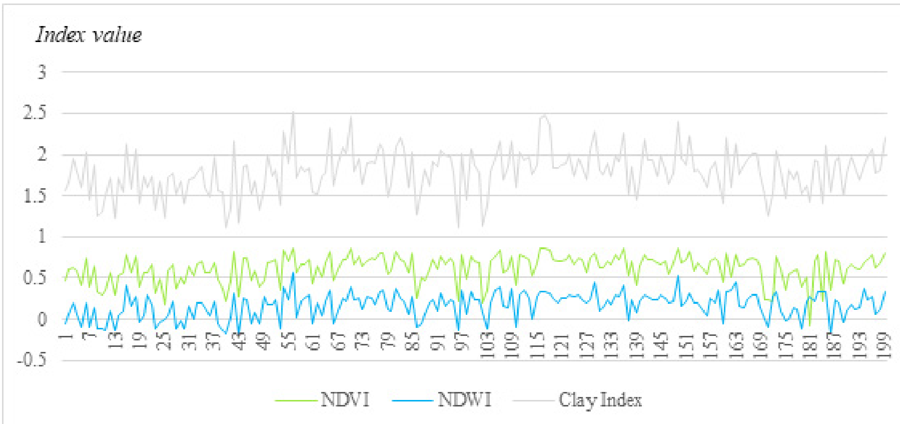
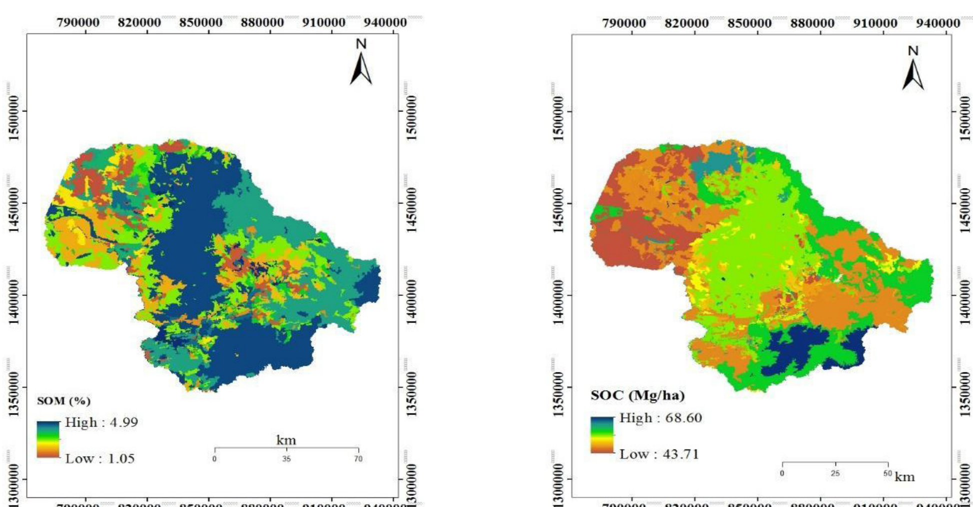


Figure 6: NDVI, NDWI and Clay Index of the validation samples

3.3. CART Validation and Prediction

To implement the training and validating of the CART algorithm, approximately 70 % of the data was used for training, while the remaining 30 % was reserved for validation purposes. The performance of the model was evaluated using RMSE. The findings reveal that the RMSE of the model during training was 1.197, with a standard error of 0.091. During validation, the RMSE and standard error were 1.323 and 0.165, respectively. These results indicate reasonably accurate performance of the model and support its application in predicting SOM in Dak Lak province using CART. Based on the validation results, the SOM map is predicted over the whole province.



(a) SOM (%) ***(b) SOM (Mg/ha)***

Figure 7: Soil organic matter estimated by CART

Soil organic carbon varies significantly in space, depending on topography, soil type, and land use in the area. Topography strongly influences SOM variation, with higher SOM content generally found in higher elevation areas where natural forests still remain, and lower SOM content on plains where coffee plantations or orchards are more common. Soil organic carbon is closely related to soil types in the province. Soils derived from organic-rich materials, such as peat and muck, tend to have higher SOM content than soils derived from igneous or sedimentary rocks, which have lower SOM content. Ferralsols are dominant in the area and contain a higher amount of SOM than other soil groups such as Fluvisols and Acrisols. The type and density of vegetation or land use covering the topsoil layer can also influence SOM content, as different crops produce varying quantities and qualities of organic residues. Forest soils tend to have higher SOM content than crop and grass soils. In general, soils under natural forests have higher SOM content than those under croplands because natural ecosystems retain more plant residues through litterfall and root exudates and have more diverse soil microbial communities that promote SOM formation and stabilization. Using the data of soil bulk density in the topsoil layer of 30 cm, together with the area extent in terms of ha of each soil, and with carbon content in OM is 58 %. The total soil organic carbon is estimated. The result indicates that the total amount of soil organic carbon is currently 70.22 millions of tonnes of carbon in the topsoil of the province.

4. Conclusions

The study findings indicate that the integration of Landsat 8 imagery and CART model is a useful tool for estimating SOM at large scale. The analysis of the covariables indicates that spectral indices such as NDVI, NDWI, Clay Index were significant for SOM estimation. The validation result of the CART indicates that RMSE and standard error of the model are 1.323 and 0.165, respectively. The calibrated CART model was applied to estimate the spatial patterns of SOM in Dak Lak province. The estimation result indicates that the total amount of soil organic carbon is approximately 70.22 millions of tonnes of carbon in the 30 cm topsoil of the province. The CART-based SOC estimation provides detailed insights into spatial distribution of SOC in the study area and supports soil conservation efforts as well as baseline information for future SOC estimates in the province.

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STATUS OF RESIDENTIAL SOLID WASTE MANAGEMENT. A CASE STUDY IN DONG ANH DISTRICT, HANOI, VIETNAM

Nguyen Mai Lan, Dao Hoang Tung*, Bui Sy Bach
Hanoi University of Natural Resources and Environment, Vietnam

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Abstract

Residential solid wastes have been becoming an environmental threat for every city, especially crown and high population. The status of Residential Solid Waste (RSW) in a large city, such as Hanoi in general and Dong Anh district in particular, can bring a better vision for management activities. In this study, RSW will be carried out to assess the sources and component contribution being inputs for further forecasting of generated RSW until 2025 in study areas, Dong Anh district, the Tien Duong, and Uy No communes. This study applies the separation of the waste in sites and surveys to calculate the Generated Residential Solid Waste Rate (GRSWR) and in combination with the increased population rate from the famous Euler's model to predict and forecast the Generated Residential Solid Waste (GRSW) in Dong Anh in the 5 years (2020 - 2025). The results show that the increase in population for every study region will lead to an increase in RSW. In particular, the total GRSW will increase by more than 1,000 tons/year with only 1,000 raised citizens in 5 years. The overall trash collection rate reaches 86.5 % of the total waste generated in the area. The residential waste composition of the Dong Anh district is extremely diverse, with organic matter accounting for nearly 75 %, higher than the average of Hanoi. The important thing is to rigorously and thoroughly implement waste classification at the source according to the regulations of the Law on Environmental Protection (2020) to reduce the amount of waste generated that needs to be collected.

Keywords: Residential Solid Waste; Hanoi; Environmental sanitation.

***Corresponding author, Email:** dhtung@hunre.edu.vn

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1. Introduction

Environmental pollution has recently been the cause of many global issues, including a decrease in human health, diseases, animal mutation, and a reduction in life expectancy. These problems have become worse in the past decade among developing countries, in which industrial activities and the increase of household waste are booming. The total amount of waste rapidly increased in all European countries to over 235 million tons per year in 2020 [1]. Vietnam is one of the fastest countries in the world in both economy and population. Following this trend, the increase in residential waste, both solid and recycled, creates so many problematic environmental and health issues. In the national environmental report in 2019 [2], the total waste from households in all cities was estimated to be up to 36 thousand tons per day, rating about 55 % of all solid wastes in the nation. However, the figures could become even worse in that 92 % of solid waste could be collected in cities and 66 % in the countryside.

Residential solid wastes can be dumped into the environment from different sources. Households, shopping malls, offices, and institutions are the typical sources due to the great use of the household, such as plastic bags, broken electricity pieces of equipment, food, and many others. Additionally, construction waste with a high quantity of steel, broken concrete, bricks, and PVS piles became the secondary sources. The components of wastes can have some threatening potentials, including (1) Ignitable components from papers, clothes, food disposal, wooden pieces of equipment, plastic, and leather, and (2) Non-flammable materials, e.g., steels, concretes, bricks, or glasses. Whereas wastes in type (1) can be found in households, shopping malls, or offices due to their common use, the most typical wastes in type (2) are dumped from construction and industrial sites. Furthermore, due to the lack of technique for dividing components, solid or residential wastes can be more complicated to manage. As a result, negative effects on the environment and residents' health become the main problems for every large city, leading to great pressure on waste management.

Solid waste management in Asian countries can be recycling processes, flame disposal, bio- and chemical disposal, open-dump sites, and sanitary landfills, which are the most used due to lower capital, maintenance cost, and operational. Becoming common, the use of open dump sites for household wastes leads to an overwhelming amount of air, groundwater, and water pollution [3]. In Vietnam, a total of 1322 solid waste disposal sites, 381 flame disposal stations, 37 compost processes, and 904 open-dump sites resulted in 13, 16 and 71 % of waste disposal, respectively [2]. As a result, the effects of ineffective management on human health, including physical, biological, non-communicable diseases, psychological and ergonomics, health risks [2 - 5].

In the past decade, the living standards have been improved significantly, leading to an accompanied rise in a deterioration in the quality of the environment. Residential wastes, mostly from offices, enterprises, and households, are now becoming a serious threat. Moreover, it is recognized that the management of the mobile trash locations is under control due to the lack of quantity and quality. Additionally, the mindset for reusing plastic products, such as plastic cans and pesticides/medicine bottles, is faulty since those products are still widespread among the residents of the municipality. The indiscriminate dumping of waste and untreated domestic wastewater has caused most of the drainage canals to be black in color and smell of rottenness, which has a great impact on the surrounding environment. Nevertheless, the timely intervention of the functional agencies in the area is still weak and not synchronized between the various sectors. The management of the environment by the specialized agencies in the ward still reveals many limitations. At present, in these areas, the rate of new garbage collection is only 85.6 % of the amount of waste generated at the current time, and the waste treatment technology does not meet environmental hygiene requirements. [2].

Several studies have been conducted on household solid waste management, which aims to assess the current state of waste management practices, including collection, disposal, and recycling [6 - 8]. According to Van den Berg (2018) [9], the collection of solid waste in Hanoi currently has two forms, consisting of (i) Garbage trolley system, (ii) Direct trucks, and (iii) Container systems. Garbage trolleys are mostly used in crowded areas where garbage trucks are difficult to pass through. Small and medium-sized garbage trucks (e.g., total volume from 5 to 15 m^3) are typically used to directly collect wastes and transport them to disposal or treatment sites without the secondary transmitter station. However, this process is commonly expensive and inconvenient to collect in narrow roads and crowded areas. Unlike hazardous waste, there are no specific licensing requirements for collecting municipal solid waste. Many outdated waste collection trucks need replacement or supplementation with newer compactor trucks. The report also outlines various scenarios for improving waste management in Hanoi, including the forecasted waste quantities for the period from 2018 to 2030 in Vietnam, infrastructure requirements for waste handling under different scenarios and impacts on investment costs and operations, and the associated effects on fee increases and remaining financial deficits, which can, directly and indirectly, influence individual spending, business investment, and budget deficits.

In the need to understand solid waste status for forecasting, this study will carry out an analysis of solid waste in Dong Anh district, Hanoi, Vietnam. Firstly, a brief description of study areas and interpretation of waste separation will be presented in the Methodology section. Next, this study will carry out an analysis of waste components and a forecast for 2025 of waste in the study areas. Finally, discussions and conclusions will be due.

2. Methodology

2.1. Study areas

Dong Anh, North of Hanoi, is a suburban district that covers an area of 4.45 km^2 and is home to around 32,766 people. Dong Anh is also an economic and political center and has a concentrated population with relatively high living standards. Additionally, the neighboring communes, Tien Duong in the East and Uy No commune in the West (Figure 2b) are the focused areas in this study. Tien Duong and Uy No communes are covered by areas of 10.09 km^2 and 7.72 km^2, respectively, with corresponding populations of around 19,118 and 18,501 citizens. Accordingly, Tien Duong is the second largest area in the district; however, it has a low population density. The majority of the population follows agriculture, providing mainly fresh vegetables to the other neighboring regions. There is also the Medical Center of Dong Anh district with the commune medical station, and together with 3 levels of kindergartens, primary schools, and secondary schools. As located close to Dong Anh district, Uy No is also quite bustling with business activities, including trade, transportation, and markets, and one known as the famous To market. Interestingly, as known as a home of a high population and economic center, Dong Anh and the two studied areas are presented as a good example to assess residential solid waste.

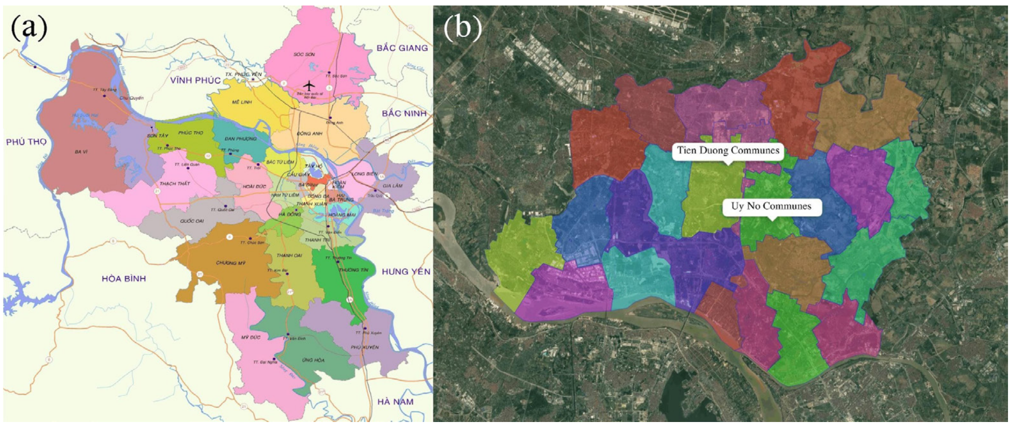

Figure 1: (a) The overview of Dong Anh district and (b) Tien Duong and Uy No communes and Dong Anh district center

2.2. Waste separation

To estimate the rate and volume of residential solid wastes in the study area, this study conducts a determined calculation for the Generated Residential Solid Waste Rate (GRSWR) based on the weight of solid waste per household, which is yielded:

$$GRSWR = \frac{W_{RSW}}{N_P} \qquad (1)$$

where, GRSWR (kg/person/day) is the resident solid waste rate of a person created in a day, W_{RSW} (kg) is the total weight of solid waste per household, and NP is the number of people in a household.

Next, the residential solid waste type is manually separated into several types, including decomposed solid wastes (organic type), recycled and reused solid wastes (paper and plastic products), and other types (ceramics, glass, and other components), calculated as their percentage rate, following equation:

$$RSW_{type} = \frac{W_{N\_RSW}}{SW_{RSW}} \qquad (2)$$

where, RSW_{type} (%) is the percentage of a type of waste, W_{N_RSW} and SW_{RSW} (kg) are the weight of the sample wastes and the standard weight (10 kg), respectively.

In this study, the $GRSWR$ and RSW_{type} can only be done manually with 10 random households in the study area. For each household, the total weight is measured within a full day (24 hours) with an advanced notification. Data collection is repeated three times per week and lasts for one week. The *GRSWR* will be calculated following the Eq.(1). Simultaneously, the component rate (RSW_{type}) is determined based on standard weight (10 kg) and separated into different types, such as organic, recycled, reused and other components. Afterward, it will be estimated by Eq.(2).

Additionally, this study introduces forecasting of the total volume of residential solid waste generated until 2025 based on the famous advanced Euler model using the population forecasting input in Dong Anh district. The prediction values in this study will be determined by the increased population rate from the Euler model (Eq. 3) multiplied by the *GRWR* (Eq. 1) and the total population in the study area, which can be yielded as follows:

$$N_{i+1}^{*} = N_i + rN_i\Delta t \quad (3)$$

$$Total_{RSW}^{i+1} = GRSWR \times N_{i+1}^{*} \quad (4)$$

where, N_{i+1}^{*} and N_i are the total population in year i and $i + 1$ (after a year), r is the natural population increasing rate, and Δt is the time resolution. In Eq.(4), $Total_{RSW}^{i+1}$ is the total generated residential solid waste in a full day (24 hours) in the year $i + 1$ in the study area, considering the prediction of residential solid waste per day.

3. Results

3.1. Residential solid waste components

In this study, the sources of RSW are relatively determined from different sources (Figure 2), which are from residential areas, markets, hospitals, health care, schools, and government offices. As can be seen in Figure 2a, the majority of waste is from the household at about 83 %, while markets, offices, and schools are only under 8 %.

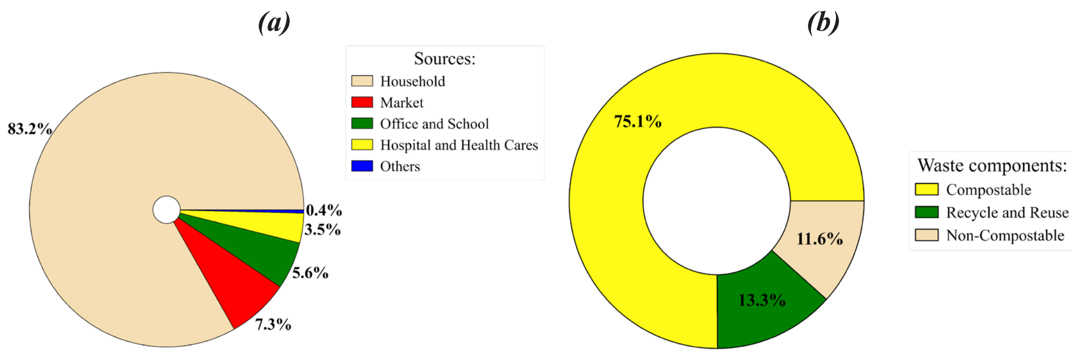

Figure 2: (a) Sources of Residential solid waste and (b) Residential solid waste components

Furthermore, a report by Dong Anh Urban Environment Joint Stock Company in 2020 [10] accordingly stated that the rate of waste found to be the highest from the household at 83.2 %, corresponding to about 210.56 tons/day. In the market, waste is mainly composed of biodegradable organic waste with many different items such as food, vegetables, fruits, and damaged fruits rounding at 18.47 tons/day, whereas a large number of plastic products (packaging and nylon bags) was dominated at 7.3 %. Moreover, waste from offices and schools is relatively simple in composition found at 5.6 %, roundly equal to 14.17 tons/day.

In Dong Anh district, four large hospitals, 23 health cares, and more than 200 private clinics are currently active, leading to enormous waste at 8.86 tons/day (3.5 %, see Figure 2a). Specifically, various components, including newspapers, documents, and plastic gloves from patient and doctor activities) and hazardous waste (used syringes, bandages, or scalpels are the original. Only 0.4 % of sources (Figure 2a) are wastes generated by pedestrians or randomly dumped. However, this source contributes quite less as an important role which can be neglected in calculation.

In Figure 2b, the average composition waste per household in a standard weight consists of the largest proportion, 74.35 %, while the non-compostable and recycle and reuse are quite similar at 13.3 % and 11.97 %, respectively. The recycle and reuse components tend to increase over time because of the awareness improvement mindset in waste sorting. However, the improvement progress is quite slow due to the lack of understanding about reasonable waste sorting by regulations.

Table 1. Residential solid waste weight by households

No.	Location	GRSWR (kg/person/day)	WRSWR (tons/day)	Total WRSWR (tons/year)
1	Dong Anh district	0.62	20.315	7,414.97
2	Tien Duong	0.58	11.088	4,047.12
3	Uy No	0.56	10.36	3,781.4

Table 1 shows the Generated Residential Solid Waste Rate (GRSWR, see Eq. 1), the weight of Residential Solid Waste per day (WRSWR), and the total Weight of Solid Waste per year (Total WRSWR), which is calculated through residential waste collection and survey collecting activities. It can be seen that Dong Anh district, with a larger population and larger area, produces more waste than both Tien Duong and Uy No communes, even though the GRSWR is quite similar. Moreover, the composition of generated residential solid waste generated in three types of waste in all study areas. It is recognized that the weight of types 2 and 3 has similar numbers. The number in two communes (Tien Duong and Uy No) is relatively lower than it is in Dong Anh district. However, it is interesting that the non-compostable waste of Tien Duong is nearly double that of Uy No communes. This can be explained by the consumption habits of residents in Uy No are quite different from the Tien Duong community.

Additional information from Table 1 shows that the average residential waste generation rate was 0.59 kg/day (Table 1). At the end of 2020, the population of Dong Anh district was calculated at 399,162 by the Euler method. Therefore, the amount of residential waste generated in Dong Anh district is 85,959 tons/year.

Table 2. Composition of generated residential solid waste

Type	RWS type		Weight (kg)		
			Dong Anh district	**Tien Duong**	**Uy No**
1	Compostable waste		62.3	55.9	30.1
2	Recyclable/ reusable waste	Paper	6.1	2.16	1.7
		Plastic	4.4	3.47	2.3
		Plastic bag	3.1	2.2	1.8
3	Non - compostable waste	Ceramic	4.8	3.02	1.9
		Other	6.3	5.22	2.7
Total			**87.1**	**72**	**40.4**

The composition and the weight of solid waste depends on some factors, such as food habits, cultural traditions, and socio-economic status (time at home, living needs, and jobs). The waste generation was found to increase gradually with the increase of income per month. The daily waste volume of households depends on their occupation. The officers or agricultural employees have less weight on solid waste than commercial employees and service households. In Tien Duong and Uy No communes, agricultural, livestock, and poultry activities are popular, so a part of the household waste was mainly kitchen waste (excess food or damaged) that is reused.

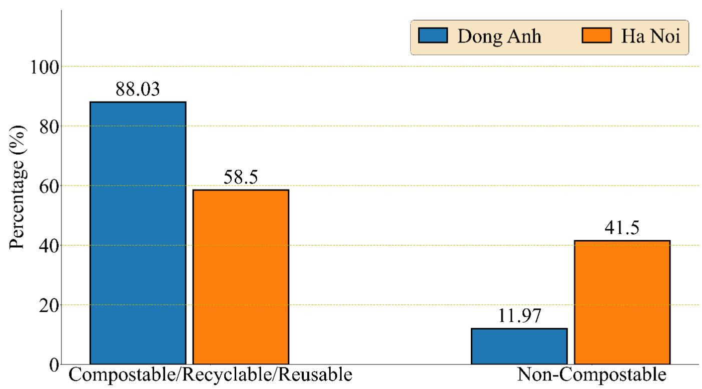

Figure 3: Percentage of RSW composition in the research area and Hanoi city

In Figure 3, the average generation index of RSW in the study area (0.59) is low compared to the general generation index of Hanoi city (0.81) [2]. The reason is that this is a suburban area with low population density, and agricultural activities are still relatively popular in people's daily lives. Compostable, recyclable, and reusable waste in the study area accounted for 88.03 %, higher than the average level of these wastes in Hanoi city (58.5 %). Non-compostable waste is only 1/3 of the average level of the whole city of Hanoi.

3.2. Forecast of residential solid waste volume generated by 2025

The calculation of the population forecast for Residential solid wastes of Dong Anh district until 2025 is presented in Table 3, showing that the number of RSWs tends to increase. As can be seen, the total GRSW increases along with the increase of population by more than 12,000 units per year with 20,000 citizens.

Table 3. Forecast of RSW generated in Dong Anh district to 2025

Year	Population	Coefficient of GRSW (kg/people/day.night)	Amount of GRSW (tons/day.night)	Total of GRSW (tons/year)
2020	399,162	0.59	235.51	85,959
2021	403,552	0.60	242.13	88,378
2022	407,991	0.61	248.88	90,839
2023	412,479	0.62	255.74	93,344
2024	417,017	0.63	262.72	95,893
2025	421,604	0.64	269.83	98,486

While the amount of daily-life solid waste increased gradually over the years from 85,959 tons/year to 98,486 tons/year in the period of 2020 - 2025, that is an increase of 12,527 tons/year. At the same time, in 5 years, the population of Dong Anh district increased by 22,442 people. With the increasing consumption demand of households, the amount of waste generated will also increase, requiring more specific management and treatment solutions.

Table 4. Forecast of GRSW until 2025

Year	Population			Coefficient of GRSW (kg/people/day.night)			Amount of GRSW (tons/day.night)			Total of GRSW (tons/year)		
	Dong Anh	Tien Duong	Uy No	Dong Anh	Tien Duong	Uy No	Dong Anh	Tien Duong	Uy No	Dong Anh	Tien Duong	Uy No
2020	32,766	19,118	18,501	0.62	0.58	0.56	20.31	11.09	10.36	7414.9	4047.2	3781.6
2021	33,126	19,328	18,704	0.63	0.59	0.57	20.87	11.41	10.66	7617.4	4162.3	3891.4
2022	33,490	19,540	18,910	0.64	0.60	0.58	21.43	11.72	10.97	7823.4	4279.4	4003.3
2023	33,859	19,755	19,118	0.65	0.61	0.59	22.01	12.05	11.28	8033.1	4398.6	4117.1
2024	34,231	19,973	19,328	0.66	0.62	0.60	22.59	12.38	11.59	8246.4	4519.9	4232.9
2025	34,608	20,192	19,541	0.67	0.63	0.61	23.18	12.72	11.92	8463.4	4643.3	4350.8

Last but not least, Table 4 presents the forecast of GRSW until 2025 for all three study areas, Dong Anh, Tien Duong, and Uy No. The total GRSW has appeared to be enormous, corresponding to the large population, even though the increase rate is similar to each neighboring region. Interestingly, the increase in population of all study areas is relatively low while a quick rise of GRSW is recognised to be greater every year. For example, there is about a 1,000 residents gap in 5 years in either Tien Duong or Uy No, but the total of GRSW increased by over 1,000 units. This is due to either the life standards being considered to level up or the development of industry and economic needs, therefore becoming greater.

4. Discussion

4.1. Residential waste management

The results above show how great GRSW could be in a short period and it will increase even faster in the next decade due to urban development. However, those numbers only present the total generated wastes since the separated calculation of each component (see Figure 2b) is nearly impossible.

In Dong Anh, all municipal solid waste collection and transportation areas are taken care of by Dong Anh Urban Environment Corporation. Three main collection and transportation routes are currently active, including [Route 1]

Along National Highway No. 3 through Dong Anh district, Uy No commune, [Route 2] Along National Highway 23, Tien Duong, Uy No communes, Dong Anh district, and [Route 3] Along Uy No, Dan Di road toward Dong Anh district. Moreover, the distribution of trolleys and human resources for those routes is relatively limited, which is corresponding to 60 wheelbarrows and 20 employees, once a day for Route 1, 50 wheelbarrows and 18 employees, twice a day for Route 2, and finally 35 wheelbarrows and 12 employees, 2 - 3 times a day for Route 3.

In villages and surrounding areas, the collected garbage is taken to collection points on the highway for easy collection by compactors. The waste collection process involves gathering mixed waste without sorting it at the source. The garbage from markets and other locations is manually collected using handcarts and transported to designated collection points. In addition to street, office, and residential waste, we also collect from municipal garbage bins. Collection frequency and timing are customized to meet people's needs. Route 1, located in the urban center with high waste volume, is collected once daily. Routes 2 and 3 are serviced two to three times daily. Despite limited human resources, the overall trash collection rate reaches 86.5 % of the total waste generated in the area. Collection fees are 3,000 VND per person per month for households and 30,000 - 50,000 VND per household per month for restaurants and eateries.

At present, the waste of Dong Anh district is transported to Nam Son Waste Treatment Complex for disposal. However, in the last 2000s, the Nam Son landfill had closed due to overflow. This has caused many problems, such as illegal dumping, lack of transportation, lack of sanitation facilities, and loss of urban aesthetics. Consequently, the People's Committee of Dong Anh district is directing the acceleration of the completion of a Waste Treatment and Recycling Plant in Duy Tu, Dong Anh, with an area of 71,739 m^2 and an investment of nearly VND 20 trillion (20 trillion Vietnam dongs). However, the project still faces many problems due to the request for additional licenses to process hazardous industrial and medical waste.

With the understanding of the limitation of human resources in collecting wastes, a collection, classification, and treatment program at source has been initiated in Dong Anh in 2021 [11], which is now expanded with many positive results. The program included sorting activities at the source household for solid waste and regularly collected by self-managed volunteer teams. The teams are then transported to central points for processing following standard procedures.

According to a Ministry of Natural Resources and Environment report in 2022 [11], a total of 23 communes and a town in Dong Anh District participated in the program nationwide until the end of March 2022, and it continued to implement others with three communes, Lien Ha, Duc Tu, and Viet Hung, and villages. Moreover, more than 20 communes have implemented this program in at least one hamlet or multi-housing block. With more activities and practices, the program still tends to set a new mindset on residents, managers, and agencies.

However, it recognized that the difficulty for social impacts on what has been set deeply into resident's minds. Whereas those programs need to be kept for the longer term, improvements also need to consider, for example, the impact of social networks (Facebook, YouTube, or Google) [12]. Later programs should focus on more communication methods to make a successful way for a better living environment.

4.2. Improvement of current residential solid waste management

a) Advantages of the current management system

The effective enforcement of environmental protection laws and regulations has led to positive changes in environmental activities. Local governments now prioritize environmental protection, utilizing communication tools. Each commune has an environment manager, ensuring rigorous and effective handling of environmental issues. Awareness of environmental protection has increased across all levels and sectors, resulting in environmental campaigns. Government environmental management has also improved. At the local level, teams handle residential solid waste collection and disposal. People are now conscious of waste classification and proper disposal. Additionally, many organizations, such as the People's Committee, Women's Union, and Youth Union, collaborate effectively in environmental protection efforts. Besides, there are still large natural areas in Dong Anh suitable for landfill construction.

b) Limitations of the current management system

Several segments of the community still lack awareness, leading to the persistence of uncontrolled landfills. Long-term investment in waste management projects and local programs remains insufficient. Coordination among environmental protection departments is poor. The existing system of environmental management agencies does not adequately address the needs of environmental protection activities and lacks clear division. Additionally, many activities remain informal.

c) Solutions to improve the management of residential solid waste

In Dong Anh district, strengthening enforcement of penalties for administrative violations in the field of environment according to Decree 45/2022/ND-CP of the Government on sanctioning of administrative violations in the field of environmental protection.

Increasing allowances for environmental sanitation workers to create the best conditions for them to do the collection and transportation of waste. It is recognized that the current income for waste collecting workers is seriously under-rated by their contribution. It is necessary to have solutions to propagate and raise public awareness continuously and extensively. Mobilize all the organizations of Youth Unions, Women's Union, Farmers' Union, Veteran's Association, and Elderly Association to actively participate in the declaration, collection, and management of domestic waste more effectively.

Moreover, integrating environmental protection criteria into the assessment of cultural families. Re-implement the "Program on collection, classification, and treatment of waste at source" built-in 2021 with the people of the whole district. Also, strengthening training and fostering knowledge of domestic solid waste management for district-level grassroots staff in general and full-time agents in particular. Improving the knowledge and training of environmental sanitation workers, improving the quantity and quality of the waste collection team.

Last but not least, the implementation of waste classification at the source is being promoted. By no later than December 31, 2024, all households are required to carry out waste classification according to regulations according to the Law on Environmental Protection (2020) [13], with the result that compostable waste requiring collection accounts for 74.35 % of the waste generated in the research areas, The number of vehicles and personnel for waste collection can be reduced in the future to align with the actual needs and bring economic efficiency to the local area.

5. Conclusion

Based on the investigation and survey of domestic waste in Dong Anh district, Tien Duong, and Uy No communes, it has been found that 235,505 tons of residential solid waste per day in the whole Dong Anh district, with an average coefficient of 0.59 kg of waste per person each day. It was discovered that the majority of localities did not have enough collection capacity, sufficient handcarts, specialized trucks, or enough collection points. This makes the collection of waste difficult.

The residential waste composition of the Dong Anh district is extremely diverse, with organic matter accounting for nearly 75 %, higher than the average of Hanoi. The important thing is to rigorously and thoroughly implement waste classification at the source according to the regulations of the Law on Environmental Protection (2020) to reduce the amount of waste generated that needs to be collected.

Despite the presence of protective equipment, there is still a need for more gear, and interest in the work remains low. Additionally, the frequency of waste collection is not consistent, as it should be performed once every day. Furthermore, there has been positive progress in terms of raising awareness and interest in environmental protection waste management. However, the environment is still not adequately protected, and the waste has not been properly sorted at the source. It is therefore important to take further steps to promote environmental protection and efficient waste management in the Dong Anh district.

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ASSESSING THE AUCTION WORK OF RESIDENTIAL LAND USE RIGHTS IN BAO YEN DISTRICT, LAO CAI PROVINCE

Nguyen Thi Hue[1,*], Nguyen Thi Khuy[1] , Tran Trong Nghia[2]

[1]Hanoi University of Natural Resources and Environment, Vietnam

[2]Land Fund Development Center, Bao Yen district, Lao Cai province, Vietnam

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Abstract

The study aims to assess the current status of land use rights auctions in Bao Yen district, Lao Cai province. Secondary data was collected mainly at the Land Fund Development Center of Bao Yen district, primary data was investigated from 30 people who won auctions of residential land use rights using pre-printed questionnaires with questions in 4 categories: The group includes 15 criteria with evaluation scores from 1 to 5. During 2021 - 2023, Bao Yen district successfully auctioned 35 residential land projects with 248 plots of land, total area of 54,237 m^2. The average starting price from 2021 to 2023 is 2,612.68 thousand VND/ m^2, respectively; 2664.2 thousand VND/ m^2; and 18,240 thousand VND/ m^2. The average winning price has a difference coefficient of 1.001 to 1.015 compared to the starting price. People rated the auction work with an overall satisfaction score of 3.62 points (quite satisfied). However, there are still some limitations regarding people's ability to access auction information, which is still low, the starting price is high compared to people's income... From there, it is necessary to develop solutions to enhance village access to information. They are auctioning people's residential land use rights and increasing the ability to successfully auction them with people in need.

Keywords: Bao Yen district; Land auction; Starting price; Winning price.

Corresponding author, Email: nthue@hunre.edu.vn

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1. Introduction

Land auction is the granting of land ownership or use rights to subjects in need through land bidding. Many countries worldwide have used land auctions to distribute different types of land to users, which is clarified in studies by [1 - 4]. In Vietnam, according to the 2013 Constitution regulations, the land is owned by the entire people with the State representing the owner and uniformly managing it [5], so a land auction is an auction of land use rights. This is the local competent authority organizing a public auction of land plots to obtain capital for other purposes in the locality according to the order and procedures prescribed by the Land Law and the Law on Land. Law on asset auctions and conduct them openly, continuously, objectively, honestly, equally, protecting the legitimate rights and interests of participating parties [6] or we can understand land use rights auctions in general and auction of residential land use rights, in particular, is a form of granting land use rights to subjects who need to use land publicly and the person who is awarded land use rights is the person who offers the highest price, unique [7]. The auction of residential land use rights is implemented based on market land prices, which plays an important role for land users and the real estate market. The auction of land use rights helps the State mobilize maximum revenue for the budget, and create investment capital for infrastructure construction and economic development. Thereby, contributing to creating stability, transparency, and social justice in land allocation and land leasing activities, ensuring the interests of the State and land users [8].

Bao Yen district, Lao Cai province is the Eastern gateway of Lao Cai province, 75 km from Lao Cai city, and 263 km from Hanoi. Has a natural area of 818.34 km^2. In recent years, the district has paid special attention to land management for comprehensive economic, political, and social development. Therefore, the work of auctioning land use rights in the district is given special attention with the aim of both mobilizing land resources and putting land to use reasonably. In addition to the achievements, the auction of land use rights also faces some difficulties such as low educational levels, many ethnic minorities in mountainous areas have low education levels, so access to information is limited. The starting price is higher than people's income, the cost of creating a large land fund, and the phenomenon of land speculation,... Therefore, the author conducted this research to answer the question: What is the current status of auctioning residential land use rights in the Bao Yen district? How satisfied are people with the auction of land use rights in the Bao Yen district?. What are the advantages and disadvantages?, and What solution to complete the auction of land use rights in Bao Yen?

2. Research methods

2.1. Research scope

The study evaluates the current status of land use rights auctions in Bao Yen district, Lao Cai province in the period 2021 - 2023.

2.2. Data collection methods

Secondary data on natural, and socio-economic conditions, and land use rights auctions were collected at the Land Fund Development Center of Bao Yen district. The study also directly investigated land use rights auction winners in the period 2021 - 2023, using pre-printed ballots because they fully grasped information related to land auctions from auction announcement to actual land handover. Location and receive a land use right certificate according to Formula (1) [9].

$$n = \frac{N}{1 + e \;\; * N} \qquad (1)$$

in which: - number of survey forms (number of winners of residential land auctions who responded to the survey); - total number of land use rights auction winners in the period 2021 - 2023 (N1 = 248 people); e - allowable error (e = 5 - 15 %), choose e = 5 %. Substituting into formula (1), we have, = 18.5. To increase reliability, the study investigated 30 votes, each auction winner answered 1 vote. Information about auction winners is taken from auction participation records.

The content of the auction winner investigation includes: Basic information about the winner of the land use right auction; Comments on auction information at projects; Purpose of use of auctioned land; Auction participation procedures; Facilities and human resources to serve valuable land; Financial obligations that must be fulfilled; Opinions on the winning land price and auction starting price; Certificate issuance deadline; Level of satisfaction with some auction factors,… The level of satisfaction of land auction winners with some factors is assessed on a 5-level Likert scale (Very satisfied - 5 points, quite satisfied - 4 points, moderately satisfied - 3 points, less satisfied - 2 points, dissatisfied - 1 point) [10].

2.3. Methods of synthesizing, analyzing, and comparing data

Collected data is processed, analyzed, and synthesized using Excel software. Compare the auction starting price with the market land price; The winning price is the starting price of the auction. Evaluation of the level of satisfaction impact on 4 criteria groups including 15 criteria including: Information group on land use rights auctions, assessment group on officials involved in land use rights auctions, group land use rights auction procedures, satisfaction level about land use rights auctions.

The level of satisfaction is determined based on the value of the satisfaction index of each factor group (Hi) (very satisfied - Hi ≥ 4.20, quite satisfied - Hi = 3.40 ÷ 4.19, moderately satisfied - Hi = 2.60 - 3.39, less satisfied - Hi = 1.80 ÷ 2.59, unsatisfied Hi < 1.80) [10]. The value of the satisfaction index of each group of auction criteria is determined according to Formula 2.

$$H_i = \frac{1}{n} * \sum_{i=1}^{q} \sum_{j=1}^{n} x_{ij} \qquad (2)$$

in which: H_i - value of ith satisfaction index, n - number of people responding to the survey; q - number of factors surveyed about satisfaction level, x_{ij} - assessment score of the jth respondent's satisfaction with the ith factor. The value of the overall satisfaction index with the land auction of the auction winners is determined according to Formula 3.

$$\mathbf{H} = \frac{\mathbf{1}}{\boldsymbol{q}} * \sum_{i=1}^{q} \mathbf{H}_i \qquad (3)$$

in which: H - is the value of the overall satisfaction index for land auctions of the auction winners; H_i - is the satisfaction index for ith factor; q - is the number of factors surveyed about satisfaction level.

The overall satisfaction level of land auction winners is determined according to the value of the general satisfaction index (very satisfied - H ≥ 4.20, quite satisfied - H = 3.40 ÷ 4.19, moderately satisfied - H = 3.40 ÷ 4.19), average - H = 2.60 - 3.39, less satisfied - H = 1.80 ÷ 2.59, dissatisfied H < 1.80) [10].

3. Results and discussion

3.1. The current status of land use rights auctions in Bao Yen district

Bao Yen is a lowland district of Lao Cai province, located 75 km Southeast of Lao Cai province center with a total natural area of 81,834.48 hectares. Bao Yen district's population according to 2023 statistics is 88,795 people, mainly working in the fields of agriculture, forestry, and rural development. The total residential land area in Bao Yen district is 559.32 hectares, including 500.52 hectares of rural land and 58.8 hectares of urban land, accounting for 14.19 % of the total non-agricultural land area.

In the period 2021 - 2023, Bao Yen district will organize 11 auctions of land use rights for 35 projects; The total number of winning auction documents is 248 documents. In particular, in 2021, there will be 5 batches with 123 winning documents, in 2022 there will be 4 batches with 100 winning documents, and in 2023 there will be 2 batches with 25 winning documents (Table 1).

Table 1. Summary of the number of successful auction documents for residential land use rights in Bao Yen district

Phase	Number of documents winning the auction of residential land use rights		
	2021	2022	2023
1	12	84	1
2	2	3	24
3	28	4	-
4	31	9	-
5	50	-	-

Source: Bao Yen district Land Fund Development Center for the period 2021 - 2023

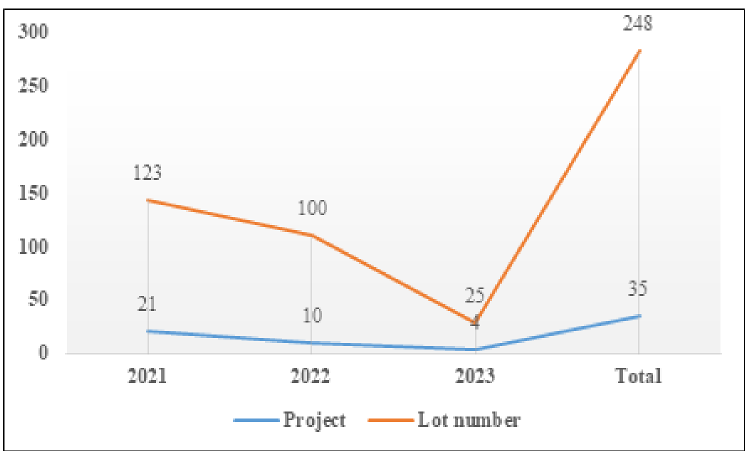

Figure 1: Summary of project numbers and land use rights auction lots

3.2. Assessing the results of the auction of use rights in Bao Yen district

Table 2. Results of the auction of land use rights in the Bao Yen district period 2021 - 2023

Year	Area (m^2)	Amount collected (thousand VND)	Average amount collected (thousand VND/ m^2)
2021	13,387	40,689,400	3,039
2022	11,270	41,191,557	3,655
2023	2,462	10,625,453	4,316
Total	**54,237**	**185,012,819**	**14,422**

Source: Bao Yen district Land Fund Development Center for the period 2021 - 2023

In the period 2021 - 2023, Bao Yen district will auction land use rights for 35 projects with a total successful auction area of 54,237 m^2, and total proceeds of 185,012,819 thousand VND (Table 2).

Results Table 2 shows that in 3 years of organizing land use rights auctions in Bao Yen district, there was no unsuccessful auction of land plots, and the successful residential land use rights auction rate reached 100 %. The most residential land area auctioned is in 2021 with 123 auctions, an area of 13,387 m^2, however, the highest amount of money collected in 2022 is 41,191,557 thousand VND with only 100 auctions. The reason is that the average auction land price in 2022 is 20.27 % higher than in 2021. In 2023, the highest average winning price in 3 years was 4,316 thousand VND. In 2023, there will only be 25 auctions, much less than in 2021 and 2022.

The starting price is determined according to Circular No. 36/2014/TT-BTNMT dated June 30th, 2014, of the Ministry of Natural Resources and Environment, detailing the method of determining land prices; Building and adjusting land prices list; Determining specific land prices, and advising on land price determination. During the period 2021 - 2023, Bao Yen district will conduct 35 auctions with different starting prices, the lowest starting price is 240 thousand VND/ m^2, and the highest starting price is 7,300 thousand VND/ m^2. The average starting price in 2021 is 2612.68 thousand VND/ m^2, in 2022 it is 2664.20 thousand VND/ m^2, the highest average starting price in 2023 is 18240 thousand VND/ m^2, (Table 3).

Table 3. Starting prices of land plots in the Bao Yen district

TT	Starting price (thousand VND/m^2)	Lot number		
		2021	**2022**	**2023**
1	240	0	3	0
2	560	1	0	0
3	1000	2	0	0
4	1400	3	8	0
5	1500	9	10	1
6	1800	18	0	0
7	2600	32	0	0
8	2800	6	7	0
9	2900	0	58	0
10	3000	17	0	0
11	3100	2	0	0
12	3200	21	0	0
13	3400	2	0	0
14	3500	5	9	14
15	3600	3	0	0
16	4000	1	4	0
17	4200	0	1	0
18	5000	0	0	9
19	5200	1	0	0
20	7300	0	0	1
Lot Total		**123**	**100**	**25**
Average starting price		2,612.68	2,664.2	18,240

Source: Bao Yen district Land Fund Development Center for the period 2021 - 2023

According to summary data from the Bao Yen district Land Fund Development Center, the average difference between the winning land price at the auction of residential land use rights and the starting price is from 1,001 to 1,015 %. The relatively low difference reflects the reality of the small number of people participating in the auction of land use rights. The reason is that the auction price of residential land use rights is still high compared to the income of local people, due to the specific terrain of the mountainous province, leading to machinery costs to level the ground and create a large clean land fund. Most of the auction winners came from other localities. This also poses a potential risk of land speculation when people who need to use the land do not have enough funds to buy it, and the bidders are people who have money but do not need to use it.

3.3. Assessing the level of satisfaction with the auction of land use rights in Bao Yen district

3.3.1. Assessing the information on the auction of residential land use rights

The majority of people surveyed believe that information about auctions of land use rights in Bao Yen district is publicized in many forms such as posting information on the website of Bao Yen district and other agencies. Relevant authorities such as the Center for Land Fund Development, Department of Natural Resources and Environment, or remote village areas, publicize it at the Commune People's Committee and call on loudspeakers. That's why 80 % of respondents rated it 3 points (publicity level), 13.33 % rated it 4 points (clear disclosure) and 6.67 % rated it 5 points (very clear transparency).

Regarding the criteria of accessibility to information about auctioned land plots, 86.67 % of respondents answered that access was averagely easy, while 13.33 % rated it as difficult to access. The reason is that people in remote villages are not proficient in information technology, so access to information on electronic portals is very limited. Although there is also a form of calling on loudspeakers or publicizing it on the People's Committees of communes, people often ignore it, so very few people know the information about the auction of residential land use rights in the district. When it is necessary to introduce the project location in the field, people are brought to the field by officials in charge of auctioning residential land use rights, so 23 people rate this criterion at level 3 (medium). Average), 7 people at level 4 (fast), (Table 4).

Table 4. Assessing the auction information for residential land use rights

Assessment criteria	Rating score (point)					Rate (%)				
	1	2	3	4	5	1	2	3	4	5
1. Publicize information about the auction project	0	0	24	4	2	0.00	0.00	80.00	13.33	6.67
2. Ability to access information about auctioned land plots	0	4	26	0	0	0.00	13.33	86.67	0.00	0.00
3. Introducing the project location in the field	0	0	23	7	0	0.00	0.00	76.67	23.33	0.00

3.3.2. Assessing the auction and certification procedures

Regarding administrative procedures when participating in land auctions, 100 % of respondents said that the auction procedures were simple and by the law at auctions, specifically 50 % rated it as 3 (normal procedure), and 50 % rated it as 4 points (simple procedure). This is completely consistent with the reality of implementing the auction of land use rights in the district. Bao Yen district hires an auction organization, this unit is responsible for guiding auction participants on auction procedures, how to participate, how to pay, auction regulations,... Therefore, compliance procedures at auctions of residential land use rights are always well guaranteed.

Specifically, 83.33 % of interview respondents rated 3 points (average compliance), and 16.67 % rated 4 points (good compliance). The criteria for granting land use rights certificates after winning the auction are also highly rated, with 66.67 % rating 4 points (good), and the remaining 33.33 % rating 3 points (average). Most respondents understood that after paying the full auction winning amount, after 30 days of applying for a land user certificate, the certificate will be issued, by the provisions of the Land Law (Table 5).

Table 5. Assessing auction procedures and issuance of land use rights certificates after winning the auction

Assessment criteria	Rating score (point)					Rate (%)				
	1	2	3	4	5	1	2	3	4	5
1. Procedures for participating in the auction of residential land use rights	0	0	15	15	0	0.00	0.00	50.00	50.00	0.00
2. Comply with procedures at the residential land use rights auction	0	0	25	5	0	0.00	0.00	83.33	16.67	0.00
3. Time to issue Land Use Rights Certificate after winning the auction	0	0	10	20	0	0.00	0.00	33.33	66.67	0.00

3.3.3. Assessing the officials involved in Land use rights auctions

Based on the evaluation results of Table 6, the criterion “Conduct of officials towards the people” in the auction of land use rights in Bao Yen district is highly appreciated, the interviewees rated it highly. The officials have a gentle, friendly, and dedicated attitude toward the people, so 66.67 % rated it 4 points (good behavior), 26.67 % rated it 5 points (very good behavior), and only 6.67 % rated it 3 points (average). The working style of the ministries is rated at two levels: 3 and 4, corresponding to 33.33 % and 66.67 %, which is an average and good professional style. With the criteria of guiding administrative procedures, 16.67 % rated the average - 3 points, and the remaining 83.33 % rated the enthusiastic and detailed guidance - 4 points. All people’s questions were answered clearly and promptly, so 83.33 % rated it 4 points - satisfied, the remaining few rated it average - 3 points.

Table 6. Evaluation of officials involved in land use rights auctions

Assessment criteria	Rating score (point)					Rate (%)				
	1	2	3	4	5	1	2	3	4	5
1. Behavior of officials towards people	0	0	2	20	8	0.00	0.00	6.67	66.67	26.67
2. Working style of staff	0	0	10	20	0	0.00	0.00	33.33	66.67	0.00
3. Instructions for implementing administrative procedures	0	0	5	25	0	0.00	0.00	16.67	83.33	0.00
4. Answer people's questions	0	0	5	25	0	0.00	0.00	16.67	83.33	0.00

3.3.4. Assessing the level of satisfaction with the auction of residential land use rights

Table 7 shows that the criteria for satisfaction with auction participation procedures are evaluated well with 28 votes of 4 points (satisfaction) accounting for 93.33 %, with only 2 votes of 3 points (average satisfaction) accounting for 6.67 %. This is consistent with the current situation of the auction of residential land use rights in Bao Yen. Because a third party is hired to organize the auction, the procedures are explained and supported by the consulting unit. Until completed. Regarding the level of satisfaction, the organization hosting the auction was also highly appreciated, with 25 votes corresponding to 83.33 % rated 4 points (satisfied), and 5 votes corresponding to 16.67 % rated 3 points (average satisfaction). It can be seen that the above evaluation results accurately reflect the reality of auctions, there is always an auctioneer running the auction, coordinating smoothly with the finance and tax departments under the supervision of leaders. Bao Yen district, inspection department, and Land Fund Development Center, collectively known as the supervision team.

Those who carry out auction administrative procedures (auctioneers) are all certified in auctions, have a neat and professional working style, and therefore meet the criteria of satisfaction with the person carrying out the procedures. Auction administration reached 90 % of respondents satisfied (4 points), and only 10 % rated average satisfaction (3 points). Regarding facilities to serve the auction of land use rights, all auctions of Bao Yen district are held at the cultural center and cultural house of Bao Yen district, so the facilities are quite good. Therefore, 26 interviewees rated 4 points (good), and 4 people rated 3 points (average) corresponding to 86.67 % and 13.33 %.

Table 7. Evaluate the level of satisfaction with the auction of residential land use rights

Assessment criteria	Rating score (point)					Rate (%)				
	1	2	3	4	5	1	2	3	4	5
1. Level of satisfaction with auction participation procedures	0	0	2	28	0	0.00	0.00	6.67	93.33	0.00
2. Level of satisfaction with the organization hosting the auction	0	0	5	25	0	0.00	0.00	16.67	83.33	0.00
3. Level of satisfaction with the person carrying out auction administrative procedures	0	0	3	27	0	0.00	0.00	10.00	90.00	0.00
4. Level of satisfaction with auction facilities	0	0	4	26	0	0.00	0.00	13.33	86.67	0.00

The objective assessment results have reflected the actual level of satisfaction of participants with the auction of residential land use rights in Bao Yen district, Lao Cai province with different levels. With satisfaction with information on auctions of residential land use rights reaching 3.12 points (average level); Regarding auction procedures and issuance of certificates of residential land use rights, the score was 3.58 (quite satisfied); Regarding officials involved in the auction of residential land use rights and the level of satisfaction with the auction of residential land use rights both reached 3.88 (quite satisfied). Thus, with 4 groups of evaluation criteria, 3 groups of criteria reach a good level, and 1 group of criteria reaches an average level. The overall level of satisfaction that interviewees assessed about the auction of residential land use rights reached 3.64 (quite satisfied). This confirms that the auction of residential land use rights in Bao Yen district, Lao Cai province is being implemented well and receiving high appreciation from auction participants (Figure 2).

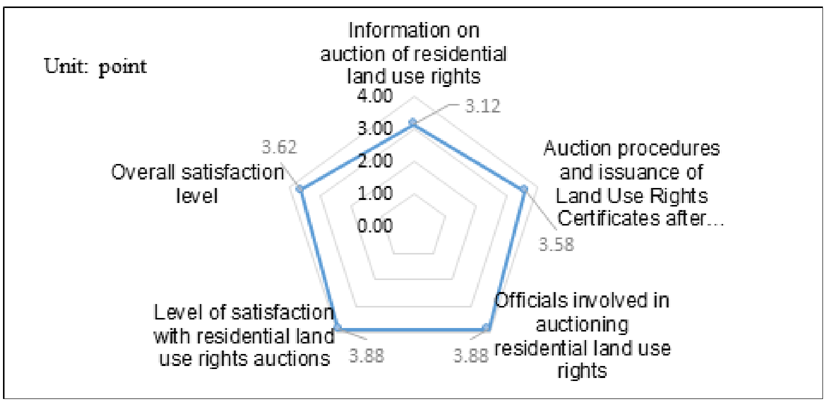

Figure 2: Level of satisfaction with the auction of land use rights in Bao Yen district

3.4. General assessment

3.4.1. Advantage

The auction of land use rights in the Bao Yen district is closely cared for and directed by leaders at all levels. The organization and implementation process is methodical, open, and transparent. The auction format currently applied is appropriate and achieves high results. After the auction, the infrastructure at the auction site was built better than before, and the urban landscape was more spacious. The auction of land use rights in Bao Yen district has achieved certain economic and social effects such as contributing to reasonable exploitation of land funds, increasing revenue for the budget, and creating investment capital for building facilities, and infrastructure.

3.4.2. Disadvantage

The ability of people in villages to receive information about auctions of residential land use rights is limited because people are not proficient in technology and receiving information on electronic websites is still difficult. The starting price of land use rights is higher than people’s income due to the cost of machinery to level the ground and create a land fund in large mountainous terrain.

There is a phenomenon of land speculation when some winning documents for land use rights auctions are people from other provinces who came to participate in the auction but they have no real need for housing.

3.5. Solution to complete auction of land use rights in Bao Yen district

3.5.1. Enhance access to information on land use rights auctions

It is necessary to continue to promote and improve the quality and effectiveness of propaganda and dissemination of information about residential land use rights auction projects to people, especially people in remote villages by diversifying propaganda methods that are more effective than loudspeaker calls or publicity at commune People's Committees, such as sending officials to homes to disseminate information about projects, holding meetings to disseminate information. General information in the villages and hamlets of the people.

At the same time, it is necessary to organize training classes on the use of technological means to update information related to Land Law policies in general and information on land use rights auctions in particular for people who are not high-level.

3.5.2. Increase the ability to successfully auction residential land use rights of people in need

It is necessary to balance people's income level with the starting price of auctioned land plots to increase the likelihood of successfully auctioning people's residential land use rights. Research options to reduce site leveling costs and create a land fund so that people in need can easily access the starting price when auctioning land use rights. Additional policy solutions such as supporting loans with low interest rates to auction residential land use rights in particular and auction land use rights in general for local people.

3.5.3. Policy solutions to combat land speculation

The state needs to take measures to limit land speculation by individuals with money from other localities participating in the auction, leading to even higher residential land prices. From there, the legal system can consider progressive land taxation for second and subsequent real estate to avoid speculators creating virtual land fevers, pushing up land prices, making it difficult for People's opportunity to use land to become even lower.

4. Conclusion

During the period 2021 - 2023, Bao Yen district successfully auctioned 35 residential land projects with 248 plots of land with a total area of 54,237 m^2. The average starting price at auction from 2021 to 2023 is 2,612.68 thousand VND/ m^2, respectively; 2664.2 thousand VND/ m^2; and 18,240 thousand VND/ m^2. The average auction winning price has a difference coefficient from 1.001 to 1.015 compared to the starting price, the average difference coefficient between the auction winning price is quite satisfied with the overall satisfaction score reaching 3.62 points (fair level), satisfied).

Land use rights auctions have brought about economic, social, and state management effects on land. However, there are still some limitations such as people's ability to access land use rights auction information is low, the starting price is high compared to people's income... From there, it is necessary to develop solutions to strengthen people's ability to access residential land use rights auction information and increase the ability to auction residential land use rights with people in need successfully.

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APPLICATION OF INTERFEROMETRIC SYNTHETIC APERTURE RADAR DATA IN ASSESSING LAND SUBSIDENCE RESULTING FROM HUMAN FACTORS IN NINH BINH PROVINCE, VIETNAM

Nguyen Mai Lan[1,*], Nguyen Duc Anh[2]

[1]Hanoi University of Natural Resources and Environment, Vietnam

[2]Institute of Geological Sciences, Vietnam Academy of Science and Technology

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Abstract

The method of Satellite Interferometric Synthetic Aperture Radar, based on analyzing the phase difference of radar complex images recorded from two different positions simultaneously observing a terrain area where the signals have the same amplitude, frequency, and wavelength but different phases, the deformation of the terrain surface in Ninh Binh province is analyzed and calculated. The preliminary results include the construction of a deformation map of the ground surface in the Ninh Binh province for the period 2020 - 2021, consisting of 78,077 points. The map shows areas that have been uplifted with values of 3 - 5 mm/year and >5 mm/year, particularly highlighting areas with significant subsidence velocities of <-10 mm/year (Kim Son and Yen Khanh districts), some areas with subsidence velocities ranging from -5 to -10 mm/year (Yen Nhan commune, Yen Mo district, Nam Binh ward, Ninh Phong district in Ninh Binh city), and subsidence values of 0 to -5 mm/year in the communes bordering between Nho Quan and Gia Vien districts. These results provide a basis for identifying the causes of terrain surface changes and proposing solutions to prevent and mitigate damages in Ninh Binh province; In-depth studies will continue.

Keywords: Interferometric Synthetic Aperture Radar; Surface deformation; Uplifted; Subsidence; Ninh Binh.

[*]**Corresponding author, Email:** nmlan@hunre.edu.vn

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1. Introduction

Interferometric Synthetic Aperture Radar (InSAR) is a remote sensing technique widely used in the study of terrain changes both globally and in Vietnam. By analyzing the phase differences of radar signals collected by satellites over time, InSAR can detect and measure subtle surface movements. It has been applied in various domains including geology, environmental monitoring, and urban planning. In the global context, InSAR has provided valuable insights into tectonic movements, volcanic activities, and land subsidence in regions prone to natural hazards [1, 2, 3, 4]. Alex Hay-Man Ng. (2012) discussed the use of InSAR to monitor land subsidence in Jakarta, a city prone to significant ground deformation [5]. Muhammad Afaq Hussain (2022) used the Persistent Scatterers In-SAR technique for monitoring land subsidence in a coastal city in Pakistan [6].

In Vietnam, InSAR has been instrumental in monitoring land subsidence in the Mekong delta region due to groundwater extraction and understanding the deformation of the Red River delta [7]. Additionally, other studies such as the project "Research on the scientific basis and propose solutions for predicting ground subsidence in Hanoi city using interferometric radar techniques" code DTDL.2012-T/28, led by the Institute of Geology [17], applied Alos-Palsar images from 2007 - 2011 and Cosmo-Skymed, TerraSAR-X images from 2011 - 2014 using interferometric radar methods to study surface deformation in the central area of Hanoi. The study identified high subsidence areas such as Hoang Cau, Ha Dong, Tan Mai, Phap Van - Linh Dam, and widespread subsidence areas like Ha Dinh, Thanh Xuan, and Tan Mai. Notably, in the Tram Troi area, many high-speed subsidence areas with rates < -15 mm/year were detected. Areas with little subsidence, even with positive velocity values (uplift according to radar data), are concentrated in the northern key areas such as Tay Ho district, and Cau Giay district, including Nghia Tan and Nghia Do. The research results from the project "Researching on the scientific basis and proposing the solutions for early warning of landslides, flash floods, mud and rock floods in Northern Vietnam using remote sensing technology and data on geological structure" code VT-UD.05/18-20 [16] have been confirmed in land subsidence studies in the Cam Pha - Quang Ninh area. As a result of Radar interference analysis, it was found that the subsidence area in Cam Pha city center is concentrated in the two districts of Cam Dong and Cam Son districts, and extends beyond the study area to Cua Ong and Mong Duong districts. The average subsidence rate is -3 to -5 mm/year. In these studies, field verification has shown that satellite radar technology using interferometric radar methods allows for the identification of subsidence areas in both spatial and temporal dimensions

From 2019 to now, there have been continuous subsidence incidents in Ninh Binh province. These subsidence incidents always occur on traffic routes and around construction areas [10, 11, 12, 13, 14, 15]. That is the reason, the project "Research on the assessment of land subsidence, ground fissures, and propose solutions for prevention and mitigation of damage in Ninh Binh province", led by a group of scientists at the Institute of Geology, has been proposed for implementation during the period 2022 - 2025. This paper presents the initial results achieved through the use of satellite interferometric radar technology, laying the foundation for more in-depth studies to understand the causes of subsidence in Ninh Binh, thereby proposing preventive and mitigation solutions for the study area.

2. Methods and materials

2.1. Area research

Ninh Binh is the southernmost province of the North Delta, located between 190°50’N and 200°27’N, 105°32’E and 106°27’E. The Tam Diep mountains run in a Northwest - Southeast direction and form the natural boundary between her two provinces, Ninh Binh and Thanh Hoa. It is surrounded by the Day River to the East and Northeast, borders Ha Nam and Nam Dinh provinces, Hoa Binh province to the North, and the East Sea to the South.

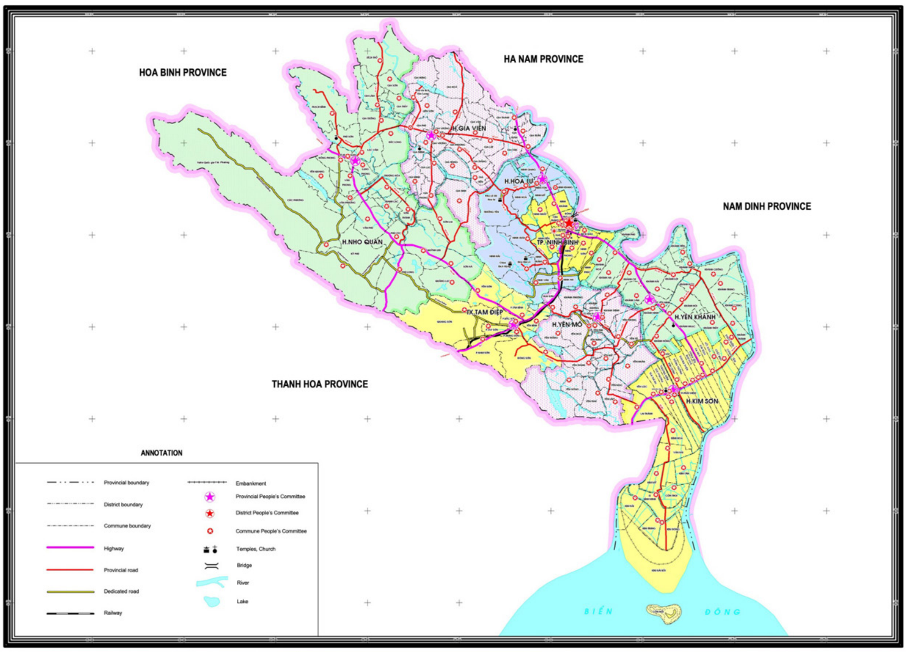


Figure 1: Map of Ninh Binh

Ninh Binh has three distinct regions.

* *Delta region:* occupies 71.1 % of the province’s natural area, it is the most densely populated area in the province, home to about 90 % of the province’s population. The area has an average elevation of 0.9 - 1.2 m. The land is mainly alluvial

* *Mountainous and Semi-mountainous regions:* This region is located in the Western and Southwestern parts of the provinces. The entire region covers an area of about 35,000 hectares, accounting for 24 % of the state’s natural area. The average height is 90 - 120 meters. Somewhere, rocky areas are more than 200 m high. Up to 90 % of the state’s mountain and forest area is concentrated in this region.

* *Coastal region:* Ninh Binh has more than 15 km of coastline. Covering an area of about 6,000 hectares, it accounts for 4.2 % of the state’s natural area. The land here is still very salty due to new deposits and is currently undergoing refurbishment.

Ninh Binh has a tropical monsoon climate. The annual weather is divided into 4 distinct seasons: Spring, summer, autumn, and winter. The average annual temperature is about 23 degrees Celsius. The average number of sunshine hours in a year is over 1100 hours. The average rainfall per year is 1,800 mm.

Ninh Binh is an important intersection from the North to the Central and the South with many important roads, railways, and waterways running through. The river system in Ninh Binh includes the system of Day Rive, Hoang Long river, Boi River, An River, Vac River, Lang River, and Van Sang river, with a total length of 496 km, widely distributed throughout the province. The average density of rivers and streams is 0.5 km/ km^2, rivers usually flow in the direction of Northwest - Southeast to empty into the East Sea.

Sentinel-1 data is currently completely free of charge. Within the research area of the project, Sentinel imagery data can be downloaded from the website: https://scihub.copernicus.eu/

The research area images are in VV polarization with an Ascending orbit. The time is from 2014 until now, however, the quantity and the availability of images provided may vary depending on different research areas.

The Sentinel-1 images used in this study are in Interferometric Wide (IW) mode. The data has a swath length of 250 km with a spatial resolution of 5 × 20 m (single-look). The IW mode captures three sub-swaths through the Terrain Observation with Progressive Scans SAR (TOPSAR) scanning technique. With the TOPSAR technique, beam steering is not only controlled in azimuth as in ScanSAR, but also electronically steered in the reverse direction for each acquisition, avoiding misalignment and ensuring image quality consistency throughout the swath [8].

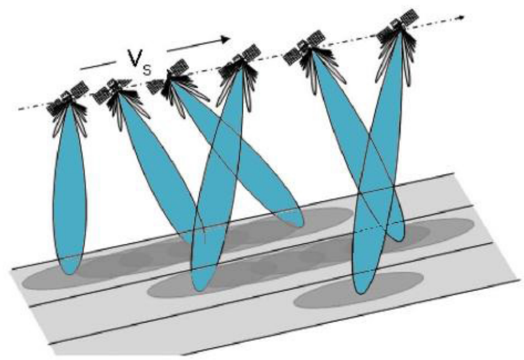


Figure 2: Acquisition mode of TOPSAR Sub-Swath

Each captured image has three vertical IW sub-strips labeled IW1, IW2, and IW3 from right to left. Each IW has 9 - 10 bursts depending on the research area.

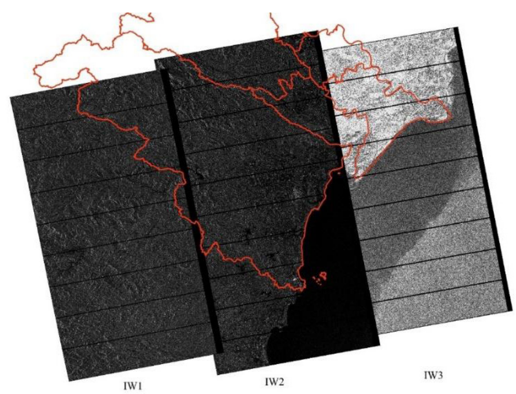


Figure 3: Track and burst information received from Sentinel Ninh Binh province on February 9th, 2020

2.2. Method research

SAR is a special radar imaging technique at high resolution, which uses the motion of a satellite or a carrier to simulate the antenna size (also known as synthetic) to improve the spatial resolution of the imaging radar. Currently, the SAR technique in photography is used more and more widely in Environmental monitoring, earth-resource mapping, and military systems.

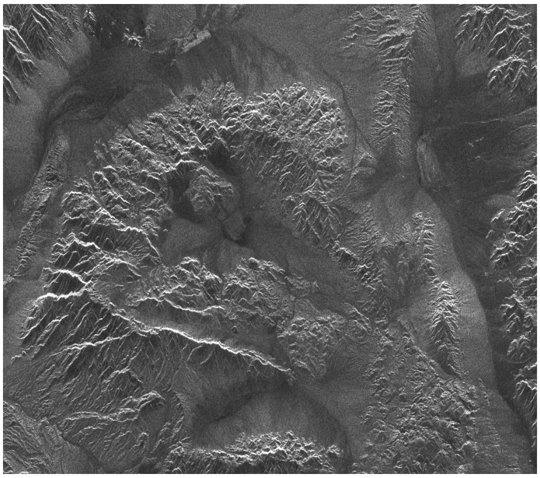


Figure 4: Example of SAR image

SAR data also enables an analytical method called interferometry (InSAR). InSAR uses the phase information recorded by the sensor to measure the distance from the sensor to the target. If at least two observations are made of the same target, the distance from the sensor and the additional geometric information can be used to measure changes in the topography of the earth's surface. These measurements are very accurate to centimeters and can be used to identify areas of deformation. If two or more images are a series of images covering the same area and are used, for example, to determine terrain variation, these images need to be spatially aligned with each other during image registration. In this case, it is resampled to change the relative translation, rotation, and scale (for pixels of different sizes). SAR image interferometry combines two or more complex-valued SAR images and utilizes phase difference values to extract information about image objects. Images used for interference must differ in at least one element (such as the baseline).

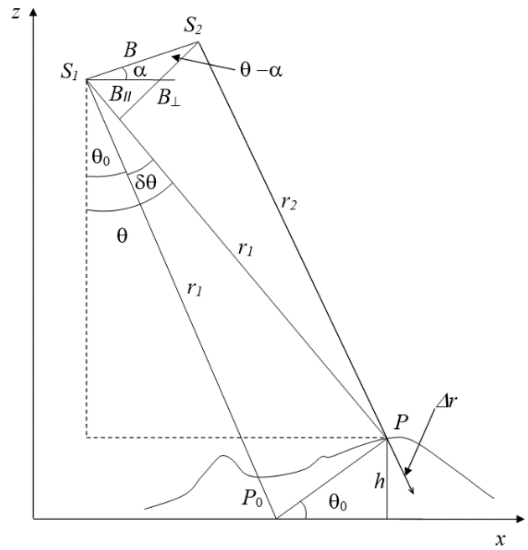


Figure 5: Basics of Interferometric SAR (INSAR)

From the above figure, the phase component depends on the terrain, and the phase shift in the line of sight direction is due to the terrain change by an amount of $r_2+\Delta r$ where Δr is the component of displacement parallel to the radar source

$$\phi_p \approx -\frac{4\pi}{\lambda} B\sin(\theta-\alpha)+\frac{4\pi}{\lambda}\Delta r \qquad (1)$$

The phase displacement is determined by $4\pi\Delta r/\lambda$ which is the displacement in the line of sight, and each fringe corresponds to half of the wavelength.

Thus, radar interferometry (InSAR) by extracting phase information from the interferometric image pair allows the study of surface deformation and is based on this formula:

$$\varphi_{interferometry} = \varphi_{topo} + \varphi_{defo} + \varphi_{atm} + \varphi_{noise} \qquad (2)$$

where: $\varphi_{interferometry}$: Interference phase

φ_{topo}: Topographic phase

φ_{defo}: Deformation phase

φ_{atm}: Atmospheric influence phase

φ_{noise}: Noise phase

The interference phase of the radar image pair includes the topographic phase, deformation phase, atmospheric influence phase due to signal delay when passing through the atmosphere, and other noise phases such as geometric decorrelation or baseline, temporal decorrelation, thermal noise, etc.

The deformation phase is calculated according to the formula:

$$\varphi_{defo} = \frac{4\pi\Delta r}{} \qquad (3)$$

where: Δr is the deformation component in the line of sight or parallel to the slant range direction of the radar signal transmitted to the ground, λ wavelength of radar.

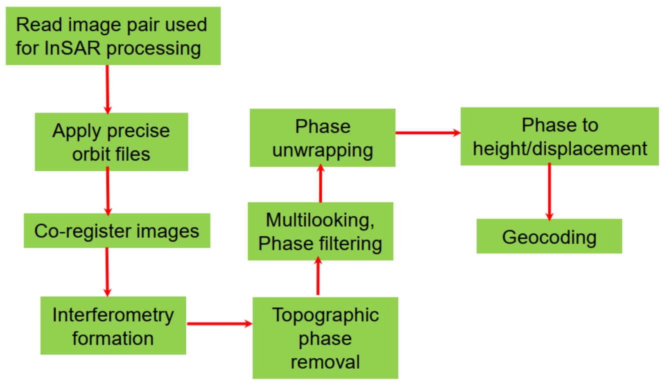


Figure 6: Processing Workflow of InSAR from Radar Images

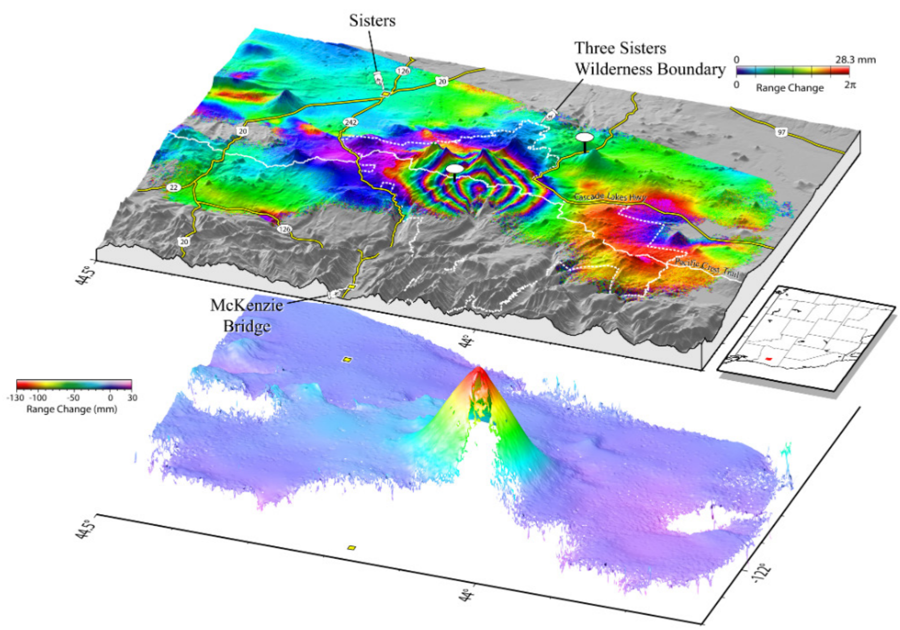


Figure 7: Interferogram image made from InSAR monitoring, showing 1995 - 2001 ground-uplift pattern centered 5 km (3 mi) West of South Sister volcano, Oregon

(Source: Public domain)

The PSInSAR (Persistent Scatterer Interferometry) method is applied for the Ninh Bình area. The processing steps of this method are carried out using SNAP and STAMPS.

The interferometric processing step using the Sentinel image set is performed on SNAP according to the following procedure (Fig. 8).

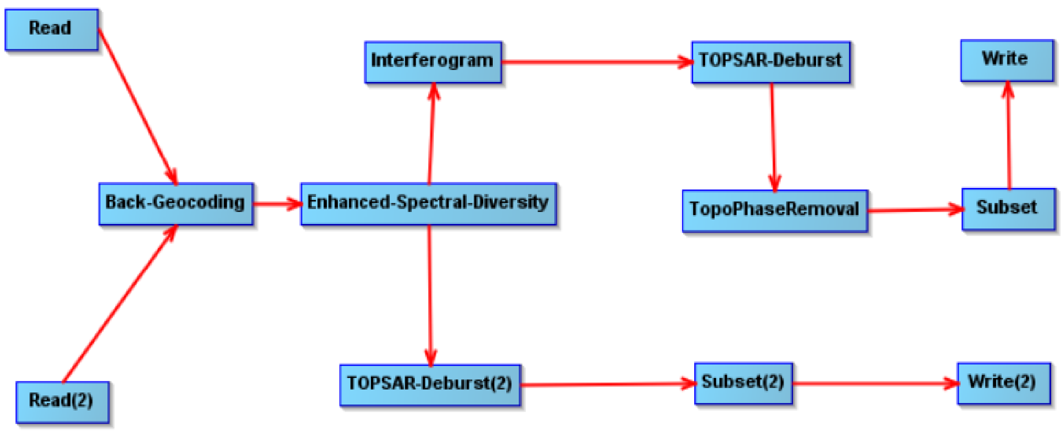


Figure 8: Interferometric Processing Workflow for Sentinel-1 Images in SNAP

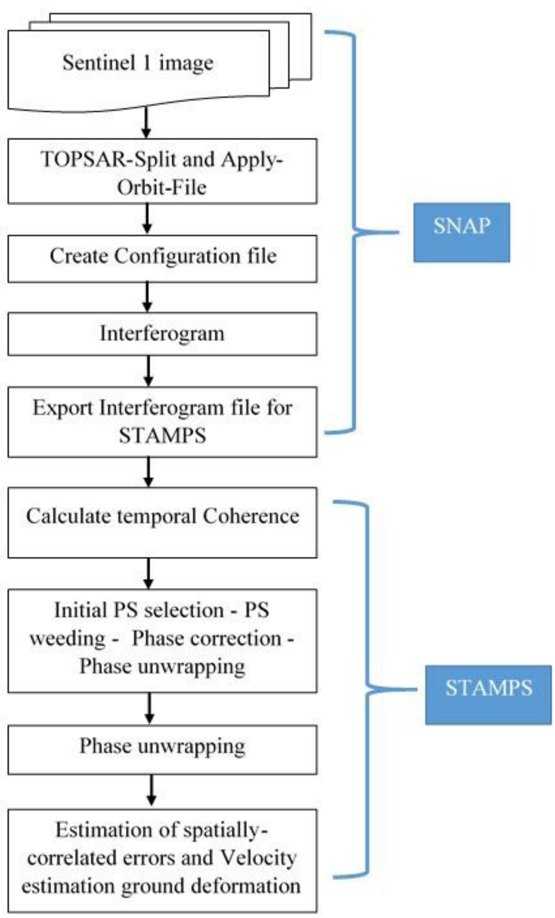


Figure 9: Diagram of image processing workflow combining SNAP and STAMPS

2.3. Material

53 photos were used from the beginning of 2020 to the end of 2021 in this study area. All image data were selected at no rainfall times.

The study area belongs to two swaths (IW2 and IW3) on Sentinel-1 images

Table 1. Collection of Sentinel-1 image data in Ninh Binh province for the period 2020 - 2021

Ord.	Date	Ord.	Date	Ord.	Date	Ord.	Date
1	09/02/2020	14	07/8/2020	27	22/01/2021	40	27/6/2021
2	21/02/2020	15	19/8/2020	28	03/02/2021	41	09/7/2021
3	16/03/2020	16	31/8/2020	29	15/02/2021	42	21/7/2021
4	28/3/2020	17	12/9/2020	30	27/02/2021	43	02/8/2021
5	09/4/2020	18	24/9/2020	31	11/03/2021	44	14/8/2021
6	21/4/2020	19	06/10/2020	32	23/3/2021	45	07/9/2021
7	03/5/2020	20	18/10/2020	33	04/4/2021	46	19/9/2021
8	15/5/2020	21	11/11/2020	34	16/4/2021	47	01/10/2021
9	08/6/2020	22	23/11/2020	35	28/4/2021	48	25/10/2021
10	20/6/2020	23	05/12/2020	36	10/5/2021	49	06/11/2021
11	02/7/2020	24	17/12/2020	37	22/5/2021	50	18/11/2021
12	14/7/2020	25	29/12/2020	38	03/6/2021	51	30/11/2021
13	26/7/2020	26	10/01/2021	39	15/6/2021	52	12/12/2021
						53	24/12/2021

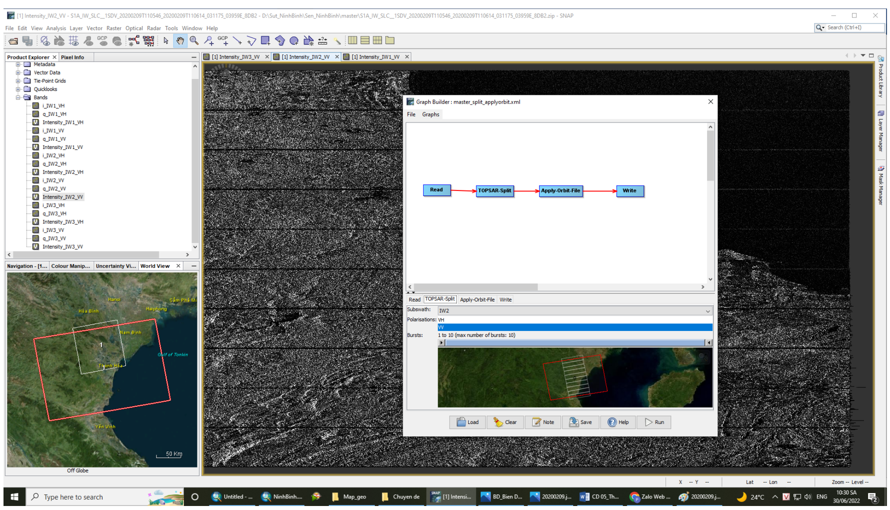


Figure 10: Registering Images of the Study Area in Ninh Binh province from Sentinel-1

3. Results and discussion

3.1. Advantages - disadvantages of InSAR

Analyzing the principles behind the creation of InSAR has demonstrated its potential application for studying land subsidence, ground cracking, both in spatial and temporal dimensions, over a wide area with millimeter-level accuracy. However, this technology also possesses both advantages and disadvantages in the processing phase.

The advantages of this technology include:

- Active satellite radar remote sensing allows for the transmission and reception of signals, enabling the study of subsurface objects during both day and night, and being less affected by weather conditions.

- Satellite radar remote sensing helps in monitoring and researching objects in hard-to-reach areas on the Earth's surface.

- Utilizing satellite radar in studying surface deformation provides highly accurate results down to the millimeter level.

The drawbacks of this technology mainly arise from the transmission and reception of signals from subsurface objects:

- It is affected by the terrain, as well as short-range phenomena, overlapping, and shadows in radar images.

- The results of radar processing can be influenced by various sources of noise.

However, these drawbacks can be overcome during the processing phase, making this technology highly reliable for studying land subsidence, ground cracking, and achieving high-quality results.

3.2. Result of InSAR application in land subsidence in Ninh Binh

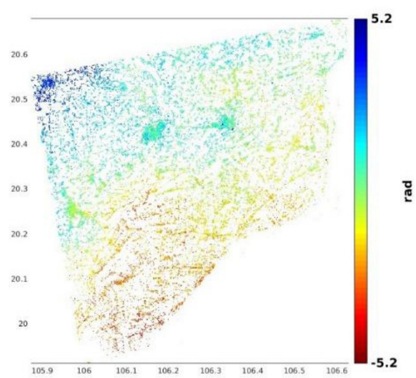


Figure 11: Results of the deformation phase of the study area after separating the topographic phase for each time point

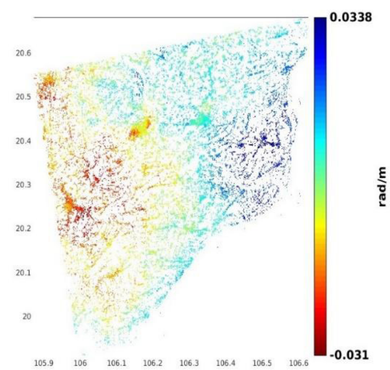
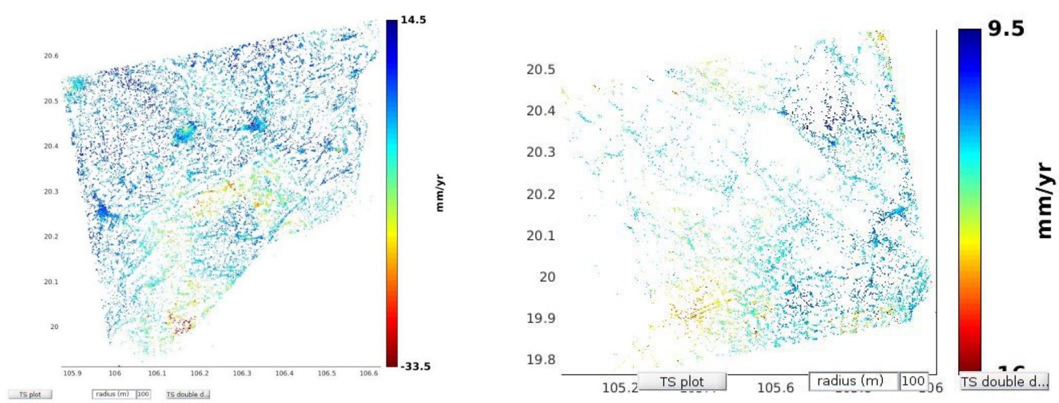


Figure 12: DEM terrain error value by satellite's orbit and angle of incidence



(a) IW3 ***(b) IW2***

Figure 13: Topographic distortion in the center of Sentinel-1 image for the period 2015 - 2019 after removing atmospheric noise (A3)

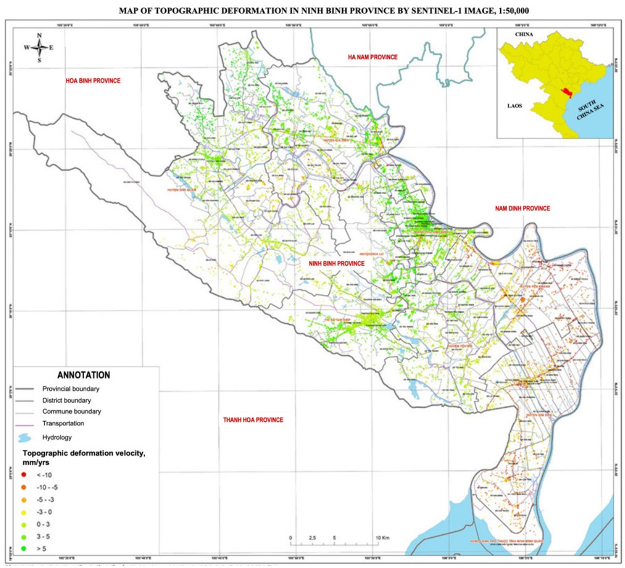


Figure 14: Results of ground deformation velocity in Ninh Binh province by Sentinel-1 image in the period of 2020 - 2021 (1:50,000)

From the results of the surface deformation map in Ninh Binh province during the period of 2020 - 2021, which includes 78,077 PS points, several areas of land subsidence have been identified. These areas include Kim Son district and Yen Khanh district, with many regions exhibiting subsidence velocities of <-10 mm/year. Some areas, such as Yen Nhan commune in Yen Mo district, Nam Binh ward, and Ninh Phong ward in Ninh Binh city, as well as the areas of certain communes located in the border region between Nho Quan district and Gia Vien district, show subsidence velocities ranging from -5 to -10 mm/year. There are also regions indicating subsidence values of 0 to -5 mm/year.

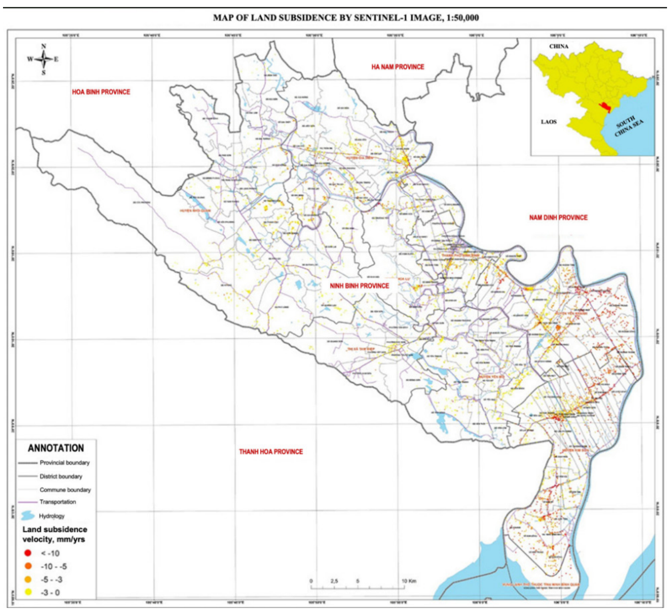


Figure 15: Results of land subsidence velocity in Ninh Binh in the period of 2020 - 2021

3.3. Discussion

InSAR results show that the points of land subsidence are concentrated in densely populated areas such as towns and cities in the province. The distribution of the subsidence points around areas undergoing urban development and transportation routes suggests that the subsidence is likely due to human-induced factors rather than natural causes.

The reality shows that from 2019 to now, there have been continuous subsidence incidents in Ninh Binh province. These subsidence incidents always occur on traffic routes and around construction areas. Specifically, in February 2019, a section of the road more than 60 m long in Thon 1, Kenh Ga, Gia Thinh commune, Gia Vien district sank into the river, houses were cracked, gates and yards were eroded [10]. In November 2020, the houses of the households in Kim Dai village, Kim Chinh commune, Kim Son district, next to Vac River, next to the construction site of the Kim Dai wharf project suffered foundation subsidence, and the wall was cracked [11]. In December 2021, a sinkhole appeared on provincial road 477 (ĐT477) through Gia Phuong commune, Gia Vien district [12]. In July 2022, the area of Ngo Quyen temple, Hamlet 6, Khanh Trung commune, Yen Khanh district was cracked and subsided during the construction of the traffic route connecting Khanh Trung commune and Khanh Cong commune (Yen Khanh district) [13]. In February 2023, many subsidence points appeared on the Cau Gie - Ninh Binh highway, especially the area adjacent to the highway surface and the civilian underpass bridge [14]. In September 2023, the construction area of the Kim Doi irrigation pump station project and level 1 irrigation system, Gia Lam commune, Nho Quan district suffered subsidence, and the canal bank leading to the suction tank of the pump station was broken [15].

The above research results of ground subsidence using radar interferometry need to be verified experimentally. The research results from project code VT-UD.05/18-20 have been confirmed in land subsidence studies in the Cam Pha - Quang Ninh area. As a result of Radar interference analysis, it was found that the subsidence area in the Cam Pha city center is concentrated in the two districts of Cam Dong and Cam Son districts, and extends beyond the study area to Cua Ong and Mong Duong districts (Fig. 16) [16]. The average subsidence rate is -3 to -5 mm/year. The sinkholes in the Cam Tay area, Cam Pha were recorded on October 6, 2018. The value chain processed from Sentinel-1 image data shows the time when abnormal fluctuations occurred before the sinkhole appeared for a long time. Figure 17 shows the data series recording abnormal fluctuations starting from June 2, 2018. The strong subsidence phenomenon started to occur on September 18, 2018.

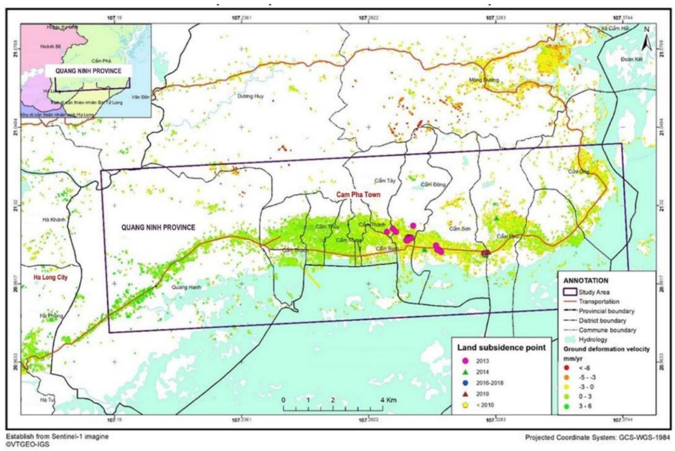


Figure 16: Integrated land subsidence statistics on terrain surface deformation data in Cam Pha - Quang Ninh

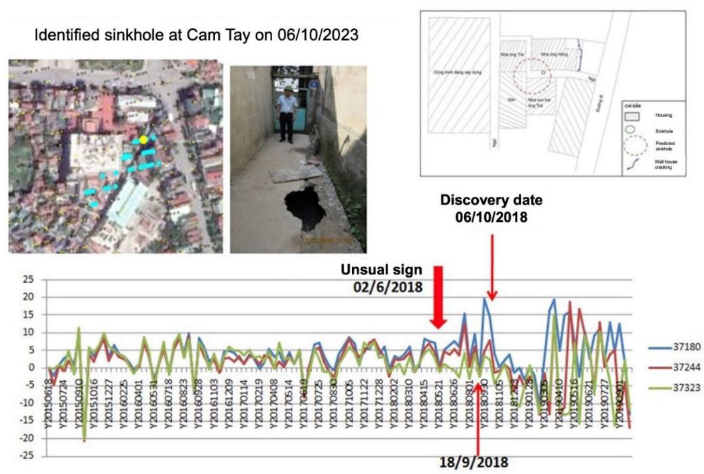


Figure 17: Time series data of Land subsidence in Cam Tay - Cam Pha - Quang Ninh by InSAR method

Thus, the results of radar interference analysis show reliability with the ability to anticipate abnormal signs that can lead to actual sinkhole phenomena.

To accurately determine the cause of the subsidence in the research area, it is necessary to employ various types of research. From there, appropriate solutions can be proposed to prevent and mitigate damages in Ninh Binh province.

4. Conclusion

Through the method of satellite interferometry, we can establish surface deformation maps for different areas. The results of the surface deformation maps allow us to determine and assess the current status of areas experiencing land subsidence and ground cracking within the research area.

The construction of the surface deformation maps using the radar interferometry method in this study is performed through two platforms. The input data processing for the image dataset, the interferometric processing on the Snap platform using the Python language, and the processing of the unwrapping phase, noise removal, and elimination of low correlation points on Stamps are carried out on the Linux operating system.

Field studies show that the application of radar interference methods to study terrain surface deformation *(*specifically subsidence) with millimeter accuracy shows reliability with the ability to anticipate abnormal signs that can lead to actual phenomena.

In this study, using radar interferometric processing for a dataset of 53 Sentinel-1 images from 2020 to 2021 in Ninh Binh province, a total of 77,087 Persistent Scatterer (PS) points were obtained. The maximum subsidence value is found to be less than -10mm/year in the Kim Son and Yen Khanh districts.

The initial causes of the observed subsidence can be attributed to human activities in the province. Therefore, to accurately determine the underlying causes of the subsidence in the research area, it is necessary to combine multiple geological methods. This will help in identifying the specific factors contributing to the subsidence. By doing so, appropriate solutions can be proposed to mitigate and minimize the damages in Ninh Binh province.

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GOOGLE EARTH ENGINE FOR FLOOD MAPPING USING SENTINEL-1 GRD SAR IMAGES AND IMPACT ASSESSMENT ON SOCIO-ECONOMIC FACTORS: A CASE STUDY IN DA NANG

Nguyen Thi Thuy Hanh*, Quach Thi Chuc, Nguyen Xuan Bac
Hanoi University of Natural Resources and Environment, Vietnam

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Abstract

This study exploits the high computing performance of the Google Earth Engine (GEE) cloud computing platform to process Sentinel 1 images to rapidly establish a flood map in the coastal city of Da Nang through the historic flood in October 2022. The flood map is eventually exported to a shapefile and overlaid with socio-economic data in a GIS environment to assess the impact of flooding on socio-economic activities. The results indicate that the entire city has 10.505 ha flooded, concentrated in the Northwest and Southeast of Hoa Vang district, Lien Chieu district, and the results of geo-spatial statistical analysis also show that 189.161 km of flooded roads, 184 flooded residential areas, 12 flooded commercial service-school-hospital areas, and 9,786.81 ha of flooded agricultural land. The consequences were considerable damage to property, houses, crops and serious impacts on the lives and livelihoods of Da Nang residents.

Keywords: Flooding; Coastal urban; GEE; Sentinel 1; Da Nang.

***Corresponding author, Email:** ntthanh.tdbd@hunre.edu.vn

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1. Introduction

Floods are one of the most popular natural disasters and a major threat in the whole world. Recently, flood disasters have increased in frequency and intensity. The consequences of floods are complex, affecting many aspects of life, economy and society such as destroying houses, bridges, roads, trees, agriculture, causing landslides and threatening human lives, especially in urban areas - where the population is concentrated (Mai et al., 2020, Zope et al., 2016). The specific characteristics of urban flooding are that it often occurs in a short time, the urban landscape structure is complex, the proportion of impervious surfaces is large, the use of remote sensing images to detect floods in the city center is also more difficult due to the ability to reflect and backscatter from water areas that are also affected by the dispersion of (Biadgilgn buildings Demissie 2023).

Da Nang used to be a model for coastal urban development in many provinces and cities in Vietnam. However, recently, Da Nang has been continuously flooded and inundated in many residential areas. In October 2022, Da Nang experienced a huge flood, with nearly 70,000 houses in the city being flooded, thousands of cars and motorbikes damaged, and total material damage due to the flood was around 1,500 billion VND. One year later, Da Nang suffered another prolonged heavy rain and hundreds of flooded areas occurred throughout the city; the situation has highlighted the shortcomings of this coastal urban area (https://baotainguyenmoitruong.vn).

The increasing frequency of urban flooding seriously threatens the sustainable urban development and safety of citizens, leading to severe damage and loss (Wang et al., 2021, Wei et al., 2022). Therefore, timely flood monitoring (mapping, rapid impact assessment) is of great significance for urban flood management.

During the flood time, data and information collection is exceedingly difficult, and many places cannot even be accessed directly. Therefore, remote sensing has become a useful tool and has attracted the attention of many scientists. Sentinel 1 images are a source of SAR Radar data provided free of charge with the ability to collect images in all extreme weather conditions and regardless of day or night, suitable for flood monitoring, which can overcome the disadvantages of optical images in tropical and cloudy climates like in Vietnam.

The GEE cloud computing platform was launched by Google in 2010. GEE uses Google's computing infrastructure and a huge remote sensing image database (Amani et al., 2020), solving the problem of big data processing when using personal computers. Thus, exploiting GEE applications is becoming an emerging trend in flood mapping, typically the study of the UNSPIDER Organization in 2015 proposed a specific method and instructions for producing flood maps using Sentinel-1A image pairs before and during flooding (UNSPIDER, 2015) and was applied by many authors later. Some typical studies are: Biadgilgn Demissie (2023) discovered the spatial, temporal distribution model and flood evolution in the tropical urban area of Dar es Salaam. Somya Jain et al., (2022) used VH and VV polarization of SAR radar data for Odisha state in India through Google Earth Engine, the results analyzed the area and extent of floods, in addition to many other authors such as Tiwari et al., 2020; Inman & Lyons, 2020; Moharrami, 2020; Singha et al., 2020; Vanama et al., 2020; DeVries et al., 2020; Mehmood et al., 2021; Pandey et al., 2022.

In Vietnam, there have been many studies on flooding using remote sensing and GEE such as Vu Huu Long et al., (2018), Vo Quoc Tuan et al., (2018), Luu Thi Dieu Chinh et al., (2022), Chi Tran Thuy & Linh Phung Thi (2022), Nguyen Thanh Ngan & Nguyen Hieu Trung (2021), etc. In general, the studies focused on two directions: The first one is algorithm development - technical improvement - methods and the second one is flood mapping in non-urban areas, mapping and monitoring floods in complex urban environments is still a big challenge (Pelich et al., Cites2022) and there have not been many studies in Vietnam.

This study used the GEE platform to process Sentinel 1 images, for the coastal urban flood mapping - Da Nang, thereby assessing the impact of flooding on life, economy and society, including: Population, services - schools - hospitals, traffic, agriculture through the historic flood in October 2022.

2. Study area

Da Nang is a centrally run city, shaped as an important coastal urban node in the South Central region. The whole province has 7 districts on the land, in addition to Hoang Sa island district. In this study, we limit the scope to 7 districts on the land with an area of 97,988 ha, a total population of 5.8 million people (https://danang.gov.vn).

The land of Da Nang city stretches from 15°15’ to 16°40’ North latitude and from 107°17’ to 108°20’ East longitude. Da Nang has a particularly favorable geographical location for economic development. Da Nang is located on National Highway 1A and the North-South railway. Da Nang connects to the Central Highlands via National Highway 14B and is the gateway to the sea of the Central Highlands and Laos, Cambodia, Thailand, Myanmar to Northeast Asian countries and territories via the East - West economic corridor. In addition, Da Nang also has important traffic routes such as the China - ASEAN international railway, seaports and international airports. Da Nang is only about 2,000 km from the developed economic centers of Southeast Asian countries and the Pacific region, which is very convenient for economic and cultural exchanges (https://danang.gov.vn)..

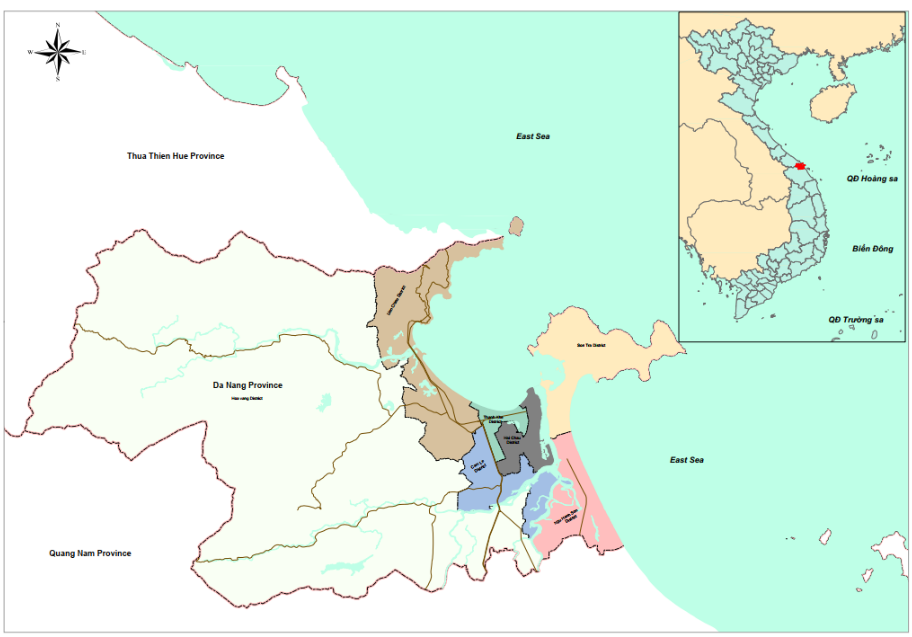

Figure 1: Location of the study area

Da Nang is affected by tides and storms. Storms in Da Nang often appear in January, October and December; storms normally are level 9 - 10, causing heavy, prolonged rain and the risk of flooding. The rivers flowing through Da Nang all have the characteristics of the central coastal region: short and steep, large fluctuations in water level and water flow, and poor alluvium. In the rainy season, river water rises quickly, causing floods in the downstream areas, whereas the flood period is short, lasting only a few days (https://danang.gov.vn).

3. Data and methods

3.1. Data

Sentinel-1 is a radar mission that continuously captures images in all weather conditions, regardless of day or night, in the C band. Sentinel-1 satellites have high reliability, improved repeat times, wide geographic coverage and rapid data dissemination, to support applications operating in priority areas such as maritime surveillance, land surveillance and emergency services (https://www.esa.int).

In this study, main input data is Sentinel 1 GRD images, the geometric resolution of 20 m, acquired from 2022-10-01 to 2022-10-10 (before flooding) and from 2022-10-14 to 2022-10-16 (after flooding) to extract information and generate an urban flood map of Da Nang.

In addition, population and socio-economic data are employed to assess the impact of flooding on people's lives. These data are all in vector format (points, lines, polygons) and are exploited from open sources, detailed information is mentioned in Table 1.

Table 1. Socio-economic data

	Socio-economic factors	Sources	Geometries
1	Transport systems	https://download.geofabrik.de/asia/vietnam.html	Lines
2	Residences	https://download.geofabrik.de/asia/vietnam.html	Points
3	Service-school-hospital	https://download.geofabrik.de/asia/vietnam.html	Points
4	Agricultures	https://dynamicworld.app/explore	Polygons

3.2. Methods

3.2.1. Google Earth Engine platform

Google Earth Engine is a cloud computing platform for analyzing remote sensing images, environmental and meteorological parameters from regional to global scales, allowing users to run geospatial analyses on Google's platform. There are several ways to interact with the platform, the Code Editor is a web-based IDE (Interactive Development Environment) for writing and running scripts, the Explorer is a web application for exploring the data catalog and running simple analyses, and the documentation library provides Python and JavaScript (Mutanga & Kumar, 2019). GEE has a built-in repository of tens of petabytes of freely available remote sensing data from NASA, the United States Geological Survey (USGS), the European Space Agency (ESA), and others. GEE's cloud computing infrastructure is optimized for spatial data processing, including time series analysis of remotely sensed data (Moore & Hansen 2011).

GEE was born from the idea of combining scientific knowledge with Google's huge data sources and the state of the art technology. This combination brings great efficiency such as processing speed and the ability to customize application development. The calculation and processing speed on GEE is unprecedentedly rapid (Mutanga & Kumar, 2019).

GEE allows the construction of calculation programs based on an application programming interface (API) using the extremely popular programming languages of JavaScript and Python (Mutanga & Kumar 2019; Moore & Hansen 2011). Thereby, the research team built a program to extract flood information from Sentinel-1 images data (Figure 2).

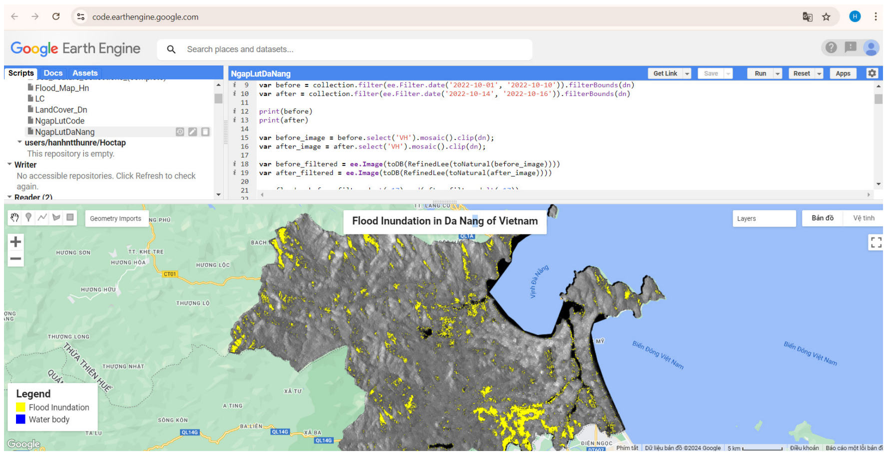

Figure 2: Illustration of data analysis on GEE

3.2.2. Satellite image processing

Sentinel-1 images are new generation satellite data of the European Space Agency. These satellites were developed to provide global remote sensing surveillance data under Europe's Copernicus Program (DeVries et al., 2020) and are currently provided for GEE's cloud computing system without charge, the product is put into use after preprocessing according to the standard process of the Sentinel preprocessing tool.

Calculate backscatter difference

Compute the backscatter difference using a simple formula: $\Delta\sigma = \sigma_{before} - \sigma_{after}$ where σ_{before} and σ_{after} represent the backscatter values of each pixel before and after flooding.

Principle: Flooded areas will have lower backscatter values compared to non-flooded conditions because the smooth water surface creates a mirror-like reflection, reducing the radar return, while other dry surfaces should show minimal change.

Apply thresholding

To identify flooded areas, apply a threshold to the $\Delta\sigma$ image. Pixels with a negative $\Delta\sigma$ (or lower than a predefined threshold) can be classified as flooded regions. The threshold can be fixed or adaptively set based on statistical analysis of the image to ensure it's suited to the specific area and environmental conditions.

To produce a flood map of Da Nang city in the historic flood of October

2022, this study used the JavaScript programming language directly on the GEE platform (https://developers.google.com/earth-engine), including declaring commands to put imageries into the platform, image processing and analysis, displaying and extracting results.

3.2.3. Spatial statistical analysis

The result of analyzing and processing Sentinel-1 data on the GEE platform is flood inundation pixels for Da Nang city. The pixels converted to shapefiles to edit into a Da Nang urban flood map in 2022, and overlaid with traffic, residential, service-school-hospital and agriculture layers through geo-spatial statistical analysis tools in the GIS environment to assess the impact of flooding on people's lives and activities. The specific implementation steps are described in the diagram as Figure 3.

3.2.4. Validation

In this study, to assess the accuracy of the flood map and the impact on socio-economic factors, we rely on reference data from reports by environmental and disaster management agencies, as well as information from local authorities and residents about flood damage published on official news sites: https://danang.gov.vn/; https://baodanang.vn/; https://baotainguyenmoitruong.vn. This information allows for qualitative comparisons of the sites and levels of flooding that occurred in the Da Nang, as well as the timing of the events.

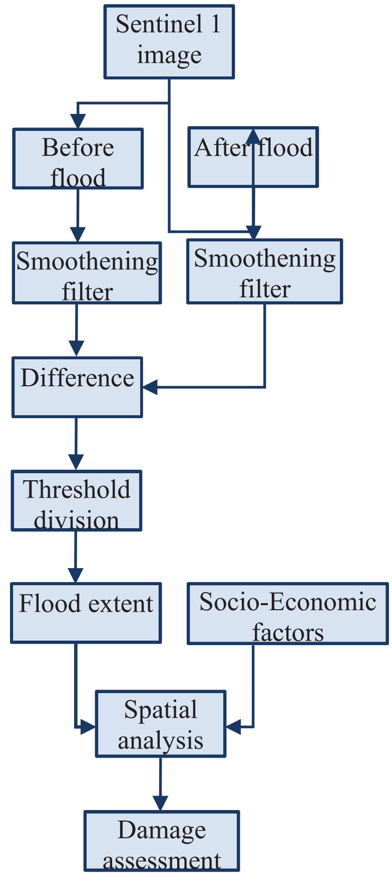

Figure 3: The flowchart and analysis

4. Results and discussion

The results are the Da Nang urban flood inundation map and map series assessing the impact of flooding on the socio-economic activities, and statistics on the damage caused by the flood in October 2022.

4.1. Urban flood map in Da Nang

According to the result of the flood map, the whole city has 10.505 ha flooded, concentrated in the Northwest and Southeast of Hoa Vang district, Lien Chieu district, Ngu Hanh Son and Son Tra district, specifically: Cam Le 103.14 ha, Hoa Vang 9183.82 ha, Lien Chieu 624.02 ha, Ngu Hanh Son 177.87 ha, Son Tra 399.88 ha, Hai Chau 16.41 ha.

The statistical chart of flooding rate in each district/total flooded area indicates that Hoa Vang district accounts for the largest rate of 71 %, followed by Lien Chieu district 12 %, Son Tra 7 %, and finally Ngu Hanh Son 5 %, Hai Chau 3 %, Thanh Khe 2 %, Cam Le 1 %.

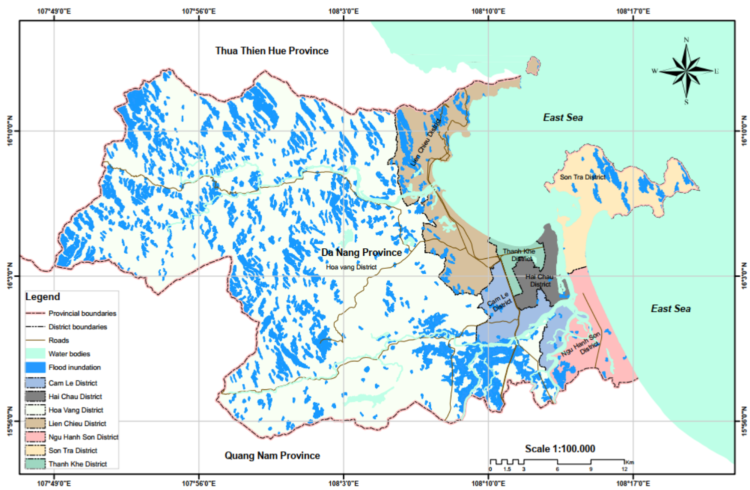

Figure 4: Urban flood map in Da Nang, Oct 2022

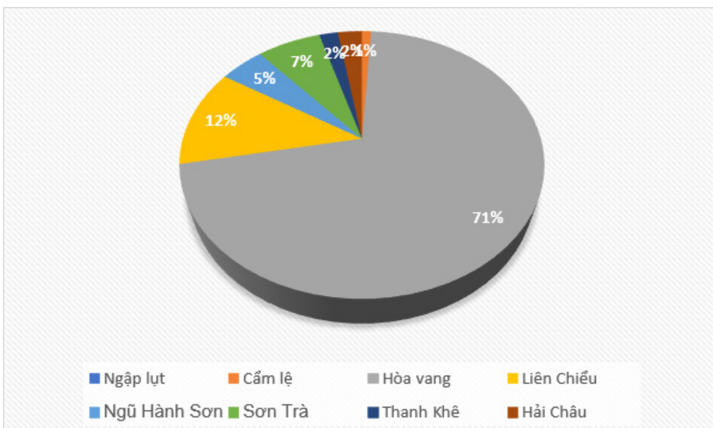

Figure 5: Percentage chart of flooded area in districts

The research results are completely consistent with the practical situation: In the evening of October 14, 2022 and early morning of October 15, 2022, in Da Nang, there was heavy rain, combined with high tides, leading to localized flooding from 0.6 to 1.5 m deep, in some places over 2 m, many households had to evacuate to safe places. A total of 124 points at risk, 10 heavily flooded points in the city including the area around Thac Gian - Vinh Trung lake, Da Nang hospital surrounding, Hai Ho street, alley 640 Trung Nu Vuong, Nguyen Nhan street (Phong Bac canal), Nui Thanh, Le Tan Trung, low-lying alleys on both sides of Me Suot street, Hoa Khanh Industrial Park gate, along Yen The and Bac Son streets, residential areas along the downstream of Khe Can sewer (Thanh Khe Tay ward, Thanh Khe district) (https://baodanang.vn).

4.2. Impact of flooding on population, socio-economic situations

4.2.1. Influences of flooding on the transport system

The study results showed that 7.626 km of National Highways were flooded, with sections passing through Hoa Vang district (1.240 km), Lien Chieu district (5.712 km), Hai Chau district (0.674 km); 2.297 km of railways were flooded, with segment passing through Hoa Vang district (0.086 km), Lien Chieu district (2.211 km); 11.114 km of provincial roads were flooded, with sections passing through Hoa Vang district (10.955 km), Lien Chieu district (0.072 km), Cam Le district (0.087 km); 168.121 km of streets and rural roads were flooded in most districts, of which 123.759 km were in Hoa Vang district, 15.210 km were in Lien Chieu district, 10.970 km were in Son Tra district, 10.160 km were in Ngu Hanh Son district, 4.379 km were in Cam Le district, and 3.643 km were in Hai Chau district. Da Nang has 13 bridges, of which 2 were flooded.

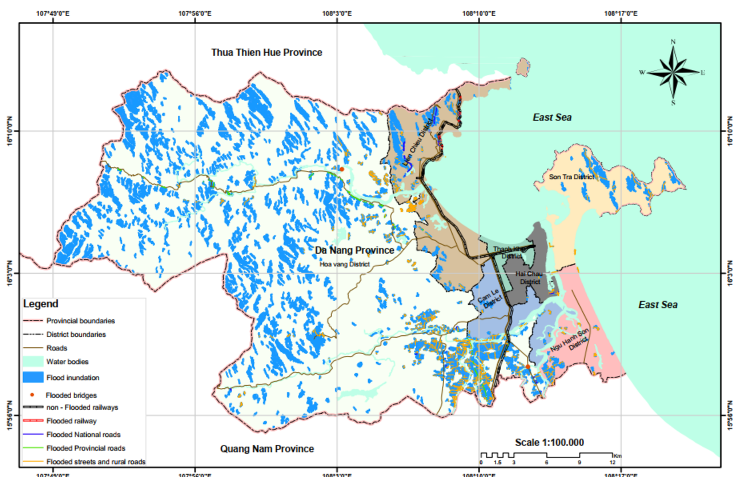

Figure 6: Map assessing the impact of flooding on the transportation system

Many flooded roads caused traffic jams, and many vehicles stalled. Particularly on the roads leading to Son Tra peninsula, some cars stalled and some areas suffered landslides. Soil, rocks, and mud on Son Tra peninsula flooded onto Le Van Luong street over a large area, obstructing traffic, affecting residents and tourists. Many roads in the city were eroded, damaged, and ruined; Severe landslide locations include Hoang Sa road, the road leading to Son Tra mountain; Nam Ky Khoi Nghia road, inter-commune and inter-village roads in Hoa Vang district, etc. Estimated damage to the transport sector is about 190.5 billion VND (https://baodanang.vn).

4.2.2. Impact of flooding on residential areas

The results show that there are 184 residential areas flooded, mainly in the Southeast of Hoa Vang district as shown as red points on the map, of which Hoa Vang district has 169 points, Lien Chieu district 4 points, Ngu Hanh Son district 2 points, Cam Le district 1 point, Hai Chau district 8 points. Causing damage to many people's properties.

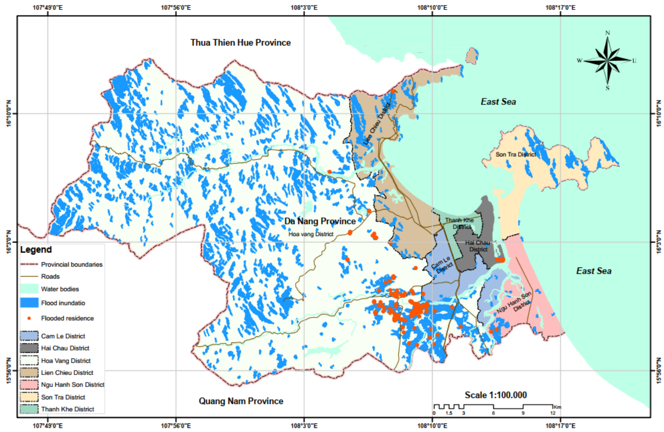

Figure 7: Map assessing the impact of flooding on the residential areas

Heavy rain at the time of high tide (high tide peaked at 1.4 m at 11 pm on October 14) caused widespread flooding in 52/56 wards and communes in 8 districts. Areas were deeply flooded, isolated and had strong currents include Hoa Khanh Nam ward, Hoa Hiep Bac ward, Hoa Hiep Nam wards in Lien Chieu district; Hoa Phong commune, Hoa Nhon commune, Hoa Bac commune, Hoa Lien commune in Hoa Vang district; Thanh Khe Tay ward, Thanh Khe district; Hoa Tho Dong ward, Hoa Phat ward in Cam Le district, Hoa Thuan Tay ward in Hai Chau district. Thousands of houses were deeply flooded, some up to 2 m deep, with a total of nearly 70,000 houses flooded, the most in Lien Chieu district with 27,328 houses, Hoa Vang district with 16,040 houses, Hai Chau district with 12,012 houses, Cam Le district with 5,398 houses, Ngu Hanh Son district with 131 houses, and Thanh Khe district with 12,009 houses. More than 14,000 people had to evacuate to safety. Heavy rains and floods have caused severe damage to houses, property and infrastructure throughout the city, greatly affecting people's lives, socio-economic activities and production (https://baodanang.vn).

4.2.3. Impact of flooding on commercial service - school - hospital areas

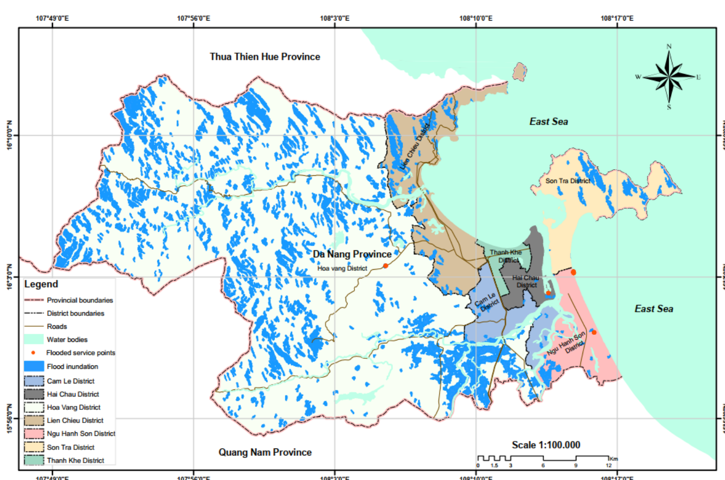

Figure 8: Map assessing the impact of flooding on commercial service - schools - hospital points

According to the research results, there are 12 flooded service - schools - hospital points, of which 1 point is in Hoa Vang district, 10 points are in Ngu Hanh Son district, 1 point is in Hai Chau district, causing damage to the library system, computers, classrooms; markets, shopping centers, schools had to close for several days, medical examination and treatment faced many difficulties.

4.2.4. Impact of floods on agriculture

Observing the map of impacts of floods on agriculture, we see that 9,786.81 ha of cultivated land are affected, the flooded areas are mostly concentrated in Hoa Vang district and Lien Chieu districts; Specifically, Cam Le district accounts for 64.97 ha, Hoa Vang district 8,631.71 ha, Lien Chieu district 561.88 ha, Ngu Hanh Son district 137.44 ha, Son Tra district 390.77 ha. The consequences have damaged and lost many vegetables and crops.

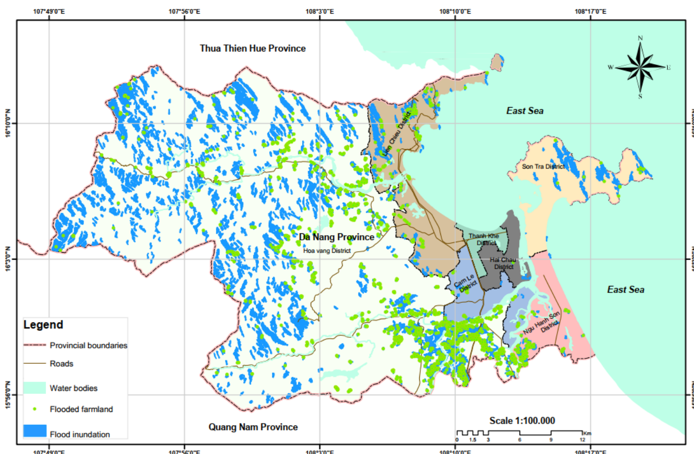

Figure 9: Map assessing the impact of flooding on agriculture

5. Conclusion

The results showed the spatial distribution of urban flooding in Da Nang during the historic flood in October 2022. Due to heavy rain combined with high tides, the entire city had flooded areas, the most severe being Hoa Vang district and Lien Chieu district. The analysis and processing of Sentinel 1 images on the GEE cloud computing platform makes flood monitoring mapping convenient, simple and rapid, easy to automate and share data with stakeholders for timely disaster response. This method is scalable and can be applied to other coastal urban areas in Vietnam.

Combining geospatial statistical analysis, a series of map was established to assess the impact of urban flooding on the transportation system (189.161 km of flooded roads), residential areas (184 flooded residential areas), commercial service - schools - hospital areas (12 flooded areas), and agricultural land area (9,786.81 ha of flooded agricultural land). The consequences were extensive damage to property, housing, food supply, and serious impacts on the lives and livelihoods of Da Nang residents.

This study investigated flooding at the urban area scale and did not delve into complex urban environments. Therefore, we recommend further research to develop advanced methods for detecting downtown flooding and address the reduction in backscattered reflections from water areas due to the dispersive effects of buildings and other urban features. Furthermore, developing methods that can integrate Sentinel-1 with other remote sensing data could be a solution to increase the frequency of observations. A comprehensive next research direction, combining Sentinel-1 imagery, measured flood data, and community participatory approaches for integrated disaster planning and management.

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ASSESSING CHANGES IN KNOWLEDGE, ATTITUDES, AND PRACTICES OF VIETNAMESE STUDENTS ABOUT MARINE PLASTIC POLLUTION

Tran Thi Minh Hang[1,*], Tran Thi Hoa[2], Le Thi Ly Na[3], Tran Thi To Uyen[1], Nguyen Thi Phuong Mai[1], Dinh Thi Diu[1], Nguyen Manh Khai[1]

[1]University of Science, Vietnam National University, Hanoi

[2]Centre for Supporting Green Development, Vietnam

[3]Le Loi Primary School, Vietnam

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Abstract

Marine plastic waste pollution significantly threatens marine ecosystems and human health, prompting global efforts to address this pressing issue. This study assesses the change in knowledge, attitude, and practice of Vietnamese youth regarding marine plastic waste pollution. Through a comprehensive analysis of survey data collected from 600 Vietnamese students before and after environmental education interventions, this research evaluates the effectiveness of educational initiatives in fostering awareness and behavioral changes among students. The findings reveal notable improvements in students' knowledge and attitudes towards marine plastic waste pollution following educational interventions. Moreover, positive shifts in behavioral practices, such as reduced plastic usage and increased recycling efforts, are observed the most among the primary students. These results underscore the importance of targeted educational interventions in promoting sustainable behaviors and combating marine plastic pollution.

Keywords: Marine plastic pollution; Knowledge, Attitude, and Practice (KAP); Environmental education.

[*]**Corresponding author, Email:** hangttm@hus.edu.vn

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1. Introduction

Vietnam ranked as the third-largest plastic consumer in Southeast Asia, with a per capita plastic consumption of 41 kg in 2015 - a tenfold increase since 1990 [1, 2]. According to a 2015 study by Jenna Jambeck et al., [3], Vietnam was identified as one of the top five countries contributing to ocean plastic pollution worldwide. Each year, an estimated 2.8 to 3.1 million tons of plastic waste is generated on land in Vietnam, with at least 10 % of this waste ending up in the ocean [3, 4].

In 2021, Vietnam generated 8,021 tons of solid waste per day, equivalent to 2.93 million tons per year. Urban areas contributed approximately 56 %, while rural areas accounted for 44 %. The volume of municipal solid waste has been steadily increasing in recent years, rising from around 2.7 million tons in 2018 to 2.83 million tons in 2019, and reaching about 2.93 million tons in 2021 [5]. The classification, recovery, recycling, and treatment of plastic waste in Vietnam remain limited [4]. Plastic waste and nylon bags make up roughly 12 % of household solid waste, with only about 11 - 12 % of this being processed and recycled. The rest is primarily buried, burned, or released into the environment. A study on the awareness, attitudes, and practices of plastic consumers in Vietnam, conducted by WWF and the International Union for Conservation of Nature [6], found that many people remain unaware of the harmful effects of plastic waste and single-use plastics on the natural environment. Most consumers view disposable plastic as a free item provided with their purchases. Additionally, according to WWF-Vietnam (2020), fewer than 3 % of those surveyed are aware of government programs and initiatives aimed at combating plastic waste pollution [6].

To address the issue of marine plastic pollution in Vietnam, commonly proposed solutions include raising community awareness, particularly among the younger generation, to foster a shift in knowledge, attitudes, and practices toward a more environmentally friendly and sustainable lifestyle [7, 8, 9, 10]. Numerous studies suggest that changing Vietnamese youth's behaviors, attitudes, and practices concerning sustainable consumption and daily environmental protection can be effectively achieved through environmental education, particularly for school students [11, 12, 13]. This study aims to assess the changes in awareness, behavior, and practices of students in select schools across Vietnam as a result of participating in experimental environmental education activities.

2. Methodology

Study site and period: The study was conducted at one elementary school, one middle school, and one university. A total of 600 students (200 from each school) were voluntarily selected from all classes to participate in training activities, waste audit classification in schools, and coastal cleanup activities between November 2022 and March 2024. The list of participating students was the same for pre-survey and post-survey.

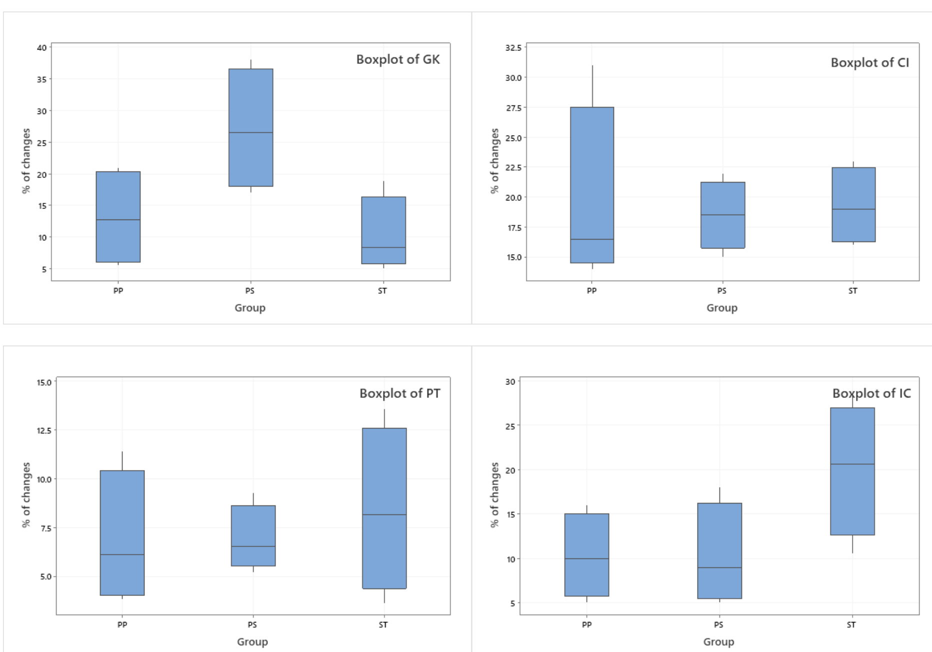
Questionnaire survey to assess changes in knowledge, attitudes, and practices (KAP): Questionnaires were distributed to students before and after their participation in environmental education and communication activities. The survey content covered: (i) students' understanding of plastic waste issues; (ii) students' attitudes and opinions towards the use of plastic-based products and plastic waste management; and (iii) student practices related to the use of plastic-based products and plastic waste management. The knowledge section consisted of 8 questions assessing students' understanding of plastic waste, with true/false answer options. The attitude assessment section includes 6 questions about students' attitudes and opinions regarding the use of plastic-based products, with response options of 'disagree', 'neutral/unsure', and 'agree'. The practical assessment section consists of 7 questions, with the response options 'practiced' or 'not practiced'.

Data synthesis, processing, and analysis: The participants' responses were compiled, statistically analyzed using box plots, and compared to evaluate the current status of Knowledge, Attitudes, and Practices (KAP) related to plastic waste among staff and students, as well as the changes observed after participating in the environmental communication activities. Box plots present the data distribution: Dispersion, shape, tail length, unusual values. The statistical values include position, lower quartile and upper quartile, maximum and minimum observed values, observe outliers [14].

3. Results and discussion

3.1. Change in knowledge of students about plastic pollution

The study surveyed the changes in the knowledge of students from universities, high schools, and elementary schools who participated in the project before and after receiving training aimed at raising awareness about plastic waste. The questions assessed participants' general knowledge of plastics (origin, production, use), causes and harmful effects of plastic waste, plastic decomposition time, information about countries affected by marine plastic pollution, the current state of marine plastic pollution, recycling possibilities, knowledge of single-use plastics, and plastic waste treatment methods. In this group of issues, eight key areas showing clear changes were highlighted as examples: general knowledge about plastic (origin, production, use) (GK), causes and harmful effects of plastic waste (CI), plastic decomposition time (PT), information about countries affected by marine plastic pollution (IC), knowledge of the current situation of marine plastic pollution (KP), information about plastic recyclability (IR), knowledge of single-use plastics (KS), and knowledge of plastic waste treatment (KT) (Figure 1).



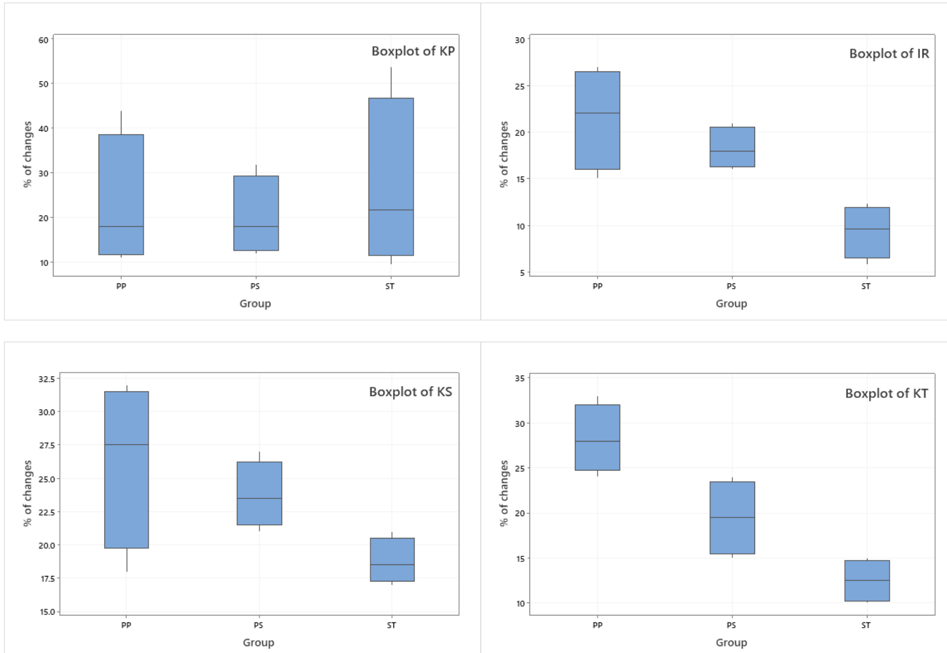


Figure 1: Changes in the knowledge of participants (elementary school students - PP, middle school students - PS, university students - ST) following environmental education and communication activities on plastic waste

The results show that knowledge about plastic, the harmful effects of plastic waste, and the recycling and treatment of plastic among participants in the project activities has significantly increased. This highlights the importance of communication efforts and raising awareness about plastic waste in schools and among younger generations to reduce its harmful impact on the environment, particularly the marine environment. Changes in knowledge have also led to noticeable improvements in behavior towards plastic products and plastic waste. However, for more complex concepts requiring foundational understanding (such as general knowledge about plastic and its decomposition time), the change among elementary students was less significant, as they may not fully grasp more advanced information about plastic products at this age.

The change in knowledge among university students was not significant before and after the environmental education activities, as this group already had a solid foundation of knowledge from previous education and demonstrated initiative in absorbing information from media and earlier lectures on the environment and sustainable development. However, for high school students, there was a notable increase in general knowledge about plastics (an increase of 27.0 ± 9.7 % compared to before the training). Among elementary school students, knowledge about plastic waste treatment increased by 28.3 ± 3.8 %. This study highlights the importance of communication efforts in shifting perceptions among young people [11].

3.2. Change in attitudes of students in plastic pollution

Changes in the attitudes of project participants were assessed using the following indicators: the need to reduce single-use plastic products (SR), views on alternatives to single-use plastics (PA), responsibility for reducing plastic waste pollution (RR), support for a green and sustainable lifestyle (MG), attitude toward waste segregation and recycling (AS), and contribution to environmental efforts and plastic reduction activities (CE), as shown in Figure 2.

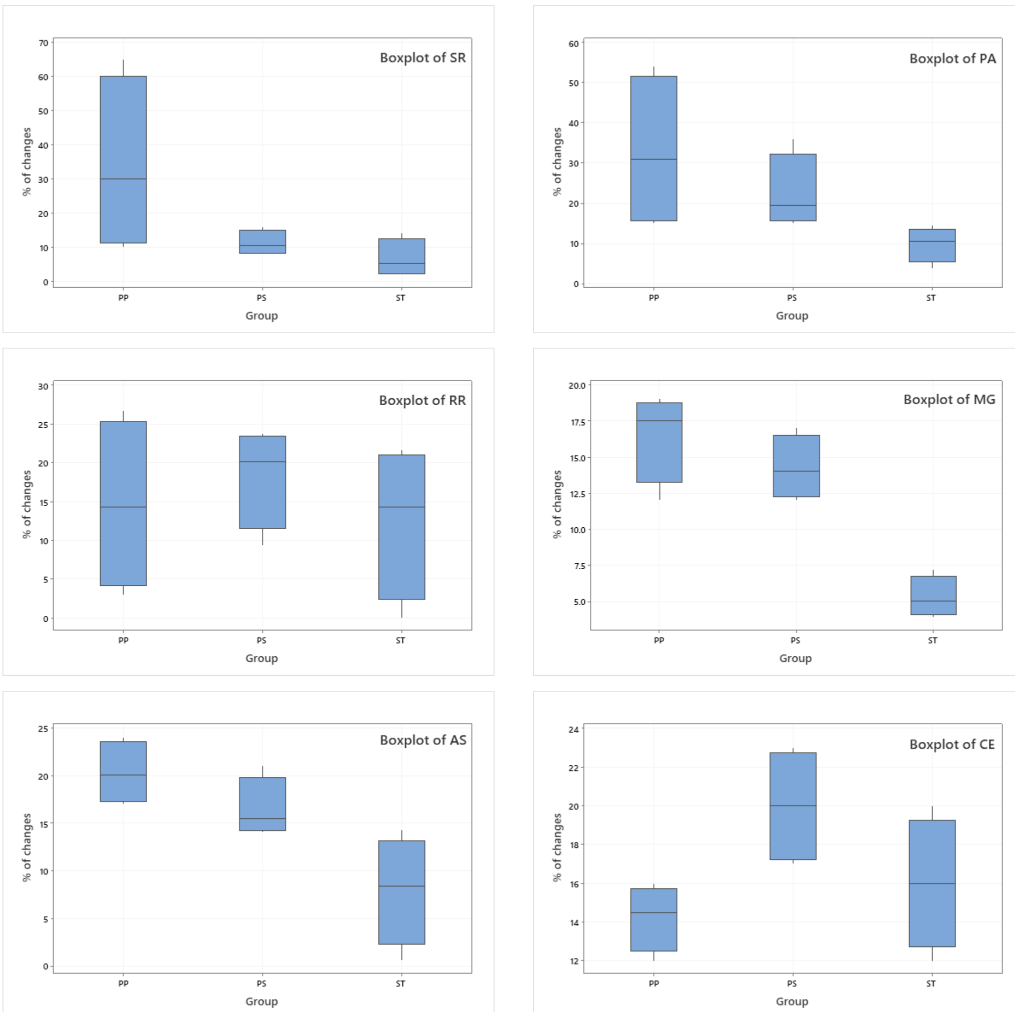


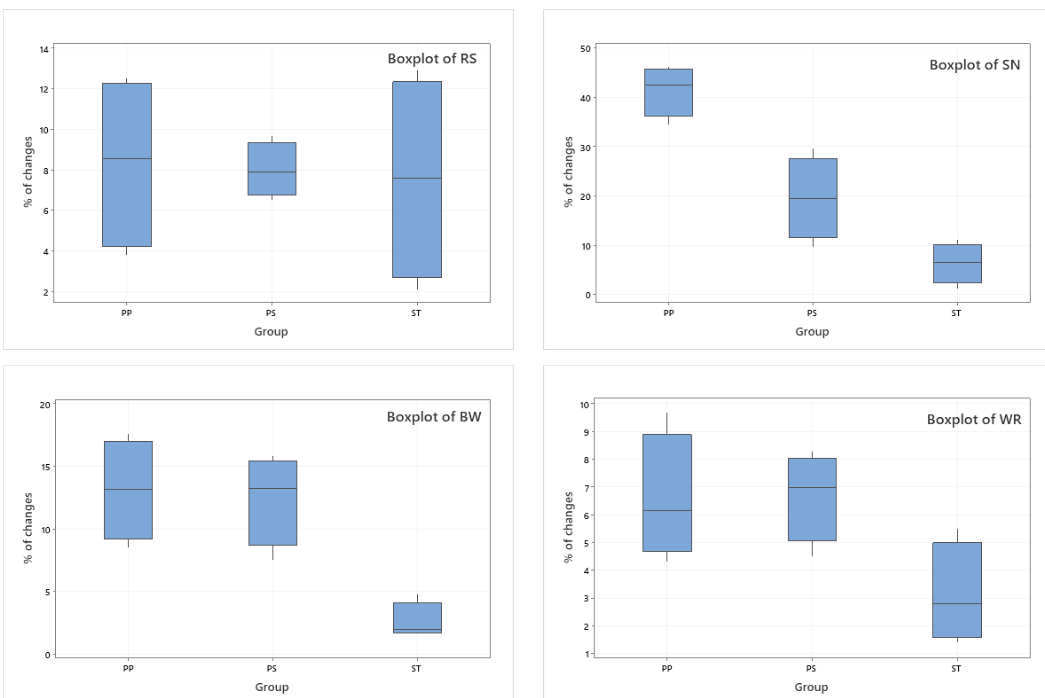
Figure 2: Changes in the attitudes of participants (elementary school students - PP, middle school students - PS, university students - ST) following environmental education and communication activities on plastic waste

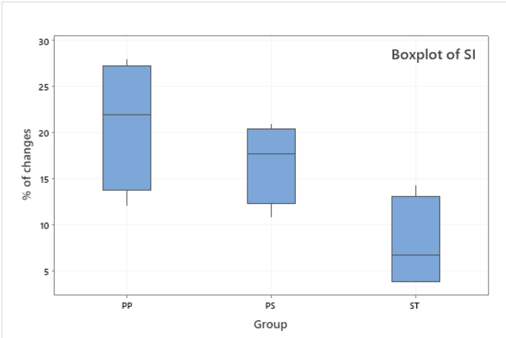
After the training course and environmental activities, most of the participating students, especially elementary school students (PP), developed a more positive attitude towards the use of plastic products and plastic waste management. Specifically, more than 65 % of students changed their views, expressing their agreement on replacing single-use plastic products with biodegradable alternatives to reduce plastic waste. Students gained an understanding of decomposition and the environmental persistence of plastic, which led to shifts in their perceptions of plastic products after use. Similarly, in terms of attitudes towards limiting the use of single-use plastic products (PA), elementary and middle school students showed a significant change, with a 15 - 54 % increase in the number of students who felt this was extremely necessary.

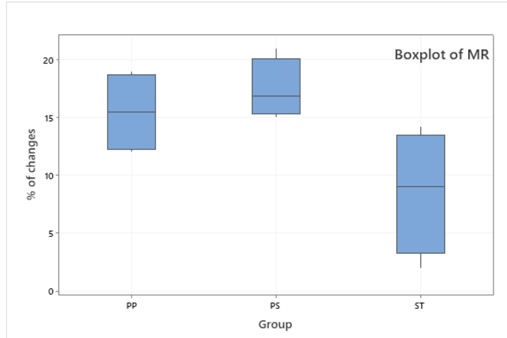
Most students across all grade levels showed positive changes in expressing their views on proactively refusing plastic products (RR) when not necessary, with 15 % ± 8 of responses reflecting a shift in opinion. They expressed a growing inclination to refuse single-use plastic products. This study aligns with findings from similar previous research by Eagles and Demare (1999); Shimray (2016) and Soares et al., (2021) [10, 11, 13].

3.3. Changes in practice towards plastic products use and plastic waste

The survey, consisting of seven questions about good practices, was conducted before and after students participated in environmental training and extracurricular activities. The questions evaluated participants' practices related to plastic products, including: reducing the use of single-use plastic bottles (RS), saying no to plastic bags (SN), bringing personal items and reusable water bottles (BW), sorting and recycling waste (WR), sharing ideas and knowledge about plastic waste with others (SI), promoting changes to reduce or eliminate disposable plastic in schools (MR), and becoming an advocate for change (AP). The results of these changes are shown in Figure 3.







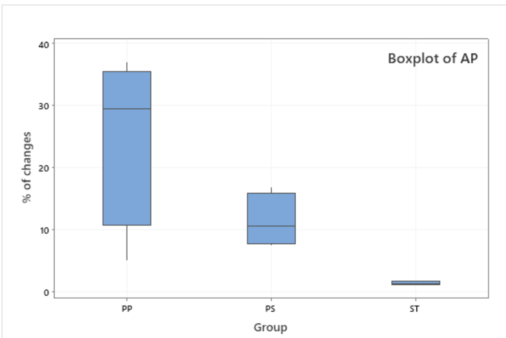


Figure 3: Behavioral changes among participants (elementary school students - PP, middle school students - PS, university students - ST) in environmental education and communication activities about plastic waste

The results show that while most students have reduced their daily use of single-use plastic bottles, the rate of improvement remains modest, averaging between 7.6 % and 8.4 %. This may be because common beverages like water and soft drinks are packaged in plastic bottles, and there is no deposit recovery program from manufacturers for these containers. In contrast, the shift away from plastic bags has been more positive, especially among elementary and middle school students, likely due to the availability of alternatives like cloth bags and reusable containers. For university students, replacing plastic bags with reusable ones has already become a habit, and their high awareness means there was little change in behavior after the training.

After participating in the study, all students demonstrated positive changes in their actions, such as carrying personal water bottles or actively using reusable cups. Elementary and middle school students showed the most significant improvement, with an increase of approximately 12.5 to 13.1 %.

The action to share personal contributions toward behavior change and plastic waste reduction has significantly increased among primary and secondary school students. Evaluation results indicated that nearly 17 % of 9^{th}-grade students and 21 % of 6^{th}-grade students developed a strong contribution to sorting and recycling plastic waste after the training. Among middle school students, 9^{th} graders exhibited the most significant change, with up to a 21 % increase in promoting activities toward green lifestyles and engaging in advocacy efforts.

4. Conclusions

Through environmental communication efforts to raise awareness about plastic waste and plastic product usage, there has been a significant increase in awareness, attitudes, and practices among the participants. Notably, the training for elementary school students has been particularly effective, equipping them with essential skills and knowledge. These students are very eager and understand well all the key information, including the history and persistence of plastic waste, its environmental and ecosystem impacts, and proper waste classification. The active involvement of all students in awareness raising activities could lead to impact on the broader community including their parents and people surrounding toward greener lifestyle preventing and mitigating the harmful effects of plastic waste. Most students participating in the project have shown an increasing interest in environmental issues and a desire to learn more about plastic waste and ways to reduce it. The research findings indicate that effectively addressing environmental pollution, particularly plastic pollution in Vietnam, requires regular training activities to change the knowledge, attitudes, and practices, promote sustainable consumption and encourage daily environmental-friendly actions of young people, especially students.

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INVESTIGATING LAND SURFACE TEMPERATURE CHANGES IN THANH HOA CITY FROM 2000 TO 2023 USING GOOGLE EARTH ENGINE

Le Thi Thuong[1], Nguyen Trong Nhan[2,*], Trinh Xuan Manh[1], Pham Minh Tien[1]

[1]Hanoi University Natural Resources and Environment, Vietnam

[2]University of Natural Resources and Environment Ho Chi Minh city, Vietnam

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Abstract

In recent years, rapid urbanization has significantly increased surface temperatures in major urban areas. Surface temperature is one of the key factors in studying the impacts of urbanization on the environment and society. This study focused on identifying changes in surface temperature values in Thanh Hoa city, located in Thanh Hoa province, from 2000 to 2023 using satellite imagery on the Google Earth Engine platform. The results indicated that land surface temperature values fluctuated over different periods in the study area. The average surface temperature reached its highest value in 2023, followed by 2015, 2019, 2001, and 2022, and the lowest in 2007. The results obtained in this paper can provide useful information to assist managers and policymakers in making decisions regarding land use planning and urban development.

Keywords: Land Surface Temperature; Google Earth Engine; Satellite imagery.

[*]**Corresponding author, Email:** ntnhan@hcmunre.edu.vn

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1. Introduction

Thanh Hoa city is the Northern gateway to the North Central economic region and serves as the economic, cultural, and political center of Thanh Hoa province. After 30 years after its establishment, Thanh Hoa city has rapidly urbanized, growing from 30 urban areas in 2016 to 70 urban areas in 2020, and Thanh Hoa city has become an urban Type I in August 2024 [15]. Urbanization has significantly increased the impervious surface area and raised environmental temperatures in Thanh Hoa city, causing ecological imbalances and urban landscape issues.

Traditional methods for determining data on temperature, rainfall, and humidity involve using monitoring stations, which can be costly and only reflect localized values, leading to errors when interpolating for larger areas [20].

Recently, remote sensing technology, with its multi-spectral and multi-temporal data, has offered significant advantages such as shorter update times and broader surface monitoring. The surface temperature value can also be monitored through thermal infrared bands. This issue has garnered considerable attention from scientists worldwide, including in Vietnam. Studies [1, 2, 6, 9, 11, 13] have investigated methods to calculate the Land Surface Temperature (LST) index to monitor temperature changes using optical images. The LST is an index used to determine surface temperature based on the energy emitted from objects captured in the thermal bands of optical images [20]. Research has evaluated urban heat islands using LST on Landsat 7 images [3], identified an inverse correlation between urban heat islands and urban green spaces on Landsat 8 images [10], and assessed the impact of human activities on thermal environments [12].

In most provinces and cities across Vietnam, significant impacts from climate change can be observed. Notably, studies indicate the expansion of thermal environments into suburban areas in Ho Chi Minh city, determining urban heat island phenomena from thermal infrared bands on Landsat images [18, 19, 8, 16, 14], or using ArcGIS to interpret Landsat satellite images to monitor urbanization processes in Ho Chi Minh city from 1989 to 2019 through impervious surfaces and Kappa coefficients [5].

Calculating the Land Surface Temperature (LST) index on the Google Earth Engine platform shows that the increase in the built-up area also contributes to rising thermal environments [17]. Another study [4] in Thanh Hoa City also identified the changes in land surface temperature in the region from 2000 to 2017 using thermal infrared Landsat remote sensing data.

The above studies demonstrate the suitability of using the LST index for monitoring thermal environmental changes with remote sensing images. Moreover, the development of remote sensing and artificial intelligence technology has led to the emergence of numerous free tools available to users. Google Earth Engine (GEE) developed by Google, with its satellite database of Earth's surface, is recognized as a cloud-based platform for processing and analyzing spatial data, allowing convenient and efficient monitoring of basin surface changes (such as surface temperature, land cover, land use situations, etc.). GEE stores vast amounts of geographical data collected from various satellite imagery sources, with regularly updated images to better serve research needs, enabling remote sensing image processing, machine learning algorithms, and spatial analysis tools to yield reliable results. GEE is built on a cloud computing platform that handles large data volumes, overcoming the limitations of data storage or image processing speed, and computational volume compared to traditional image processing methods. It can be regarded as a supportive tool for researchers to access and utilize available data in using satellite imagery for managing and monitoring natural resources and the environment [7]. This is also the approach that the paper employed to use the GEE platform for calculating the land surface temperature index through a period of 2000 to 2023. Additionally, the paper also developed the Earth Engine Apps for sharing results conveniently with users for querying information.

2. Data and research methods

This study employed the near-infrared bands, the thermal infrared bands, and the red bands from optical imagery of Landsat 5, Landsat 8, and Landsat 9, at the raw scene level, with a spatial resolution of 30 meters, the time step of acquisition is day. The images were collected during the dry season (March, April, May) over Thanh Hoa city in the years 2001, 2007, 2010, 2015, 2019, 2020, 2022, and 2023, with less than 5 % of cloud cover, provided by the United States Geological Survey (USGS). The image source information is shown in Table 1, and the workflow of the key steps in the study is illustrated in Figure 1.

Table 1. Landsat image source information

Date	Image ID	Satellite type
21/4/2001	LANDSAT/LT05/C02/T1/LT05_125052_20010421	Landsat 5
08/5/2007	LANDSAT/LT05/C02/T1/LT05_125052_20070508	Landsat 5
25/2/2010	LANDSAT/LT05/C02/T1/LT05_125052_20100225	Landsat 5
30/5/2015	LANDSAT/LC08/C02/T1/LC08_125052_20150530	Landsat 8
18/5/2019	LANDSAT/LC08/C02/T1/LC08_125052_20190518	Landsat 8
08/3/2020	LANDSAT/LC08/C02/T1/LC08_125052_20200308	Landsat 8
08/4/2022	LANDSAT/LC08/C02/T1/LC08_125052_20220408	Landsat 8
05/5/2023	LANDSAT/LC09/C02/T1/LC09_125052_20230505	Landsat 9

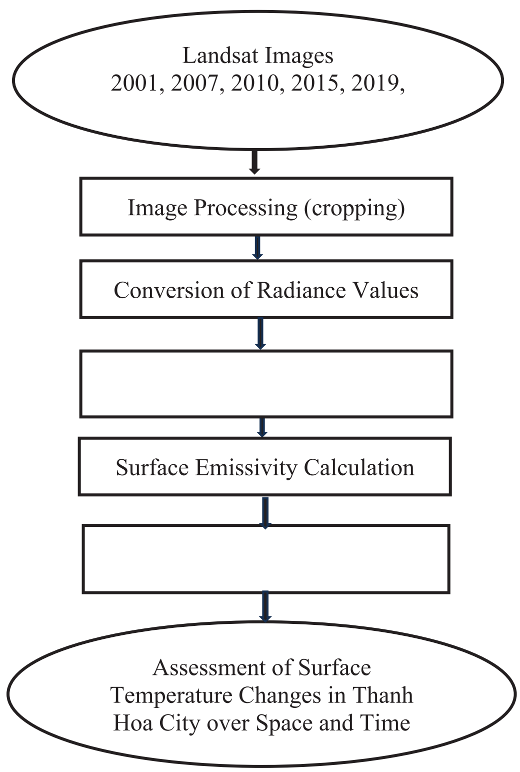


Figure 1: Workflow for evaluating the surface temperature changes in Thanh Hoa city

Surface temperature on satellite images is determined based on the energy reflected from objects on the Earth's surface, captured by sensors in the thermal infrared range [20]. According to the workflow in Figure 1, the steps for calculating surface temperature index in this paper are as follows:

Step 1: Convert Digital Number (DN) to radiance value.

For Landsat 5 images, the radiance conversion is calculated using Equation (1):

$$L_\lambda = ((L_{max} - L_{min})/(Q_{cal,max} - Q_{cal,min})) *(Q_{cal}-Q_{Cal,min}) + L_{min} \quad (1)$$

where: L_λ: Radiance value

L_{max}: Maximum spectral radiance (RADIANCE_MAXIMUM-BAND_6_VCID_1)

L_{min}: Minimum spectral radiance (RADIANCE_MINIMUM-BAND_6_VCID_1)

Q_{cal}: Pixel value of the thermal band (Band 6)

$Q_{cal,max}$, $Q_{cal,min}$: Maximum and minimum radiance values calibrated as integers.

For Landsat 8 and 9, the radiance value is determined using Equation (2):

$$L_\lambda = M_L*Q_{cal} + A_L \quad (2)$$

where: L_λ: Radiance value

M_L: Radiance scaling factor (RADIANCE_MULT_BAND_10)

A_L: Conversion factor in metadata (RADIANCE_ADD_BAND_10)

Q_{cal}: Pixel value of the thermal band (Band 10)

Step 2: Convert radiance to brightness temperature using Equation (3):

$$T_B = \frac{K_2}{ln\left(\frac{K1}{L_\lambda}+1\right)} \quad (3)$$

where: K_1; K_2: Calibration constants for the thermal infrared band of the satellite image

T_B: Brightness temperature (^oK)

L_λ: Radiance value

Step 3: Calculate surface emissivity using Equation (4), emissivity of natural surfaces may vary based on soil and vegetation characteristics, so it depends on the land cover type:

$$\varepsilon = f_v * \varepsilon_{vegetation} + (1 - f_v) * \varepsilon_{bare\ soil} \quad (4)$$

where: $\varepsilon_{vegetation}$ Emissivity of vegetation = 0.97

$\varepsilon_{bare\ soil}$: Emissivity of bare soil = 0.96

f_v: The fractional vegetation or the proportion of vegetation within a pixel. The value of f_v is calculated using Equation (5)

$$f_v = ((NDVI - NDVI_{soil})/(NDVI_{vegetation} - NDVI_{soil}))^2 \quad (5)$$

The value of f_v will be 0 for bare soil and 1 for areas fully covered by vegetation.

Step 4: Calculate the land surface temperature using Equation (6):

$$LST = \frac{T_B}{1+\frac{\lambda * T_B}{\rho} * ln\varepsilon} - 273.15 \quad (6)$$

LST: Surface temperature (^oC)

T_B: Brightness temperature (^oK)

λ : Head Channel center wavelength (Band 10)

ε: Surface emissivity

$$\rho = \frac{h*c}{K} = 1{,}438 * 10^{-2} \text{ mK}$$

h = $6{,}626.10^{-34}$ J.sec: Planck Constant;

C = $2{,}998.10^{8}$ m/sec: Speed of light;

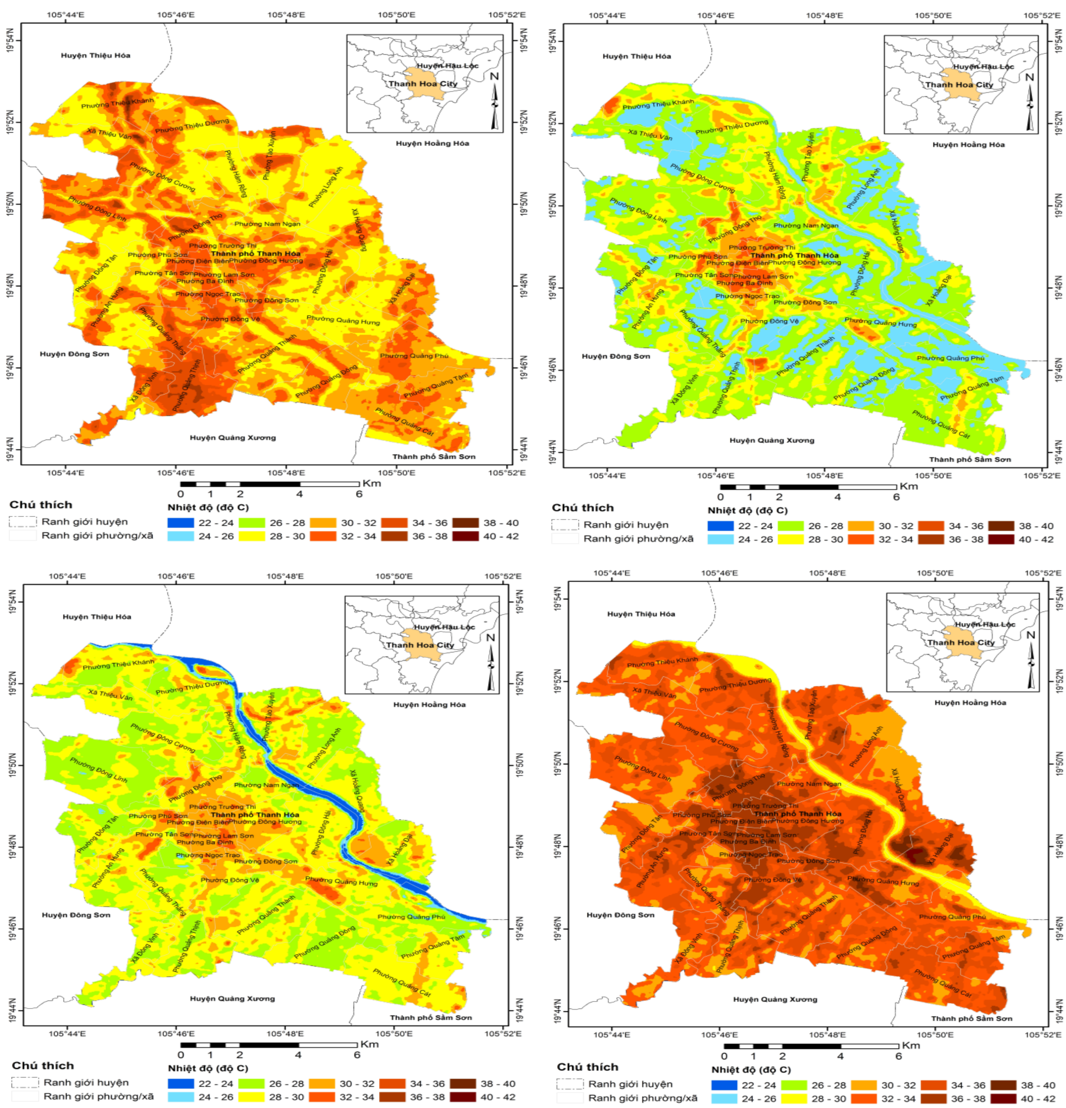
K = $1{,}38.10^{-23}$ J/K or $5{,}67.10^{-8}$ $Wm^{-2}K^{-4}$: Stefan Bolzmann Constant)

The calculations are performed on the Google Earth Engine platform, which enables quick processing and analysis of satellite imagery, helping to effectively determine surface temperatures in the study area.

3. Research results

3.1. Land surface temperature values in Thanh Hoa city from 2000 to 2023

From the land surface temperature values calculated for the area of Thanh Hoa city, the study used QGIS tools to construct thermal maps for the years 2001, 2007, 2010, 2015, 2019, 2022, and 2023. The results indicated that land surface temperature values fluctuated over different periods, as shown in Figure 2.



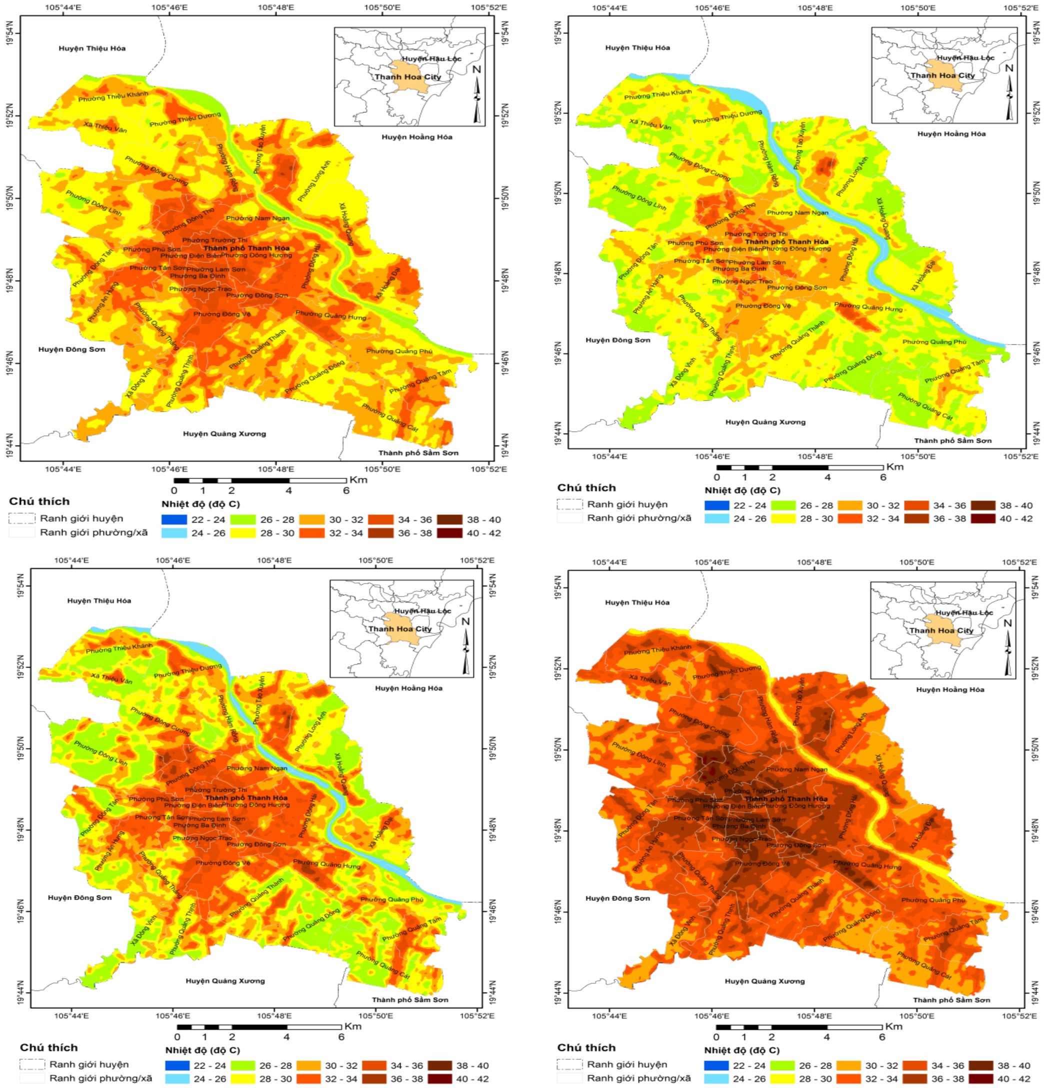


Figure 2: Surface temperature maps of Thanh Hoa city for the period 2000 - 2023

The spatial distribution of surface temperature in Thanh Hoa city, Thanh Hoa province, from 2000 to 2023, at various time points: 2001, 2007, 2010, 2015, 2019, 2020, 2022, and 2023, is shown in Figure 2. The area statistics for surface temperature in Thanh Hoa city according to different temperature groups (Table 2, Figure 3) indicate that temperatures exhibit varying trends over time and space.

Over time, it is evident that the average surface temperature reached its highest value in 2023, followed by 2015, 2019, 2001, 2022, and the lowest in 2007. From 2000 to 2023, temperatures fluctuated between 22 °C and 42 °C. The years 2015, 2019, and 2023 are considered record hot years for Thanh Hoa in general and Thanh Hoa city in particular, with observed temperatures recorded at the Thanh Hoa Meteorological Station in May being 39.8 °C (May 29, 2015), 41.0 °C (May 19, 2019), and 39.9 °C (May 17, 2023).

In 2015, areas with temperatures exceeding 32 °C were primarily concentrated in the central districts of Thanh Hoa city (in the wards of Dien Bien, Dong Tho, Truong Thi, Ba Dinh, etc.), and industrial zones located in the areas of Tay Bac Ga, Hac Thanh, and Hoang Long Bridge, with a total area of 118.07 km², accounting for 80.6 % of the total surface area of Thanh Hoa city. There were 18.81 km² of areas with temperatures exceeding 38 °C, accounting for 12.8 % of the city's total area.

From 2015 to 2023, there has been a remarkable change in surface temperature variability. In the industrial zones and inner Thanh Hoa city, high temperatures fluctuated between 38 °C and 42 °C.

Table 2. Statistics of areas corresponding to temperature groups in Thanh Hoa city from 2000 to 2023

Temperature range (°C)	Corresponding area for each year (km²)							
	2001	2007	2010	2015	2019	2020	2022	2023
22 - 24	0.00	0.00	3.51	0.00	0.00	0.00	0.00	0.00
24 - 26	0.00	31.49	2.34	0.00	0.00	4.66	3.29	0.00
26 - 28	0.00	65.66	45.50	0.00	4.90	36.93	29.36	3.45
28 - 30	50.44	34.17	69.51	4.60	52.20	69.48	40.09	28.80
30 - 32	55.22	11.80	22.63	23.79	49.98	29.77	32.70	44.21
32 - 34	29.82	3.28	2.94	56.45	30.14	5.07	29.11	36.87
34 - 36	10.00	0.09	0.04	42.81	9.18	0.46	11.10	25.36
36 - 38	0.90	0.00	0.00	17.26	0.04	0.05	0.79	7.55
38 - 40	0.08	0.00	0.00	1.39	0.00	0.00	0.01	0.20
40 - 42	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00

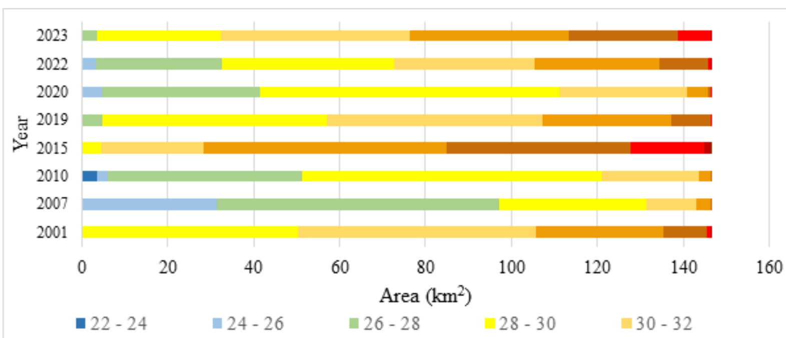


Figure 3: Statistics of areas corresponding to temperature groups in Thanh Hoa city for the period 2000 - 2023

Additionally, based on the study results calculating surface temperature values from satellite images using Google Earth Engine, the study developed a basic Earth Engine App for users to access and query surface temperature values at any location within the study area. The Earth Engine App can be accessed via the following link: https://ee-ntrnhan2022.projects.earthengine.app/view/nhietdobemat-tp-thanh-hoa.

3.2. Evaluating results of Landsat-derived surface temperature

To evaluate the accuracy of surface temperature values, the study compared the results of temperature values derived from satellite images and temperature values observed at the Thanh Hoa meteorological station. The study used temperature data observed at 3:00 p.m. each day for the 8 study years. These are the times that coincide with the time of satellite image acquisition for the study area, to compare and check the calculated values of surface temperature from satellite images through the Google Earth Engine platform, details as in Table 3.

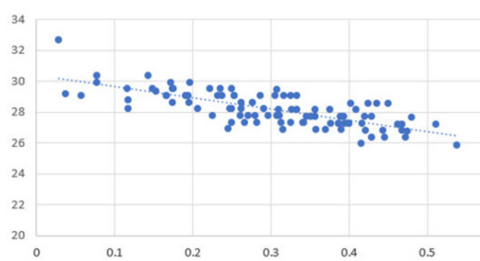
Table 3. Measured and satellite-derived surface temperature

Date	Measured temperature (°C)	Satellite-derived temperature (°C)	Difference (°C)	Relative error (%)
21/04/2001	36.3	36.9	0.6	1.65
08/05/2007	27.5	28.5	1.0	3.49
25/02/2010	30.5	29.9	0.6	1.96
30/05/2015	36.2	37.1	0.9	2.48
18/05/2019	34.8	35.3	0.5	1.43
08/03/2020	26.4	27.3	0.9	3.40
08/04/2022	29.1	30.5	1.4	4.81
05/05/2023	34.8	35.6	0.8	2.29

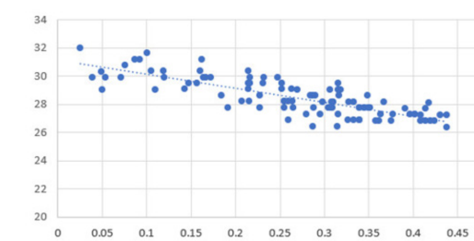
From the results shown in Table 3, it can be observed that the difference is insignificant, ranging from 0.5 °C to 1.4 °C. The difference in temperature values in 2022 is the highest at 1.4 °C and the corresponding relative error is 4.81 %. It shows that the error is within the acceptable range. Therefore, the calculated results of the surface index values from satellite images in this study are acceptable.

3.3. Correlation analysis of surface temperature and normalized difference vegetation

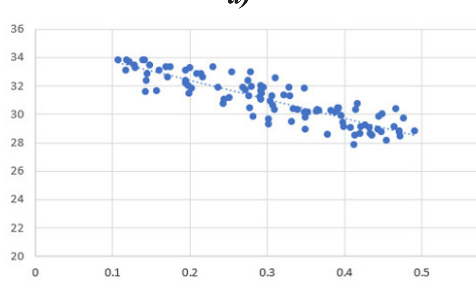
The Normalized Difference Vegetation Index (NDVI) and surface temperature index were calculated on Google Earth Engine, afterwards a correlation relationship was built based on the Pearson correlation coefficient (ρ). The results indicated that there was a negative correlation between the surface temperature and the NDVI and a high Pearson correlation coefficient: in 2007, the correlation coefficient (ρ_xy) was -0.762 (Figure 4a); in 2015, ρ_xy was -0.822 (Figure 4b); in 2019, ρ_xy was -0.865 (Figure 4c), and in 2023, ρ_xy was -0.893 (Figure 4d).



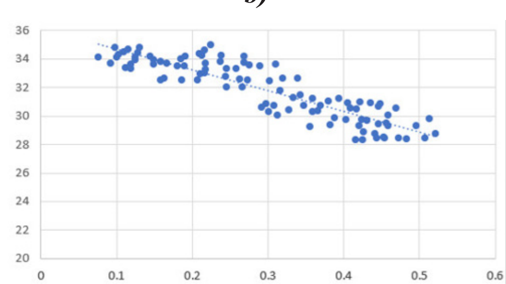
a)



b)



c)



d)

Figure 4: Correlation between surface temperature index (LST - vertical axis) and Normalized Difference Vegetation Index (NDVI - horizontal axis) of Thanh Hoa city in the period 2000 - 2023

3.4. Investigating land surface temperature in Thanh Hoa city from 2000 to 2023

It can be observed that the increase in the thermal environment in Thanh Hoa city from 2000 to 2023 can be attributed to several indirect factors, including urbanization and the structural transition of the economy, with a shift in land use from agricultural land to urban and industrial land.

From 2015 to 2023, Thanh Hoa expanded its urban units from 30 in 2016 to 70 in 2020, including the renovation and expansion of 24 urban units and the establishment of 40 new ones. In 2020, changes in land use resulted in a decrease in agricultural land, while non-agricultural land increased, especially for commercial services.

With rapid urbanization, Thanh Hoa city is expected to meet the criteria for type I urban areas by 2024. This, combined with current climate change conditions, has significantly raised surface temperatures by 2023. Areas with high surface temperatures correspond to regions with high building density, such as residential areas, urban centers, and industrial zones.

In addition, according to the resolution on the approval of the 1/2000 scale construction zoning plan for the Western Industrial Park of Thanh Hoa city in July 2024, the total planning area is about 645.2 hectares and the structure and planning criteria for land use include 447.94 hectares for factories, accounting for 69.43 % with a maximum building density of 70 %, a maximum building height of 5 floors, and a maximum land use coefficient of 3.5 times; 36.39 hectares for administrative and public-service land, accounting for 5.64 % and 8.12 hectares for infrastructure covering 1.26 %. Additionally, green space accounts for 10.14 %; Water surface for 3.04 %, and transportation for 10.49 %. Regarding spatial organization, the industrial zone, spanning approximately 645.2 ha, is divided into two sub-zones: Zone A, about 375 hectares located south of the route from Thanh Hoa city to Tho Xuan Airport, and Zone B, about 270.2 hectares located North of the same route. These favorable socio-economic development factors in Thanh Hoa province have contributed to a gradual increase in the thermal environment amidst current climate change.

Using the land surface temperature index allows for close monitoring of the trends in the thermal environment rapidly through the construction of tools to calculate temperature values from satellite images on Google Earth Engine. This shows that this tool is highly effective in extracting thermal values from satellite images, supporting thermal environmental monitoring in general and environmental resource management in particular in the context of climate change. However, the study still has data limitations due to the inability to collect satellite image data coinciding with the highest measured temperatures at monitoring stations. Furthermore, to evaluate the reasons for the transformation of land use structure and its impact on the thermal environment comprehensively, continuous monitoring of surface cover changes or mapping of the current land use status annually should be conducted using high-resolution remote sensing imagery combined with field surveys. This would contribute to the development of measures to address the existing issues in urban planning.

4. Conclusion

With the advantages of Google Earth Engine in calculating and processing satellite images to derive surface temperature values for Thanh Hoa city, the results indicated that surface temperature values in the study area have varied over the period from 2000 to 2023. Particularly, the years 2015 and 2023 recorded high surface temperatures in densely populated areas, commercial centers, and industrial zones such as Tay Bac Ga and Hac Thanh. This study demonstrated that Google Earth Engine can quickly and effectively monitor changes in the thermal environment through satellite imagery. Furthermore, the study has developed a basic Earth Engine App to allow users to easily and quickly query surface temperature values at their desired locations. However, further research is needed on surface cover changes that closely impact surface temperature trends during urbanization in major cities.

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RESEARCH ON MIXING AND COMPOSTING SLUDGE FROM THE WASTEWATER TREATMENT SYSTEM AT THE COCA - COLA VIETNAM FACTORY, HANOI BRANCH TO CREATE PRODUCTS ORIENTED FOR PLANTING

Trinh Thi Thuy[1,*], Do Thi Kim Tuyen[2]
[1]Hanoi University of Natural Resources and Environment, Vietnam
[2]Tam Viet Environment and Construction Joint Stock Company, Vietnam

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Abstract

Sludge generated from the wastewater treatment systems of the beverage production industry represents a significant environmental concern. Reusing sludge is considered a sustainable approach. This study applied methods of blending sludge with other biomass materials, such as rice husk charcoal, followed by anaerobic composting. The results indicate that sludge from the wastewater treatment system of the Coca-Cola Vietnam factory, Hanoi branch, mixed with rice husk charcoal at a volumetric ratio of 80:20 and composted anaerobically for 30 days, produced a suitable substrate for tabletop ornamental plants. The study also suggests that this product has the potential to replace traditional growing media, thereby reducing treatment costs while simultaneously delivering both economic and environmental benefits.

Keywords: Sludge; Wastewater treatment; Ornamental plants.

[*]**Corresponding author, Email:** ttthuy.mt@hunre.edu.vn

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1. Introduction

In the wastewater treatment industry, sludge is the residue produced by biological and chemical wastewater treatment processes. Sludge from wastewater treatment processes can contain many organic substances, heavy metals, and other pollutants, which, if not properly managed, will negatively impact the water, soil, and air environment [1]. Many studies have confirmed that traditional methods, such as landfilling or incineration, often treat sludge. However, these methods are costly and pose a risk of environmental pollution [2]. Finding solutions to reuse sludge more effectively, such as producing fertilizers or environmentally friendly products, is receiving attention. Composting is an effective method to treat and stabilize sludge, transforming it into safe and nutritious products [3]. In Vietnam, some studies have been conducted on composting from industrial sludge, but mainly on sludge from seafood and beer processing [4, 5].

The beverage industry is growing strongly in Vietnam, with Coca-Cola being one of the leading brands. However, the beverage production process generates a large amount of wastewater and leads to sludge from the wastewater treatment system. The large volume of sludge generated at the factory is causing significant challenges for businesses and industrial waste management. If inadequately treated, sludge can result in adverse impacts on water, soil, and air environments. Currently, the predominant sludge treatment methods include landfilling and incineration. However, landfilling poses the risk of long-term environmental pollution, while incineration is associated with high operational costs. At the Coca-Cola Vietnam factory, Hanoi branch, although a modern wastewater treatment system has been implemented to ensure that the treated effluent meets environmental standards, a significant amount of sludge is still generated from the wastewater treatment process. Currently, the plant adopts landfilling as the primary method for sludge disposal. However, this approach is associated with high treatment costs and poses potential environmental risks [6]. Therefore, exploring options for reusing sludge to minimize costs and mitigate environmental impacts is crucial.

Nowadays, the trend of using bonsai trees for offices and homes is becoming more and more popular in big cities like Hanoi. Therefore, the demand for specialized soil, substrate, and fertilizer products for bonsai trees is increasing. However, research on developing these products by mixing sludge from wastewater treatment systems and other materials for use in ornamental plants still needs to be completed.

Rice husk charcoal, a product of rice husk combustion, is widely used in agriculture due to its superior properties [7]. Physically, rice husk charcoal has a porous structure with a large surface area, which helps improve the water retention and air permeability of the growing medium, which is especially important for bonsai grown in small pots [8]. Chemically, rice husk charcoal has a neutral to slightly alkaline pH, which helps balance the pH of acidic sludge [9] while adding trace elements such as silicon, potassium, and calcium, creating a balanced nutritional medium [10]. In addition, rice husk charcoal has natural antibacterial properties, limiting pathogens and creating a favorable environment for beneficial microorganisms, improving plant health.

Based on the above facts, this study aims to mix and compost sludge from the wastewater treatment system of the Coca-Cola Vietnam factory, Hanoi branch with rice husk charcoal to produce a product suitable for growing ornamental plants. The research holds not only scientific significance but also practical value, contributing to reducing waste treatment costs and creating an environmentally friendly, useful product.

2. Materials and methods

2.1. Materials

The sludge used in this study was collected from the wastewater treatment system of the Coca-Cola Vietnam factory, Hanoi branch. The sludge sample utilized for the research was obtained after the treatment process and dewatered into sludge cakes. Rice husk charcoal was procured from a water filtration materials supplier and was produced through the pyrolysis of rice husks under anaerobic conditions.

Three popular ornamental plants were selected for the study: *Philodendron Selloum* (Thanh Xuan pothos), *Philodendron emperor* (De Vuong pothos), and *Monstera deliciosa* (Monstera pothos). The selection of these three plants was based on their classification as low-maintenance species with strong growth adaptability under low-light conditions, making them well-suited for indoor or office spaces. This characteristic ensures that the results of the substrate trials can be broadly applicable to other indoor ornamental plants and office landscaping. Additionally, these plants have moderate nutrient requirements and can readily adapt to various substrate types. This makes them ideal for assessing the effectiveness of the new substrate composed of sludge blended with rice husk charcoal without the need for significant additional nutrient supplementation under normal conditions.

2.2. Research methods

2.2.1. Methods of analyzing sludge composition

The sludge composition is determined to guide its use as a growing medium. The methods of analyzing sludge composition are shown in Table 1.

Table 1. Indicators and analysis methods

No	Parameter	Method	STT	Parameter	Method
1	Moisture	TCVN 6648:2000	4	Total carbon	ISO 16948:2015
2	Flexible phosphorus	TCVN 10678:2015	5	Total nitrogen	ISO 16948:2015
3	Potassium	TCVN 8660 : 2011	6	Total sulfur	ISO 16948:2015

2.2.2. Experimental design method

a. Research on the different mixing ratios of sludge with rice husk charcoal and incubating time

Mix sludge and rice husk charcoal in volume ratios of 70:30, 75:25, 80:20, 85:15, and the total volume of the mixture is 0.2 m^3. The selected ratio range of 70:30 to 85:15 was chosen to balance the amount of sludge and rice husk charcoal, ensuring sufficient nutrient supply from the sludge while maintaining the porous structure provided by the rice husk charcoal. Additionally, this ratio range allows for effective control of salt levels and pH in the substrate, creating a healthy growth environment for plants.

Put the mixture into a styrofoam box with a lid and incubate the mixtures in order of 45 days, 30 days, and 15 days. One box of un incubated mixture was prepared on the final day of the incubation process. The boxes were finished incubating on the same day, then proceeded to plant trees. Do not disturb the mixture during the incubation process.

The mixtures after mixing and incubation were denoted as follows:

Table 2. Symbols of mixed mixtures between sludge and rice husk charcoal

Mixing ratio	Incubation time	ID of mixture	Mixing ratio	Incubation time	ID of mixture
70:30	No incubation	U1.0	80:20	No incubation	U3.0
	15 days	U1.1		15 days	U3.1
	30 days	U1.2		30 days	U3.2
	45 days	U1.3		45 days	U3.3
75:25	No incubation	U2.0	85:15	No incubation	U4.0
	15 days	U2.1		15 days	U4.1
	30 days	U2.2		30 days	U4.2
	45 days	U2.3		45 days	U4.3

- After incubation, the mixtures were analyzed for some basic parameters according to the methods in section 2.2.1.

b. Planting bonsai using the mixtures after incubating

For each experimental mixture, three types of plants are planted, including *Philodendron Selloum, Philodendron emperor,* and *Monstera deliciosa*. The mixtures, after incubation, were put into black nursery pots made from recycled PE plastic of 17 × 2.5 cm. The plants were seedlings that were purchased at the nursery. All plants were measured by height and the number of leaves. All ornamental plants were planted on the same day with the same care conditions (watering once a day, same amount of water). Each experimental model was repeated three times.

Control experiment: The *Philodendron Selloum*, *Philodendron emperor*, and *Monstera deliciosa* were grown on soil taken from a garden in Hong Van commune, Thuong Tin district, Hanoi city. Control experiments were denoted as MD.

Monitor the growth and development of the plant through the following parameters: Plant height, and number of leaves, with a measurement frequency of 40 days/1 data during the period of 4 months (from March 10, 2024 to July 10, 2024). The results were the average of 3 replicates for each experiment.

3. Results and discussion

3.1. Results of determination of the sludge composition

The results of the composition analysis of the sludge are shown in Table 3.

Table 3. Composition of sludge from the wastewater treatment system of Coca-Cola Vietnam factory, Hanoi branch

No	Parameters	ID	Unit	Sludge
1	Humidity	W	%	80, 54
2	Flexible phosphorus	P_2O_5	%	3, 63
3	Potassium	K	mg/100 g	0.675
4	Total Carbon	C	%	14.85
5	Total Nitrogen	N	%	1,236
6	Total sulfur	S	%	0.002

According to the data in Table 3, the sludge from the wastewater treatment system of the Coca-Cola Vietnam factory, Hanoi branch is a rich source of nutrients, especially in flexible phosphorus (3.63 % P_2O_5), total nitrogen (2.536 %) and total carbon (14.85 %). These values are similar to many other types of wastewater sludge [11] .

3.2. Results of sludge analysis after mixing and incubating with rice husk charcoal

The results of analysis of some components of the sludge after mixing and incubating with rice husk charcoal are shown in Table 4.

Table 4. Composition of the mixture of sludge and rice husk charcoal before and after incubating

ID of Mixture	Ingredient				ID of Mixture	Ingredient			
	P_2O_5 (%)	N (%)	C (%)	K (%)		P_2O_5 (%)	N (%)	C (%)	K (%)
U1.0	2.681	2.118	18.403	0.554	U3.0	3.271	2.050	26.897	0.418
U1.1	2.885	2.157	16.185	0.691	U3.1	2.151	2.134	15.829	0.877
U1.2	3.012	2.084	20.106	0.703	U3.2	3.173	2.208	20.135	0.871
U1.3	2.651	2.119	16.457	0.652	U3.3	3.338	2.177	18.185	0.782
U2.0	2.696	2.043	21.478	0.449	U4.0	3.210	2.026	22.980	0.597
U2.1	2.922	2.023	15.559	0.554	U4.1	3.143	1.737	19.546	0.601
U2.2	3.235	2.187	15.919	0.533	U4.2	2.971	1.975	17.498	0.664
U2.3	2.681	2.118	18.403	0.550	U4.3	2.892	1.932	15.961	0.456

According to the data in Table 4, after mixing the sludge with rice husk charcoal at different ratios and the days of incubating, the nutritional composition of the mixtures changed. The content of flexible phosphorus ranged from 2.151 to 3.338 %, which decreased compared to the original sludge but remained high. The total nitrogen content in the mixtures ranged from 1.737 to 2.208 %, which remained relatively stable and high. These mixtures were all rich in nitrogen. The organic carbon content in the mixtures ranged from 15.559 to 26.897 %, higher than that of the original sludge. This increase could be due to the contribution of rice husk charcoal, a carbon-rich material. The high C content helps improve soil structure and increase water retention, which is suitable for the nutritional needs of plants. The C/N ratio is about 10:1, suitable for microbial decomposition. Thus, regarding nutritional composition P, C, and N, the above mixtures are suitable for growing plants in general and growing bonsai in particular.

However, the total potassium content in the mixtures is quite low, ranging from only 0.418 to 0.877 mg/100 g. Therefore, when using these mixtures as growing media, it may be necessary to supplement the K source to ensure nutritional balance for the plants.

In terms of mix ratio, mixes with higher sludge ratios of 80:20 and 85:15, respectively, tend to have higher nutrient content. These results reflect the fact that the nutrient content of P, C, and N of sludge is often much higher than that of rice husk charcoal. Composting time also affects decomposition and nutrient conversion. Composting mixtures of 30 - 45 is generally more nutritionally stable.

When compared to organic compost derived from brewery and seafood processing sludge (37.12 - 54.74 % C, 1.81 - 2.39 % N, and 3.31 - 4.99 % P_2O_5) [4], the mixture of sludge from the wastewater treatment system of the Coca-Cola production plant and rice husk charcoal has significantly lower carbon and phosphorus content but exhibits a comparable total nitrogen percentage. Both mixtures have similarly low potassium levels, with K_2O only reaching 0.18 - 0.20 %, highlighting the need for potassium supplementation from other sources to balance the nutrients.

Compared to organic compost from shrimp pond sludge (19.91 - 23.75 % C, 1.59 - 3.95 % N, and 0.28 - 0.68 % P_2O_5) [12], the sludge-rice husk mixture demonstrates lower carbon content but comparable total nitrogen levels and higher available phosphorus content. Notably, the C/N ratio of the Coca-Cola wastewater sludge and rice husk mixture, approximately 10:1, is lower than that of shrimp pond sludge, which is approximately 23:1. This lower C/N ratio facilitates faster and more efficient organic decomposition. However, shrimp pond sludge, with its higher carbon content, is better suited for improving soils deficient in organic matter.

3.3. Results of growing test using waste sludge products after mixing and incubating

3.3.1. Results of survey on growth of tree based on the height

The height of the tree was measured in four batches (Batch 1: The first day of planting, Batch 2: After 40 days of planting, Batch 3: After 80 days of planting, Batch 4: After 120 days of planting). The data obtained are summarized in Table 5.

Table 5. Data on the height of ornamental plants

ID of mixture	Philodendron Selloum			Philodendron emperor			Monstera deliciosa		
	After 40 days	After 80 days	After 120 days	After 40 days	After 80 days	After 120 days	After 40 days	After 80 days	After 120 days
	(cm)			*(cm)*			*(cm)*		
MD	1.7	2.5	3.4	1.6	3.1	3.9	1.7	3.7	4.8
U1.0	1.8	2.8	3.8	1.9	3.0	4.1	1.8	4.7	5.8
U1.1	3.7	6.2	8.7	1.8	3.1	4.3	1.3	4.3	6.0
U1.2	3.9	6.4	8.9	1.3	2.7	4.0	1.8	4.6	5.5
U1.3	3.8	6.3	8.8	1.4	3.0	4.5	1.5	4.8	6.5
U2.0	1.7	3.0	4.2	1.9	3.3	4.7	1.8	4.0	4.3
U2.1	3.6	5.8	7.9	1.1	2.4	3.7	2.0	5.9	7.8
U2.2	2.8	4.8	6.8	1.2	2.5	3.8	1.3	3.5	4.3
U2.3	3.7	5.2	6.7	1.9	3.8	5.7	2.5	5.4	5.8
U3.0	4.6	6.5	8.4	2.7	3.6	4.4	2.7	5.2	4.9
U3.1	2.8	5.0	7.2	2.2	3.5	4.8	1.6	4.6	6.0
U3.2	3.7	6.8	9.8	2.5	4.5	6.4	3.4	7.9	8.9
U3.3	3.4	7.0	9.2	2.3	5.4	7.2	2.0	4.8	8.1
U4.0	2.9	4.7	6.4	1.9	2.7	3.4	2.8	6.4	7.2
U4.1	2.7	5.1	7.4	3.5	4.8	6.0	2.5	6.1	7.1
U4.2	1.9	3.9	5.8	1.9	3.0	4.1	3.0	5.2	4.4
U4.3	3.6	5.9	8.1	1.8	3.1	4.3	2.2	4.7	4.9

According to the data in Table 5, most of the mixtures gave better results than the control experiment (MD) in all measurement batches. The results for the growing medium were labeled U3.2, and U3.3 (ratio 80:20:00, incubation for 30 and 45 days) gave the highest efficiency for all three types of pothos plants. The ratio of 80:20:00 provides a good balance between sewage sludge (the main source of nutrients) and rice husk charcoal (improves aeration). The mixture with this ratio optimizes the growing media's water retention and air permeability. The incubation time of 30 and 45 days allows the microbial decomposition process to take place fully, helping to stabilize the nutritional composition of the mixture. The combination of wastewater sludge from the water treatment system and rice husk charcoal can create a substrate with good porosity, water retention and aeration capacity, and adequate nutrition, which are important substrate characteristics for growing plants. Although there were slight differences between species, all three types of pothos grew well on substrates labeled U3.2 and U3.3. The mixtures with 85 % wastewater sludge did not give the best results, although they were still better than the plants that were grown on garden soil (MD experiments). This may be due to the high proportion of wastewater sludge reducing the aeration of the substrate, affecting the development of the roots.

3.3.2. Results of survey on growth of tree based on the number of leaves

The number of leaves on the tree was counted in four batches at the same time as the height measurement (Table 6).

Table 6. Data on changes in the number of leaves

ID mixture	Philodendron Selloum			Philodendron emperor			Monstera deliciosa		
	After 40 days	After 80 days	After 120 days	After 40 days	After 80 days	After 120 days	After 40 days	After 80 days	After 120 days
	Number of leaves			Number of leaves			Number of leaves		
MD	2.0	3.0	4.0	2.0	3.0	4.0	1.0	2.0	3.0
U1.0	2.0	3.0	5.4	2.6	4.6	6.3	1.0	2.0	4.7
U1.1	1.3	2.3	4.3	2.0	4.0	6.0	2.0	3.0	5.0
U1.2	2.0	3.0	5.0	2.4	4.4	6.7	2.0	3.0	5.0
U1.3	2.4	3.4	6.4	2.0	4.0	6.0	1.0	2.0	4.0
U2.0	3.0	4.0	7.4	3.0	5.0	8.0	1.6	2.6	4.0
U2.1	3.0	5.0	7.0	2.4	4.4	8.0	2.0	3.0	4.0
U2.2	2.0	4.0	6.0	3.0	5.0	7.0	1.0	2.0	4.0
U2.3	2.0	4.0	7.0	2.0	4.0	6.0	1.0	2.0	4.0
U3.0	2.4	4.4	5.7	3.0	5.0	7.4	2.4	3.4	5.0
U3.1	2.0	4.0	7.0	3.0	5.0	8.0	2.0	3.0	4.0
U3.2	3.4	5.4	8.0	3.0	5.0	8.0	2.0	3.0	6.4
U3.3	3.6	4.3	6.3	2.3	4.3	7.3	2.0	3.0	6.0
U4.0	2.4	3.4	6.4	2.0	4.0	5.0	1.0	2.0	5.0
U4.1	3.0	4.0	8.0	1.3	2.3	5.3	2.0	3.0	5.0
U4.2	2.0	3.0	6.4	3.0	4.0	6.0	2.0	3.0	5.0
U4.3	2.0	3.0	7.0	2.3	3.3	5.3	2.0	3.0	5.0

The data in Table 6 indicate the increased number of leaves of three types of pothos plants after 40, 80, and 120 days of planting. Similar to height growth, most ornamental plants grown in the mixtures showed better results than those grown in garden soil (MD) at all measurement batches. After 120 days, the U3.2 mixture continued to show outstanding effectiveness with an increased number of leaves for three types of pothos *(Philodendron Selloum, Philodendron emperor,* and *Monstera deliciosa*) with an average of 8, 8, and 6.4 leaves respectively. Compared to the MD (4, 4, and 3 leaves), the plants in U3.2 developed from 2 to 2.13 times more leaves. The data collected from experiments reinforces the conclusion that the 80 % sludge ratio and 30-day incubation period create the optimal environment for the overall growth of pothos. Mixtures with sludge ratios from 70 - 80 % also have a positive effect on the leaf growth of the pothos plant.

Thus, it can be seen that the U3.2 mixture (sludge: Rice husk charcoal ratio 80:20, incubation for 30 days) gave the significant best results for all three types of pothos plants in terms of both height and number of leaves. The results reveal that the optimal balance between nutrients from the sludge and soil structure from the rice husk charcoal, along with a sufficiently long composting time to stabilize the organic matter, can support good conditions for plant growth. Mixtures in which the sludge accounted for about 70 - 80 % and an incubation time of 15 - 45 days also gave better results than the MD. However, a sludge ratio that was too high (85 %) did not give the best results that confirm the importance of balancing nutrients and soil structure in the growing medium.

4. Conclusion

The study has mixed sludge from the wastewater treatment system of the Coca-Cola Vietnam factory in Hanoi and rice husk charcoal with different mixing ratios, then incubated, and evaluated the effectiveness of using these mixtures to grow three types of ornamental plants: *Philodendron Selloum, Philodendron emperor,* and *Monstera deliciosa*. The results showed that most of the mixtures significantly improved plant growth compared to normal soil. The U3.2 mixture (waste sludge: Rice husk charcoal ratio 80:20 by volume, incubated for 30 days) was determined to be the most effective. Mixtures with a sludge ratio of 70 - 80 % and an incubation time of 15 - 45 days gave better results than mixtures with a sludge ratio of 85 %. This study shows the potential of reusing sludge from wastewater treatment systems as a growing medium. However, the study has not yet delved into the long-term impacts of these mixtures on plant health and the environment, particularly the potential accumulation of heavy metals and other toxic substances from sludge in soil and plants. Additionally, the scope of the research primarily focuses on ornamental plants and has not been extended to agricultural crops or various soil conditions, which limits the practical applicability of the findings on a larger scale.

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ASSESSMENT OF FOREST AREA CHANGE TRENDS IN HA TINH PROVINCE USING NON-PARAMETRIC ESTIMATION METHODS

Le Duc Dung[1,*], Hoang Anh Huy[2], Do Van Tu[3]
Cung Hong Viet[4], Nguyen Quang Chien[5]

[1]National Institute of Mining - Metallurgy Science and Technology, Vietnam
[2]Hanoi University of Natural Resources and Environment, Vietnam
[3]Institute of Ecology and Biological Resources, Vietnam Academy of Science and Technology
[4]Vietnam Institute of Meteorology, Hydrology and Climate Change
[5]Institute for Agricultural Environment, Vietnam Academy of Agricultural Sciences

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Abstract

This article applies non-parametric estimation methods to assess forest area change trends in Ha Tinh province from 2017 to 2023. The study focuses on analyzing changes in various forest categories, including protective forests, special-use forests, and production forests, across districts within the province. Results indicate an increase in protective and production forest areas in regions such as Ky Anh and Cam Xuyen districts, while other areas like Duc Tho district and Hong Linh town show a trend of decline or stability. Overall, these changes align with the province's forestry development policies and strategies. This research aims to provide a scientific basis for developing forest management policies. Additionally, it offers statistical analyses to support climate change response efforts, advancing toward sustainable development goals.

Keywords: Non-parametric estimation; Trend analysis; Forest area; Special-use forests; Protection forests; Production forests; Mann-Kendall; Climate change.

*__Corresponding author, Email:__ ducdung97ht@gmail.com

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1. Introduction

The Vietnamese government considers forests an important ecological resource with valuable contributions to socio-economic development and improving the quality of life for communities across the country [1, 2]. Currently, about 25 million Vietnamese people derive 20 to 40 % of their annual income from forests [3]. In addition, forests play an extremely important role in climate change adaptation through environmental functions such as erosion control and maintaining air circulation. According to data from the Global Forest Watch platform (WRI, 2002), in 2023, Vietnam lost 94.2 hectares of natural forest, equivalent to releasing 118 million tons of CO_2 emissions into the atmosphere. The North Central region, including Ha Tinh province, also has a rich forest system with many rare tree species, which plays a significant role in protecting river basins and related ecosystems. According to the Ha Tinh Department of Agriculture and Rural Development, by 2023, the province will have nearly 360,000 hectares of forest and forestry land, accounting for over 60 % of its natural area [4]. Comparing the total forest and forestry land area in 2022 with 2015, the province experienced a reduction of 1,185 hectares.

Resolution No. 01-NQ/DH dated October 16, 2020, of the 19th Ha Tinh Provincial Party Congress, term 2020 - 2025, details the development of forestry. Specifically, the resolution emphasizes harnessing the potential and advantages of forest resources and forestry land. The measures outlined include managing, protecting, and developing special-use forests, upstream protective forests, coastal forests, and natural forests to enhance resilience to climate change. The resolution also encourages the development of concentrated medicinal and raw material forest plantations, intensively cultivated in partnership with processing factories to support the growth of other economic sectors [2]. In addition, the Vietnam Forestry Development Strategy for the period 2021 - 2030, with a vision toward 2050, has been approved to build the forestry sector into a modern, efficient, and highly competitive economic-technical sector. This strategy includes development orientations such as natural forest restoration, agroforestry development, non-timber forest products, and improving the productivity and quality of planted forests [5].

The departments, sectors, localities, forest owners, and relevant units in Ha Tinh Province have focused resources on forest management and protection efforts [6], however, several challenges remain due to various causes. First, natural factors: Ha Tinh frequently experiences storms, floods, and droughts, with harsh climate conditions, barren soil, and complex, fragmented terrain. Next, infrastructure-related causes: Forestry infrastructure is inadequate, including the system of patrol roads for protection, forest fire prevention and control, and the transportation of materials for forest planting, as well as for harvesting and selling forest products [6]. Finally, but no less important, the system of legal documents, mechanisms, and policies related to forestry frequently changes. Regulatory authorities have yet to provide timely, specific, and consistent implementation guidelines [7, 8]. These issues have created difficulties and challenges in the management and protection of forest resources at the local level.

The non-parametric Mann-Kendall method is widely used to assess trends in time series data. This method does not require data to follow a specific distribution, making it suitable for analyzing environmental and climatic conditions. Additionally, in forestry research, this method has proven effective in evaluating changes in forest area and deforestation. Specifically, the study by

Santos et al., (2020) applied this method to analyze changes in forest cover in the semi-arid region of Brazil, helping to identify the areas most severely affected by deforestation [9]. Another study by Zhu et al., (2021) also applied this method to analyze mangrove forest dynamics in the Qinglangang Reserve, China, enabling the tracking of decline and recovery trends within the forest ecosystem [10].

From these issues, in this article, we will present some evaluation results on forest change trends, based on the Mann-Kendall [11] and Sen [12]. Non-parametric trend calculation and testing methods. These results not only provide a scientific basis for forest management and protection policies but also help forecast and effectively respond to changes caused by climate change.

2. Research methods and data

2.1. Research methodology

The application of probability and statistical theory in social life analysis is widely popular and considered an effective approach for forecasting changes. Traditional methods such as graph theory and linear regression have certain advantages but face difficulties in analyzing forest trends, especially when dealing with diverse spatial, temporal, and environmental factors. To address these challenges, this study employs the non-parametric Mann-Kendall test and Sen's slope estimator to analyze the changing trends of different forest types.

2.1.1. Mann-Kendall Non-Parametric Test method

The Mann-Kendall test is a widely used non-parametric method for detecting trends in forest changes over time. This test aims to identify trends in a time series (a sample set) that has been arranged sequentially [11]. The method compares the relative magnitudes of the elements in the series rather than their actual values. This helps to avoid artificial trends caused by a few local extreme values, which can occur when using traditional linear trend calculations through the least squares method. Another advantage of this method is that it does not require the sample set to follow any particular distribution [13].

The calculation formulas for this method, as applied in the study, are briefly described below. Suppose there is a time series (x_1, x_2, …, x_n) where x_i represents the forest area statistics at time i. The Mann-Kendall statistic (S) is defined as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k) \quad (1)$$

Since the time series of forest area statistics is short, this study uses an approach suited for small samples. The value of S is determined based on the following Mann-Kendall (Z) value:

$$\text{If } S > 0 \; Z = \frac{S-1}{\sqrt{V(S)}} \quad (2)$$

$$\text{If } S < 0 \; Z = \frac{S+1}{\sqrt{V(S)}} \quad (3)$$

$$\text{If } S = 0, \; \tau = 0 \quad (4)$$

Z is tested under the following conditions to examine the null hypothesis of no monotonic trend. The corresponding confidence levels for each hypothesis are specified below:

$$|\tau| > \{\tau(\frac{1-0.99}{}) = 2.576\} \quad (5)$$

with the confidence level 99.5

$$|\tau| > \{\tau(\frac{1-0.95}{}) = \mathbf{1.96}\} \quad (6)$$

with the confidence level 97.5

$$|\tau| > \{\tau(\frac{1-0.9}{2}) = \mathbf{1.645}\} \quad (7)$$

with the confidence level 95

2.1.2. Sen's slope

To determine the magnitude Q of the trend in the series, Sen's estimation method is used [12]. Q is defined as the median of the series comprising:

$$\frac{n(n-1)}{2} \ elements \left\{x_j - x_{kj} - k;\ với\ k = 1,2; \dots; n-1; j > k\right\}$$

With this definition, Q has the same sign as τ. In the figures in this study, Q will be displayed at each station point for each factor. Trends with a statistical significance level above 95% will also be indicated.

2.2. Research data

Table 1. Summary of research data by district and forest type

No.	Location	Data	Time period	Source
1	Cam Xuyen district	TDD, TPH, TSX	2017 -2023	Chi cuc Kiem Lam Ha Tinh
2	Can Loc district	TPH, TSX	2017 -2023	
3	Duc Tho district	TPH, TSX	2017 -2023	
4	Huong Khe district	TDD, TPH, TSX	2017 -2023	
5	Huong Son district	TDD, TPH, TSX	2017 -2023	
6	Ky Anh district	TDD, TPH, TSX	2017 -2023	
7	Loc Ha district	TPH, TSX	2017 -2023	
8	Nghi Xuan district	TPH, TSX	2017 -2023	
9	Thach Ha district	TPH, TSX	2017 -2023	
10	Vu Quang district	TDD, TPH, TSX	2017 -2023	
11	Ha Tinh city	TPH, TSX	2017 -2023	
12	Hong Linh town	TPH, TSX	2017 -2023	
13	Ky Anh town	TPH, TSX	2017 -2023	

Note: TDD is the total area of special-use forest, TPH is the total area of protection forest, and TSX is the total area of production forest.

Ha Tinh province currently classifies its forest data into three main categories: special-use forests, protection forests, and production forests. Each type of forest plays a crucial role in environmental protection and economic development. Special-use forests are strictly protected to preserve ecological values, natural landscapes, and cultural heritage. These forests not only serve conservation purposes but are also used for scientific research and the development of ecotourism. Protection forests play a key role in safeguarding soil and water resources, mitigating the impacts of natural disasters such as floods and landslides, and responding to climate change. Lastly, production forests are utilized for supplying raw materials for the wood processing industry and other forest products, making a significant contribution to the province's forestry economy. Data on the areas of these three forest types have been collected and compiled from official sources, such as Ha Tinh's forest status report by the Forest Protection Department, the Department of Agriculture and Rural Development, and published research studies.

3. Results and discussion

3.1. Evaluation results of the trend in protection forest area changes

According to Resolution No. 34/NQ-HDND dated December 15, 2016, the protection and development of protective forests is identified as a strategic task. Decision No. 607/QD-UBND dated March 3, 2017, by the Provincial People's Committee, detailed the measures and action plans, aiming to manage and protect an area of 101,345 hectares of protective forests annually until 2020, with an additional target of planting 2,425 hectares per year. As a result of these protective forest policies, the province has achieved significant accomplishments. From 2017 to 2023, the area increased to 108,047 hectares, thereby exceeding the management target, with an average forest area increase of 558.9 hectares per year (Figure 1).

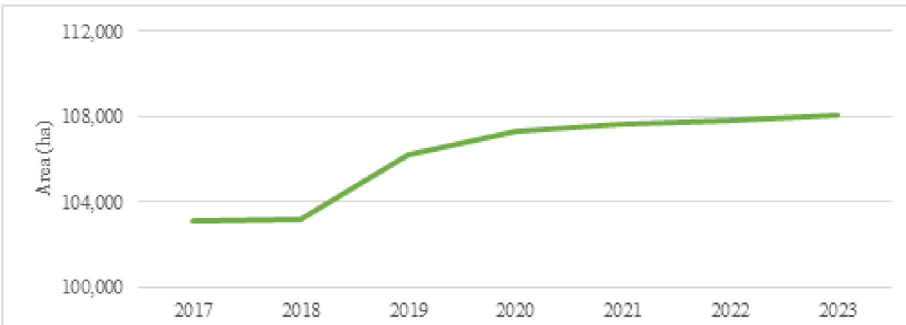


Figure 1: Trends in protection forest changes in Ha Tinh province from 2017 to 2023

Building on these efforts, Plan No. 71/KH-UBND dated March 13, 2018, issued by the Ha Tinh Provincial People's Committee, was implemented to fulfill Resolution No. 04-NQ/TU dated December 7, 2017, by the Provincial Party Committee on strengthening the management, protection, development, and effective exploitation of forest and forestry land resources until 2025 and beyond. The plan emphasizes that the Department of Agriculture and Rural Development is responsible for protecting and developing over 94,000 hectares of upstream protective forests in major river areas, such as Huong Son (Ngan Pho), Vu Quang and Duc Tho (Ngan Sau), Vu Quang (Ngan Trui), and Cam Xuyen and Thach Ha (Ke Go). This plan not only aims to protect the existing area of protective forests but also promotes the expansion of protective forests in key areas. Statistical analysis results (Table 2) show the impact of the province's sound management policies on the stable development of protective forest resources.

Table 2. Results of the protection forest trend analysis in Ha Tinh using the Mann-Kendall and Sen's slope methods

No.	Location	Mann-Kendall τ	p-value	Sen's slope
1	Cam Xuyen district	1.00	0.00	231.60
2	Can Loc district	0.20	0.72	21.63
3	Duc Tho district	-0.77	0.04	0.00
4	Huong Khe district	-0.28	0.44	-1.85

No.	Location	Mann-Kendall τ	p-value	Sen's slope
5	Huong Son district	0.73	0.06	183.98
6	Ky Anh district	0.87	0.02	223.44
7	Loc Ha district	-0.07	1.00	-0.03
8	Nghi Xuan district	0.28	0.44	0.00
9	Thach Ha district	0.73	0.06	53.08
10	Vu Quang district	0.93	0.01	7.34
11	Ha Tinh city	0.58	0.14	0.00
12	Hong Linh town	0.87	0.02	11.38
13	Ky Anh town	0.20	0.72	18.60

Specifically, the assessment results show that several districts in Ha Tinh province experienced a significant increase in protective forest area from 2017 to 2023, at a 95 % statistical significance level. Cam Xuyen and Ky Anh districts showed a notable average annual increase of 231.60 hectares and 223.44 hectares, respectively, indicating statistically significant growth with a p-value < 0.05. Similarly, Vu Quang district and Hong Linh town recorded average annual increases of 7.34 hectares and 11.38 hectares, respectively. In contrast, Duc Tho district was the only district that showed stable protective forest areas without statistically significant changes. This indicates that the protective forest development and protection measures have been effective in most districts, except Duc Tho. By 2023, protective forest areas had changed variably across regions. The group of regions with strong growth included Huong Son, with an increase of 1,830.70 hectares, and Cam Xuyen, with an increase of 664.67 hectares. The group with slight growth included Vu Quang, with an increase of 30.04 hectares, and Hong Linh, with an increase of 50.98 hectares. Duc Tho showed no change, maintaining its protective forest area (Figure 2).

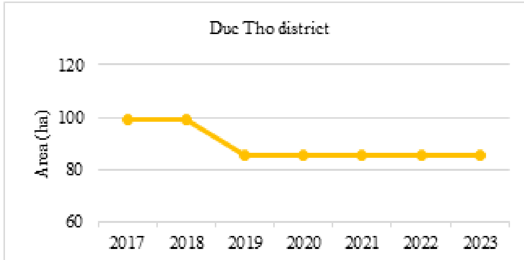


Figure 2: Trends in Protection Forest Changes (ha) in Selected Districts of Ha Tinh Province from 2017 to 2023

In addition to managing and protecting existing forests, the plan emphasizes collaboration and support for domestic and international research and development projects. The goal of these projects is to protect and improve forest quality by applying advanced techniques, technology, and new management methods. Additionally, the plan aims to leverage the ecosystem and forest landscape potential, linking it with historical sites, tourism, and implementing forest environmental service payment policies. Finally, it seeks to develop models of linkage, collaboration, and forest landscape leasing to maintain and enhance the value of protective forests.

3.2. Evaluation results of the trend in special-use forest area changes

The Mann-Kendall method was applied to analyze the trend in special-use forest areas from 2017 to 2023, but it did not show statistical significance (Table 3). The results indicate no statistically clear trend in the increase or decrease of forest area. It is noteworthy that Resolution 04/NQ-TU of the Ha Tinh Provincial Party Committee emphasizes the protection and sustainable development of existing special-use forests. The resolution specifically focuses on the strict management and protection of designated special-use forest areas to prevent disruption to the natural ecosystem structure and avert unforeseen environmental consequences.

Table 3. Analysis results of special-use forest trends in Ha Tinh using the Mann-Kendall and Sen's slope methods

No.	Location	Mann-Kendall τ	p-value	Sen's slope
1	Cam Xuyen district	-0.15	0.69	0.00
2	Huong Khe district	0.41	0.25	7.67
3	Huong Son district	-0.08	0.84	0.00
4	Ky Anh district	0.14	0.70	7.66
5	Vu Quang district	-0.08	0.84	0.00

To provide an overview and detailed insight into the current state of special-use forests, analytical charts are used to compare forest areas from 2017 to 2023, highlighting stability or minor fluctuations. This approach helps assess the effectiveness of forest protection policies.

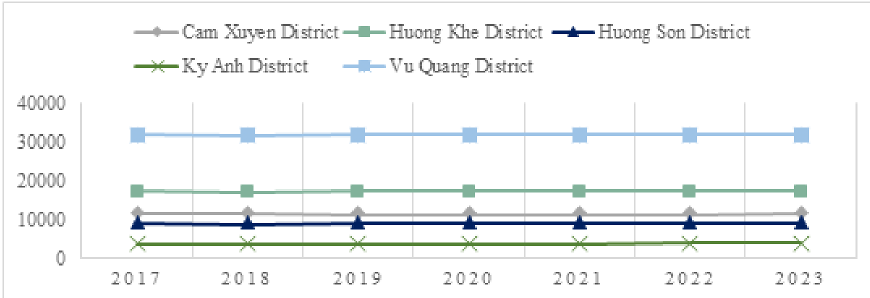


Figure 3: Trends in special-use forest changes (ha) in Ha Tinh province from 2017 to 2023

From 2017 to 2023, the total forest area in the province increased by 82.13 hectares, marking a positive step in forest resource management and protection. This growth was primarily contributed by the increase in forest area in Ky Anh district, with an increase of 38.36 hectares, and Cam Xuyen District, with an increase of 13.82 hectares. Other districts, such as Vu Quang and Huong Khe, maintained stability, which helped sustain the province's forest area. Overall, this increase reflects the efforts of these districts in protecting and sustainably developing special-use forests across the province.

3.3. Evaluation results of the trend in production forest area changes

Decision No. 886/QD-TTg dated June 16, 2017, by the Prime Minister, and Resolution No. 04-NQ/TU dated December 7, 2017, by Ha Tinh province laid a strong foundation for the development of production forests in Ha Tinh during the 2017 - 2023 period. These policies not only continued the objectives of forest protection and development but also expanded financial, technical, and seedling support. Specifically, from 2017 to 2023, the production forest area in the province increased by nearly 20,000 hectares (Figure 4), with Huong Khe, Ky Anh, and Vu Quang districts showing the highest growth.

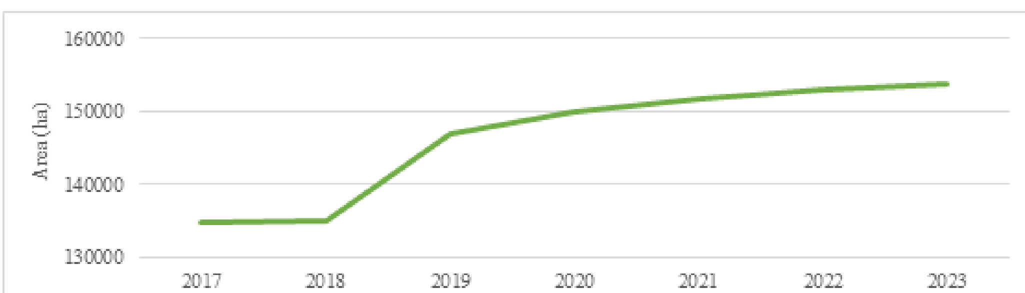


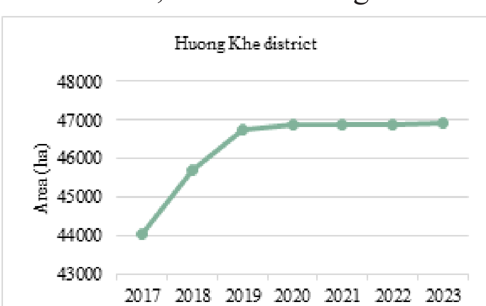
Figure 4: Trends in production forest changes (ha) in Ha Tinh province from 2017 to 2023

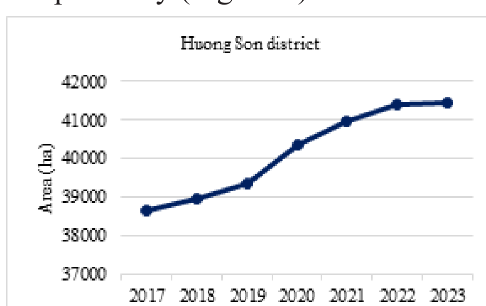
To maximize the sustainable economic potential of forest resources, Resolution No. 04-NQ/TU set a target to convert 6,300 hectares of forests and forestry land to develop key agricultural and forestry products, optimizing the production of forest areas. Ha Tinh province aims to increase the total value of goods and services from forestry land from VND 3,000 billion in 2016 to over VND 7,700 billion by 2025 and achieve an annual wood export value exceeding USD 90 million, promoting the development of the forestry processing industry. To achieve these objectives, Action Plan No. 71 from the Department of Agriculture and Rural Development reaffirms its commitment to developing timber resources and key agricultural products. The province also emphasizes controlling agricultural production on forestry land, ensuring compliance with planning and environmental protection. This facilitates residents and organizations to participate in afforestation, thereby not only expanding the production of forest areas but also contributing positively to sustainable economic development and forest resource protection in Ha Tinh. Statistical analysis results (Table 4) show uneven growth in production forest area across districts.

Table 4. Analysis results of production forest trends in Ha Tinh using the Mann-Kendall and Sen's slope methods

No.	Location	Mann-Kendall τ	p-value	Sen's slope
1	Cam Xuyen district	0.60	0.14	265.00
2	Can Loc district	-0.73	0.06	-20.37
3	Duc Tho district	0.87	0.02	21.98
4	Huong Khe district	1.00	0.00	41.88
5	Huong Son district	1.00	0.00	532.62
6	Ky Anh district	0.87	0.02	637.71
7	Loc Ha district	0.73	0.06	12.13
8	Nghi Xuan district	-1.00	0.00	-9.92
9	Thach Ha district	0.87	0.02	63.76
10	Vu Quang district	1.00	0.00	352.72
11	Ha Tinh city	-	-	-
12	Hong Linh town	-0.97	0.01	-5.34
13	Ky Anh town	0.73	0.06	146.32

Specifically, districts such as Duc Tho, Huong Khe, Huong Son, Ky Anh, Thach Ha, and Vu Quang all demonstrate a clear upward growth trend over time. Among them, Ky Anh district shows the highest increase, with an average annual growth of 637.71 hectares, corresponding to an average annual increase of 2.93 %. Similarly, Huong Son and Thach Ha districts also exhibit stable growth, with annual increases of 1.38 % and 2.12 %, respectively (Figure 5).





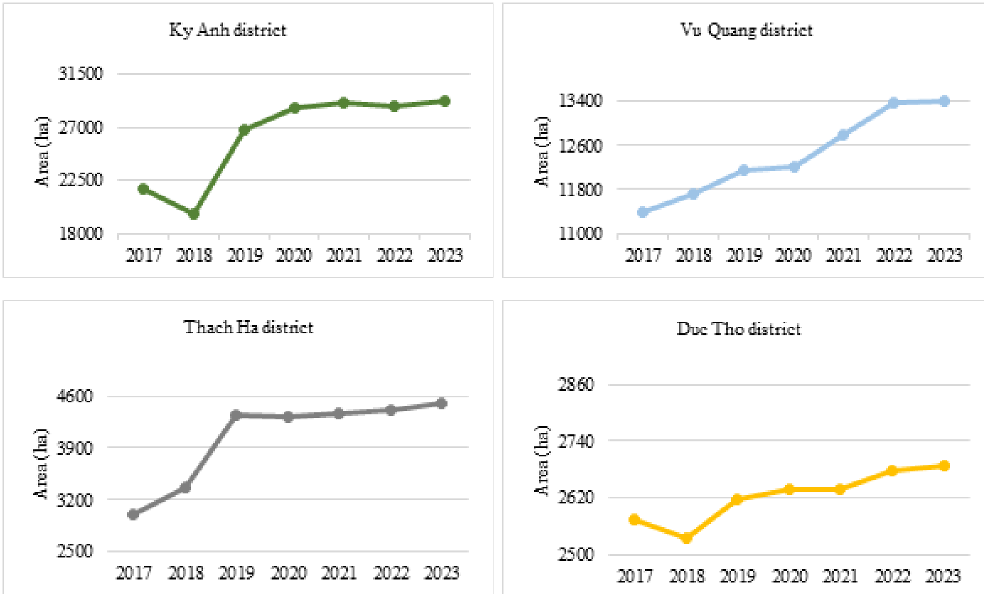


Figure 5: Trends in the increase of production forests (ha) in selected districts of Ha Tinh province from 2017 to 2023

Although the overall trend is growth, some districts still show a downward trend according to non-linear method results. The production forest area in both locations declined relatively from 2017 to 2023, with Nghi Xuan decreasing by an average of 9.92 hectares per year and Hong Linh decreasing by 5.34 hectares per year, as indicated by the non-linear method results (Figure 6).

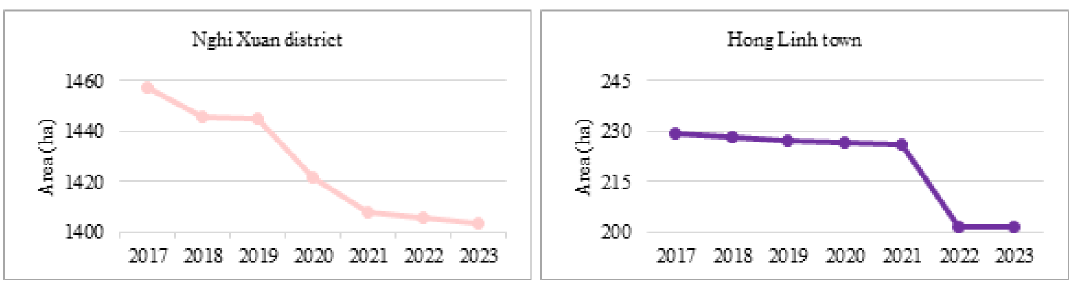


Figure 6: Trends in the decrease of production forests in Nghi Xuan district and Hong Linh town (2017 - 2023)

Specifically, the Nghi Xuan district, located in Northern Ha Tinh and bordering Nghe An, has a long coastline favorable for marine economy and tourism. Hong Linh town, centrally located in Ha Tinh, is near National Highway 1A and the North-South railway, providing advantages for industry and services. The forest cover rate in Nghi Xuan is 21.14 %, and in Hong Linh, it is 24.35 %, primarily consisting of protective forests. In Nghi Xuan, production forests occupy a small portion and do not play a significant role in the district's economic structure, with the agriculture-forestry-fishery sector accounting for only 18.56 %. In contrast, industry construction accounts for 47.67 %, and trade services make up 33.77 %, indicating a strong shift toward other economic sectors. In response, the district

People's Committee set a target to achieve the new rural development standards for Nghi Xuan by 2020 and aims to develop it as a northern economic-cultural center of Ha Tinh by 2025. Additionally, according to Resolution No. 01-NQ/TXHL dated September 24, 2016, Hong Linh town has oriented its development strongly toward industry, handicrafts, trade, and services, aiming to achieve Class III urban status before 2020. The emphasis on industrial and trade-service development, along with investment incentives for industrial clusters, clearly reflects Hong Linh's economic orientation. In this development structure, agriculture, particularly forestry, is neither emphasized nor plays a significant role. The shift in economic structure toward urbanization has significantly reduced the proportion of agriculture-forestry, which now accounts for less than 2 % of the total economic structure.

4. Conclusion

Based on the research results on the trends in forest area changes in Ha Tinh Province from 2017 to 2023, several important conclusions can be drawn. First, districts such as Ky Anh, Cam Xuyen, and Huong Khe have shown significant increases in the areas of protection and production of forests, reflecting the effectiveness of forest protection and development policies in these areas. Second, the area of special-use forests did not exhibit significant changes during the study period, aligning with strict protection policies aimed at maintaining the stability and sustainability of special-use forest ecosystems. On the other hand, districts like Nghi Xuan and Hong Linh Town, due to a strong shift in economic structure towards industrial and service sectors, have experienced a decline in production forest areas. This represents a challenge that needs to be carefully considered in the economic development planning process for these localities.

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RESEARCH ON 24-HOUR THUNDERSTORM FORECASTING IN SUMMER MONTHS FOR THE DIEN BIEN REGION USING THE STATISTICAL METHOD

Tran Chan Nam[1,*], Pham Van Quan[2], Pham Minh Tien[1]

[1]Hanoi University of Natural Resources and Environment, Vietnam

[2]Air Defense and Air Force Technical College, Vietnam

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Abstract

Thunderstorms are one of the most dangerous weather phenomena, making them a constant subject of study for meteorologists. Weather forecasting in general, and thunderstorm forecasting in particular, have seen significant advancements in Vietnam in recent years. Forecast products from numerical models, radar data, and upper-air observations have improved thunderstorm forecasts. However, in the context of global climate change, natural disasters such as storms, heavy rain, floods, and especially small-scale phenomena like thunderstorms, squalls, tornadoes, and waterspouts have become increasingly complex and unpredictable. Therefore, quantitative forecasting methods are urgently needed to help forecasters make objective assessments to support thunderstorm forecasting operations effectively. Studying thunderstorm forecasting in the summer months for the Dien Bien region using statistical methods will provide us with a more accurate approach to forecasting this phenomenon.

Keywords: Thunderstorms; Dien Bien; Statistical methods.

[*]**Corresponding author, Email:** tcnam@hunre.edu.vn

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1. Introduction

Weather forecasting in general and thunderstorm forecasting in Vietnam have seen significant developments in recent years. Thunderstorm forecast products from numerical models, radar data, and satellite data have improved the quality of thunderstorm forecasts. However, in the context of global climate change, natural disasters such as storms, heavy rainfall, and floods, especially small-scale phenomena like thunderstorms, squalls, and tornadoes, are becoming increasingly complex and unpredictable. Therefore, there is a strong need for quantitative forecasting methods to help forecasters make objective assessments to effectively serve thunderstorm forecasting efforts.

In the Northwest region in general and Dien Bien province in particular, weather forecasting still primarily relies on traditional synoptic methods, resulting in forecasts that are heavily qualitative forecasts. Since thunderstorms are one of the dangerous weather phenomena, they have always been the subject of study for many meteorologists. A notable example is Phillip E. Shafer, who used logistic regression techniques to develop a thunderstorm forecasting equation in Florida [1]. In this study, the authors utilized thunderstorm data from an observation network and selected parameters from morning-sounding data to develop same-day afternoon thunderstorm forecast equations at 11 locations on the Florida peninsula. The results demonstrated that the forecast equations exhibited relatively good forecasting skills and operational forecasting potential.

Schmeits M.J et al., [2] employed various statistical methods to analyze output data from a non-hydrostatic model from April to September in 2006 and 2007, observational data from the Lightning Location Information System (LLIS), and radar data (TEPHI). The primary objective of the study was to utilize output from numerical forecast models to predict thunderstorms using binary logistic regression. Four indices were used: The K index, the Showalter index, the SWEAT index, and the total precipitable water. Results indicated that the best models could achieve a Probability of Detection (POD) of approximately 0.9, a False Alarm Ratio (FAR) of around 0.4, and a Critical Success Index (CSI) of about 0.6.

2. Data and research methodology

2.1. Data

The study utilized data collected from 4 - 9 over seven years (2013 - 2019). Specifically:

- Data from 4 observation periods at 3 meteorological stations: Dien Bien, Muong Lay, and Tuan Giao, including thunderstorms, temperature, dew point, humidity, and atmospheric pressure.

- Upper-air data from Dien Bien station at 7:00 AM: Including meteorological elements: Temperature, humidity, pressure, geopotential height, wind, and atmospheric instability index.

From the extracted data, the study identified the following predictive factors.

- Predictive factors from surface observations (Table 1 - primary factors).

- From the set of primary factors, a set of secondary factors can be created. For example, the variation of these factors can be calculated within 24 hours, 18 hours, 12 hours, and 6 hours, as well as calculating the dew point deficit from the observed data (Table 2 - secondary factors).

Table 1. Primary forecasting factors from surface observation data (16 factors)

Obs	Factor and Symbol			
	Temperature	Dew point	Humidity	Atmospheric pressure
1	T1	Td1	U1	P1
7	T7	Td7	U7	P7
13	T13	Td13	U13	P13
19	T19	Td19	U19	P19

Table 2. Secondary forecasting factors from surface observation data (68 factors)

No.	Factor	Symbol	No.	Factor	Symbol
1	The 6-hour temperature variation starting from the observation at 1 o'clock	1BT6h	35	The 6-hour humidity variation starting from the observation at 13 o'clock	13BU6h
2	The 6-hour temperature variation starting from the observation at 7 o'clock	7BT6h	36	The 6-hour humidity variation starting from the observation at 19 o'clock	19BU6h
3	The 6-hour temperature variation starting from the observation at 13 o'clock	13BT6h	37	The 12-hour humidity variation starting from the observation at 1 o'clock	1BU12h
4	The 6-hour temperature variation starting from the observation at 19 o'clock	19BT6h	38	The 12-hour humidity variation starting from the observation at 7 o'clock	7BU12h
5	The 12-hour temperature variation starting from the observation at 1 o'clock	1BT12h	39	The 12-hour humidity variation starting from the observation at 13 o'clock	13BU12h
6	The 12-hour temperature variation starting from the observation at 7 o'clock	7BT12h	40	The 12-hour humidity variation starting from the observation at 19 o'clock	19BU12h
7	The 12-hour temperature variation starting from the observation at 13 o'clock	13BT12h	41	The 18-hour humidity variation starting from the observation at 1 o'clock	1BU18h
8	The 12-hour temperature variation starting from the observation at 19 o'clock	19BT12h	42	The 18-hour humidity variation starting from the observation at 7 o'clock	7BU18h
9	The 18-hour temperature variation starting from the observation at 1 o'clock	1BT18h	43	The 18-hour humidity variation starting from the observation at 13 o'clock	13BU18h
10	The 18-hour temperature variation starting from the observation at 7 o'clock	7BT18h	44	The 18-hour humidity variation starting from the observation at 19 o'clock	19BU18h
11	The 18-hour temperature variation starting from the observation at 13 o'clock	13BT18h	45	The 24-hour humidity variation starting from the observation at 1 o'clock	1BU24h
12	The 18-hour temperature variation starting from the observation at 19 o'clock	19BT18h	46	The 24-hour humidity variation starting from the observation at 7 o'clock	7BU24h
13	The 24-hour temperature variation starting from the observation at 1 o'clock	1BT24h	47	The 24-hour humidity variation starting from the observation at 13 o'clock	13BU24h
14	The 24-hour temperature variation starting from the observation at 7 o'clock	7BT24h	48	The 24-hour humidity variation starting from the observation at 19 o'clock	19BU24h
15	The 24-hour temperature variation starting from the observation at 13 o'clock	13BT24h	49	The 6-hour atmospheric pressure variation starting from the observation at 1 o'clock	1BP6h

No.	Factor	Symbol	No.	Factor	Symbol
16	The 24-hour temperature variation starting from the observation at 19 o'clock	19BT24h	50	The 6-hour atmospheric pressure variation starting from the observation at 7 o'clock	7BP6h
17	The 6-hour Dew point temperature variation starting from the observation at 1 o'clock	1BTd6h	51	The 6-hour atmospheric pressure variation starting from the observation at 13 o'clock	13BP6h
18	The 6-hour Dew point temperature variation starting from the observation at 7 o'clock	7BTd6h	52	The 6-hour atmospheric pressure variation starting from the observation at 19 o'clock	19BP6h
19	The 6-hour Dew point temperature variation starting from the observation at 13 o'clock	13BTd6h	53	The 12-hour atmospheric pressure variation starting from the observation at 1 o'clock	1BP12h
20	The 6-hour Dew point temperature variation starting from the observation at 19 o'clock	19BTd6h	54	The 12-hour atmospheric pressure variation starting from the observation at 7 o'clock	7BP12h
21	The 12-hour Dew point temperature variation starting from the observation at 1 o'clock	1BTd12h	55	The 12-hour atmospheric pressure variation starting from the observation at 13 o'clock	13BP12h
22	The 12-hour Dew point temperature variation starting from the observation at 7 o'clock	7BTd12h	56	The 12-hour atmospheric pressure variation starting from the observation at 19 o'clock	19BP12h
23	The 12-hour Dew point temperature variation starting from the observation at 13 o'clock	13BTd12h	57	The 18-hour atmospheric pressure variation starting from the observation at 1 o'clock	1BP18h
24	The 12-hour Dew point temperature variation starting from the observation at 19 o'clock	19BTd12h	58	The 18-hour atmospheric pressure variation starting from the observation at 7 o'clock	7BP18h
25	The 18-hour Dew point temperature variation starting from the observation at 1 o'clock	1BTd18h	59	The 18-hour atmospheric pressure variation starting from the observation at 13 o'clock	13BP18h
26	The 18-hour Dew point temperature variation starting from the observation at 7 o'clock	7BTd18h	60	The 18-hour atmospheric pressure variation starting from the observation at 19 o'clock	19BP18h
27	The 18-hour Dew point temperature variation starting from the observation at 13 o'clock	13BTd18h	61	The 24-hour atmospheric pressure variation starting from the observation at 1 o'clock	1BP24h
28	The 18-hour Dew point temperature variation starting from the observation at 19 o'clock	19BTd18h	62	The 24-hour atmospheric pressure variation starting from the observation at 7 o'clock	7BP24h
29	The 24-hour Dew point temperature variation starting from the observation at 1 o'clock	1BTd24h	63	The 24-hour atmospheric pressure variation starting from the observation at 13 o'clock	13BP24h
30	The 24-hour Dew point temperature variation starting from the observation at 7 o'clock	7BTd24h	64	The 24-hour atmospheric pressure variation starting from the observation at 19 o'clock	19BP24h

No.	Factor	Symbol	No.	Factor	Symbol
31	The 24-hour Dew point temperature variation starting from the observation at 13 o'clock	13BTd24h	65	Dew point deficit at 1 o'clock observation	HTd1h
32	The 24-hour Dew point temperature variation starting from the observation at 19 o'clock	19BTd24h	66	Dew point deficit at 7 o'clock observation	HTd7h
33	The 6-hour humidity variation starting from the observation at 1 o'clock	1BU6h	67	Dew point deficit at 13 o'clock observation	HTd13h
34	The 6-hour humidity variation starting from the observation at 1 o'clock	7BU6h	68	Dew point deficit at 19 o'clock observation	HTd19h

Predictive factors from high non-primary data in Table 3

Table 3. Primary forecast factors from the atmospheric instability index (7 factors)

Obs	Factor and Symbol						
	SI index	**LI index**	**SWEAT index**	**K index**	**T index**	**CAPE index**	**CIN index**
7	7SI	7LI	7SWEAT	7K	7TT	7CAPE	7CIN

Similarly, we can create a secondary factor set from Table 3 (Table 4 - secondary factors)

Table 4. Secondary predictive factors from data (7 factors)

No.	Factor	Symbol	No.	Factor	Symbol
1	24-hour SI variation at the 7 am observation	B7SI24h	5	24-hour TT variation at the 7 am observation	B7TT24h
2	24-hour LI variation at the 7 am observation	B7LI24h	6	24-hour CAPE variation at the 7 am observation	B7CAPE24h
3	24-hour SWEAT variation at the 7 am observation	B7SWEAT24h	7	24-hour CIN variation at the 7 am observation	B7CIN24h
4	24-hour K variation at the 7 am observation	B7K24h			

Thus, for Dien Bien, Muong Lay station, a total of 98 factors are involved in constructing the thunderstorm forecasting equation. For Tuan Giao station, due to the lack of pressure observation, factors related to atmospheric pressure are excluded from the study, resulting in a total of 78 factors involved in constructing the thunderstorm forecasting equation.

2.2. Methodology

2.2.1. Binary Logistic Regression

Binary logistic regression uses a binary dependent variable to estimate the probability of an event occurring given the information of independent variables [1].

For the forecasting problem of thunderstorm occurrence in this study, the event of having a thunderstorm is assigned a value of 1, and no thunderstorm is assigned a value of 0.

With binary logistic regression, the information we need to collect about the dependent variable is whether or not an event occurs. The dependent variable Y at this point has a value of 0 (none thunderstorm) and 1 (thunderstorm), and information about the independent variables X. From this binary dependent variable, a procedure is used to predict the probability of the event occurring according to the rule: If the predicted probability is greater than 0.5, the predicted result will be considered as "yes" the event occurs, otherwise, the predicted result will be "no" if the event occurs.

2.2.2. Forecast evaluation

For binary prediction problems such as thunderstorm forecasting, categorical statistics are commonly used to assess the frequency of occurrence of the event. Evaluation metrics are derived from a contingency table (Table 5).

Table 5. Contingency table for binary forecast

		Observation	
		Yes	**No**
Prediction	**Yes**	H	F
	No	M	CN

Or you can interpret the following letter in detail: (i) Hits (H) prediction + observation; (ii) Misses (M) = None prediction + Observation; (iii) False alarms (F) = Prediction + None observation: và (iv) Correct negatives (CN) = None prediction + None observation.

- Based on this frequency table and assuming there are N data records studied (H+M+F+CN=N), some evaluation indicators are set up to evaluate the forecasting skills of the forecasting models for the binary forecasting factor including the index

- PC/FC index (Percent Correct/ Fraction Correct): PC reflects the coincidence rate between the results of the model and the observation in both phases with and without the phenomenon. The value of the PC varies between 0 and 1.

- FBI index (BS or FBI- Bias score): is the score between the forecast zone and the observation zone. The FBI is the ratio between the number of times a phenomenon occurs according to the model and the observation. The FBI value varies between 0 and +∞

- POD index (Probability of Detection): is the probability of a phenomenon, equal to the ratio between the number of matches between the model and the observation when the phenomenon occurs (hits) and the total number of occurrences of the phenomenon in reality.

- FAR index (False Alarm Ratio): This is the ratio of false alarms to the total number of forecasts indicating no event.

- MR/POFD index (Miss Rate/ Probability of False Detection): This is the ratio of misses to the total number of times the event did not occur.

- TS/CSI index (Threat Score/ Critical Success Index): This metric reflects the relationship between the number of forecasts indicating the event occurred and the number of times the event occurred.

3. Results

3.1. Development of forecast equations

Based on the presented methods and collected data, the article conducts calculations and selects a 24-hour thunderstorm forecast equation for 3 stations in Dien Bien province, relying on model fit, testing coefficients, and overall model fit. The results of developing thunderstorm forecast equations for the three stations in the Dien Bien area in April, May, June, July, August, and September are presented in Tables 6, 7, and 8.

a) For Dien Bien station

Table 6. Thunderstorm forecast equations at Dien Bien station from April to September

Month	Forecast equations
4	$P_i=\frac{e^{z(-171.815 + 0.508*T7 + 0.163*Td19 + 0.165*P7 - 0.179*1BTd12h - 0.194*7SI)}}{1+e^{z(-171.815 + 0.508*T7 + 0.163*Td19 + 0.165*P7 - 0.179*1BTd12h - 0.194*7SI)}}$
5	$P_i=\frac{e^{z(-63.719 + 7.182*Td1 - 4.197*U1 - 0.987*7BTd6h + 0.012*7CIN + 0.383*7TT)}}{1+e^{z(-63.719 + 7.182*Td1 - 4.197*U1 - 0.987*7BTd6h + 0.012*7CIN + 0.383*7TT)}}$
6	$P_i=\frac{e^{z(-33 + 0.757*Td1 + 0.567*P7 - 0.55*P13 - 0.283*1BU24h - 0.012*7SWEAT)}}{1+e^{z(-33 + 0.757*Td1 + 0.567*P7 - 0.55*P13 - 0.283*1BU24h - 0.012*7SWEAT)}}$
7	$P_i=\frac{e^{z(-0.1 - 0.346*U7 + 0.319*U13 - 0.19*1BT6h - 0.736*1BT24h + 0.872*1BTd24h)}}{1+e^{z(-0.1 - 0.346*U7 + 0.319*U13 - 0.19*1BT6h - 0.736*1BT24h + 0.872*1BTd24h)}}$
8	$P_i=\frac{e^{z(-19.640 + 0.747*T1 + 0.538*7BT24h + 0.162*13BU18h + 0.752*7BP6h - 0.286*19BP12h)}}{1+e^{z(-19.640 + 0.747*T1 + 0.538*7BT24h + 0.162*13BU18h + 0.752*7BP6h - 0.286*19BP12h)}}$
9	$P_i=\frac{e^{z(-28.598 - 1.426*T1 + 1.345*Td1 + 1.103*U7 + 0.663*7LI + 0.223*B7TT24H)}}{1+e^{z(-28.598 - 1.426*T1 + 1.345*Td1 + 1.103*U7 + 0.663*7LI + 0.223*B7TT24H)}}$

From Table 6, it can be seen that the factors involved in the thunderstorm forecast equation for the Dien Bien area in April include T7, Td19, P7, 1BTd12h, and 7SI; in May: Td1, U1, 7BTd6h, 7CIN, and 7TT; in June: Td1, P7, P13, 1BU24h, and 7SWEAT; in July: U7, U13, 1BT6h, 1BT24h, and 1BTd24h; in August: T1, 7BT24h, 13BU18h, 7BP6h, and 19BP12h; And in September: T1, Td1, U7, 7LI, and B7TT24H. The factors involved in the forecast equation include both surface and upper-air meteorological factors.

b) For Muong Lay station

Table 7. Thunderstorm forecast equations at Muong Lay station from April to September

Month	Forecast equations
4	$P_i=\frac{e^{z(-15.028 + 0.329*Td7 - 0.431*1BT18h + 0.387*1BT24h + 0.228*1BP24h + 0.194*7TT)}}{1+e^{z(-15.028 + 0.329*Td7 - 0.431*1BT18h + 0.387*1BT24h + 0.228*1BP24h + 0.194*7TT)}}$
5	$P_i=\frac{e^{z(-3.266 - 0.879*Td7 + 0.383*U1 + 0.344*7K - 0.007*B7SWEAT24H - 0.086*B7TT24H)}}{1+e^{z(-3.266 - 0.879*Td7 + 0.383*U1 + 0.344*7K - 0.007*B7SWEAT24H - 0.086*B7TT24H)}}$
6	$Pi=\frac{e^{z(1.325 - 0.33*19BU16h - 0.732*HTd1h + 2.189*HTd7h - 0.014*7SWEAT + 0.001*7CAPE)}}{1+e^{z(1.325 - 0.33*19BU16h - 0.732*HTd1h + 2.189*HTd7h - 0.014*7SWEAT + 0.001*7CAPE)}}$
7	$P_i=\frac{e^{z(-0.897 + 0.651*1BT24h - 1.521*B7SI24H - 1.822*B7LI24H - 1.573*B7TT24H - 0.003*B7CAPE24H)}}{1+e^{z(-0.897 + 0.651*1BT24h - 1.521*B7SI24H - 1.822*B7LI24H - 1.573*B7TT24H - 0.003*B7CAPE24H)}}$
8	$P_i=\frac{e^{z(-97.175 + 10.722*Td1 + 0.28*U19 - 12.525*1BTd18h + 6.77*1BU18h - 5.659*U1)}}{1+e^{z(-97.175 + 10.722*Td1 + 0.28*U19 - 12.525*1BTd18h + 6.77*1BU18h - 5.659*U1)}}$
9	$P_i=\frac{e^{z(-368.192 + 1.392*T7 + 0.34*P1 - 16.509*1BTd6h + 9.797*1BU6h + 0.002*7CAPE)}}{1+e^{z(-368.192 + 1.392*T7 + 0.34*P1 - 16.509*1BTd6h + 9.797*1BU6h + 0.002*7CAPE)}}$

From Table 7, it can be seen that the factors involved in the thunderstorm forecast equation for the Muong Lay area in April include Td7, 1BT18h, 1BT24h, 1BP24h, and 7TT; In May: Td7, U1, 7K, B7SWEAT24H, and B7TT24H; In June: 19BU16h, HTd1h, HTd7h, 7SWEAT, and 7CAPE; In July: 1BT24h, B7SI24H, B7LI24H, B7TT24H, and B7CAPE24H; In August: Td1, U19, 1BTd18h, 1BU18h, and U1; And in September: T7, P1, 1BTd6h, 1BU6h, and 7CAPE. The factors involved in the forecast equation include both surface and upper-air observations.

c) For Tuan Giao station

Table 8. Presents the equations used to forecast thunderstorms at Tuan Giao station from April to September

Month	Forecast equations
4	$P_i=\frac{e^{z(-17.157 + 0.261*T1 + 0.184*Td19 + 3.089*1BTd18h - 2.321*1BU18h + 0.164*7TT)}}{1+e^{z(-17.157 + 0.261*T1 + 0.184*Td19 + 3.089*1BTd18h - 2.321*1BU18h + 0.164*7TT)}}$
5	$P_i=\frac{e^{z(-39.913 + 0.961*7SI + 0.276*7K + 0.680*7TT -0.182*B7K24H + 0.278*1BT18h)}}{1+e^{z(-39.913 + 0.961*7SI + 0.276*7K + 0.680*7TT -0.182*B7K24H + 0.278*1BT18h)}}$
6	$Pi=\frac{e^{z(-22.015 + 0.508*T13 - 0.348*13BT6h + 0.519*13BTd6h - 0.661*HTd1h + 0.243*7K)}}{1+e^{z(-22.015 + 0.508*T13 - 0.348*13BT6h + 0.519*13BTd6h - 0.661*HTd1h + 0.243*7K)}}$
7	$P_i=\frac{e^{z(-29.622 + 1.154*Td19 - 0.939*19BTd12h + 1.681*7SI - 1.805*7LI - 0.61*B7SI24H)}}{1+e^{z(-29.622 + 1.154*Td19 - 0.939*19BTd12h + 1.681*7SI - 1.805*7LI - 0.61*B7SI24H)}}$
8	$P_i=\frac{e^{z(20.397 + 0.219*T13 - 0.188*Td1 - 4.906*Td19 + 0.378*U13 + 2.797*U19)}}{1+e^{z(20.397 + 0.219*T13 - 0.188*Td1 - 4.906*Td19 + 0.378*U13 + 2.797*U19)}}$
9	$P_i=\frac{e^{z(-24.653 + 1.089*Td19 + 0.985*1BTd6h + 1.506*B7SI24H + 0.856*B7TT24H + 0.002*B7CAPE24H)}}{1+e^{z(-24.653 + 1.089*Td19 + 0.985*1BTd6h + 1.506*B7SI24H + 0.856*B7TT24H + 0.002*B7CAPE24H)}}$

Based on Table 8, the factors influencing the thunderstorm forecasting equation for the Tuan Giao area vary by month. For April, these factors include T1, Td19, 1BT18h, 1BU18h, and 7TT. In May, the influential factors are 7SI, 7K, 7TT, B7K24H, and 1BT18h. For June, the equation considers T13, 13BT6h, 13BTd6h, HTd1h, and 7K. July's equation involves Td19, 19BTd12h, 7SI, 7LI, and B7SI24H. August's equation uses T13, Td1, Td19, U13, and U19. Finally, September's equation incorporates Td19, 1BTd6h, B7SI24H, B7TT24H, and B7CAPE24H.

3.2. Forecast testing

The forecasting capability of these equations is evaluated through the presented evaluation criteria. The dependent data series used for evaluation was taken from 2013 to 2018, while the independent data series used for calculation was taken in 2019.

The evaluation of forecast quality for these equations is presented as follows:

a) Dien Bien station

The results of the forecast quality evaluation at Dien Bien station on the dependent data series are presented in Table 9.

Table 9. Thunderstorm forecast results on the data chain dependent on Dien Bien station

Station	Month	Frequency				Total	Evaluation criteria						
		H	F	M	CN		PC	% Prediction	FBI	POD	FAR	MR	TS
Dien Bien	4	41	39	15	46	141	0.62	62	1.43	0.73	0.49	0.46	0.43
	5	28	12	15	53	108	0.75	75	0.93	0.65	0.3	0.18	0.51
	6	4	2	39	99	144	0.72	72	0.14	0.09	0.33	0.02	0.09
	7	23	33	25	105	186	0.69	69	1.17	0.48	0.59	0.24	0.28
	8	28	19	37	102	186	0.7	70	0.72	0.44	0.40	0.16	0.33
	9	14	21	7	84	126	0.78	78	1.67	0.67	0.6	0.2	0.33

Based on Table 9, for Dien Bien station, the PC index of the forecast equations is relatively high, with values ranging from 0.62 to 0.78, and the highest PC value is for the forecast equation in September. This indicates that the coincidence rate between the model results and observations in both phases with and without the occurrence of the phenomenon from the constructed forecasts is relatively large.

The FBI index of the forecast equations in the Dien Bien area for the dependent data series in May, June, and August is less than 1, indicating that the equations produce many missed forecasts, especially for the forecast equation in June. Conversely, the forecast equations in April, July, and September are greater than 1, indicating that the equations produce many false alarms, especially the thunderstorm forecast equation for September. The forecast equations in May and July have FBI values very close to 1, meaning that the forecast regions of these models are relatively consistent with the observation regions.

The POD of the forecast equations in April, May, and September is relatively higher than the other months, with corresponding values of 0.73, 0.65, and 0.67. Conversely, the POD of the forecast equations in June, July, and August are relatively lower compared to the other months, indicating that for the calculation data series, the success rate of these equations is not high. However, it should also be noted that POD is only sensitive to undetected phenomena, not to false detections. Therefore, to comprehensively assess the equation quality, it is necessary to evaluate two indices: FAR and MR.

The FAR of the thunderstorm forecast equations in April, May, June, and August is relatively low, with the lowest being in May; The FAR value of the forecast equation in April is 0.49, indicating that the equation produces false alarms that are equivalent to cases where the occurrence of thunderstorms is correctly predicted (the number of false alarms is only slightly smaller than the number of correct forecasts). The thunderstorm forecast equations for July and September are greater than 0.5, indicating that these equations produce more false alarms than correct forecasts of thunderstorm occurrence.

The MR index of the forecast equations is quite small, ranging from 0.02 to 0.46, and it can be seen that the MR of the forecast equation in June is 0.02, which is very close to the optimal value, indicating that the impact of false alarms from this equation is almost zero for the calculation data series (in this case, it is necessary to pay attention to the F phase in the data table, the equation only gives 2 false alarms (forecast yes, observation no) out of a total of 144 forecasts), however, the miss rate of this equation is relatively high, leading to a low success score (TS) and detection probability.

The TS index values of the forecast equations in April and May are relatively higher than the other months. This indicates that, for the "occurrence of the phenomenon" phase, the forecast equation in April and May performs better than the equations in other months, and the best is the forecast equation in May. However, it should also be emphasized that for this index, the cases of "no occurrence of the phenomenon" have been ignored, and it only considers the ratio of correct forecasts to the total number of observations and forecasts with the occurrence of the phenomenon.

In summary, when comparing the calculated indices from the forecast equations for the dependent data series in the Dien Bien area, it can be seen that the thunderstorm forecast equations in the considered months can all forecast thunderstorms with a certain degree of accuracy. However, for a more objective evaluation, it is necessary to evaluate the equations with the independent data set in 2019 to draw the most objective conclusions. The evaluation results of the forecast models are presented in Table 10.

Table 10. Thunderstorm forecast results on the independent data series of Dien Bien station (in 2019)

Station	Month	Frequency				Total	Evaluation criteria						
		H	F	M	CN		PC	% Prediction	FBI	POD	FAR	MR	TS
Dien Bien	4	9	9	3	8	29	0.59	59	1.5	0.75	0.5	0.53	0.43
	5	2	9	4	16	31	0.58	58	1.83	0.33	0.82	0.36	0.13
	6	1	5	7	16	29	0.59	59	0.75	0.13	0.83	0.24	0.08
	7	4	5	5	17	31	0.68	68	1	0.44	0.56	0.23	0.29
	8	7	9	2	13	31	0.64	64	1.78	0.78	0.56	0.41	0.39
	9	2	4	3	19	28	0.75	75	1.2	0.4	0.67	0.17	0.22

As shown in Table 10, the calculated evaluation metrics based on the independent data series exhibit significant differences in the performance of thunderstorm forecast equations for the Dien Bien region across different months.

For the April thunderstorm forecast equation, the PC index is higher only compared to the May equation, but the POD index ranks second (only after the POD of the August equation) and the TS index is the highest among all equations. The FBI index being greater than 1 indicates a tendency of the equation to produce false alarms, however, the FAR of this equation is the lowest among other equations, suggesting that the rate of producing false alarms is the lowest. The MR of this equation is relatively high, reaching 0.53.

The May thunderstorm forecast equation has the lowest PC accuracy compared to the other equations, and the highest FBI, indicating that this equation tends to produce false alarms. This is also evident in the relatively high FAR of the equation, reaching 0.82, second only to the FAR of the June forecast equation.

The POD accuracy and success score (TS) of the equation are also not high. Therefore, this equation can be excluded from the selection process.

The FBI of the June thunderstorm forecast equation is less than 1, indicating that the equation tends to miss events. The POD and TS indices of the equation are the lowest compared to other equations. The highest FAR indicates that the rate of producing false alarms of this equation is much higher than the correct forecasts of thunderstorm occurrence. The MR of the equation is relatively low, but this value may be due to the tendency of the equation to miss events.

The July and September thunderstorm forecast equations have relatively high PC indices, and the FBI values of both equations are close to 1, indicating that the forecast area of the equation and the observed area are relatively consistent. The FAR and MR of these equations are also relatively low. However, the probability of detection and success score of these two equations are not significantly higher than other options. When considering the contingency table, it can be seen that the number of false alarms and missed events of these equations is much larger than the correct forecasts of thunderstorm occurrence.

Although the August thunderstorm forecast equation has an average PC accuracy compared to other equations, the probability of detection (POD) of this equation is the highest, and the TS is also relatively high, second only to the April thunderstorm forecast equation. The FAR of this equation is also relatively low. The MR of both the April and August forecast equations is quite high due to the relatively high rate of false alarms compared to the correct forecasts of no thunderstorm occurrence.

In conclusion, based on the above evaluation analysis, the April and August thunderstorm forecast equations can be selected for forecasting thunderstorms in the Dien Bien station area. For May and June, other forecasting methods should be used to obtain the most accurate forecast results. For the July and September forecast equations, further studies with longer data series are needed to accurately assess their forecasting capability.

b) Muong Lay station

The results of the evaluation of forecast quality at Muong Lay station on the dependent data series are presented in Table 11.

Table 11. Thunderstorm forecast results on the data chain dependent on Muong Lay station

Station	Month	Frequency				Total	Evaluation criteria						
		H	F	M	CN		PC	% Prediction	FBI	POD	FAR	MR	TS
Muong Lay	4	40	20	21	60	141	0.71	71	0.98	0.66	0.33	0.25	0.49
	5	50	21	19	50	140	0.71	71	1.03	0.72	0.3	0.3	0.56
	6	32	15	17	50	114	0.72	72	0.96	0.65	0.32	0.23	0.5
	7	9	3	19	56	87	0.75	75	0.43	0.32	0.25	0.05	0.29
	8	32	20	40	94	186	0.68	68	0.72	0.44	0.38	0.18	0.35
	9	14	15	6	102	137	0.85	85	1.45	0.7	0.52	0.13	0.4

From Table 11, we can see that the PC index of thunderstorm forecasting equations for the Muong Lay area is quite high, with the highest value for the September thunderstorm forecasting equation, reaching 0.85, very close to the optimal value. The lowest value is in August, with a PC index of 0.68.

The FBI index of thunderstorm forecasting equations in May and September is slightly greater than 1, indicating that these equations produce a relatively large number of false alarms. The forecasting equations for April, June, July, and August produce more misses, hence the FBI of these equations is less than 1; In particular, July has the lowest FBI as the equation yields the highest proportion of misses. In April, May, and June, the forecasting equations have FBI values very close to 1, indicating that the forecast regions of the equations are relatively consistent with the observed regions.

The POD of thunderstorm forecasting equations in May and September is higher than in other months due to a much larger number of correctly detected cases compared to the number of missed cases. Conversely, in July and August, the forecasting equations have lower POD values than other months, as these equations produce relatively many misses.

The FAR of the equations is relatively small, with the highest FAR being that of the forecasting equation in September and the lowest for the July thunderstorm forecasting equation. This indicates that for the dependent data series, the September thunderstorm forecasting equation produces relatively many false alarms, while the forecasting equations for other months produce fewer false alarms compared to the correct detections of thunderstorms.

The MR of the forecasting equations is also relatively small, ranging from about 0.05 to 0.3. The lowest MR is for the July thunderstorm forecasting equation, with an MR of 0.05, very close to the optimal value. However, it should also be noted that the low MR of the July thunderstorm forecasting equation is due to the equation's tendency to produce misses, hence the indices such as POD and TS are also very low.

The TS of the forecasting equations in April, May, and June is relatively higher than in other months. This indicates that the forecasting equations in April, May, and June have better forecasting skills compared to the forecasting equations in July, August, and September for the "occurrence" phase.

To assess more objectively the forecasting capability of the thunderstorm forecasting equations for Muong Lay station, testing on the independent data series in 2019 is needed, and the results are shown in Table 12.

The May thunderstorm forecasting equation has a moderate PC accuracy. The FBI index is very high, reaching 2.13, indicating that the equation mainly produces false alarms. Although the POD of the equation is relatively high, the FAR and MR of the equation are also very high, indicating that the high probability of detection of the equation is due to the equation's tendency to produce false alarms, which leads to a relatively low TS score and PC accuracy despite the high POD.

The June thunderstorm forecasting equation has a rather low PC accuracy. The POD and TS indices of this equation are also relatively low, and the FAR and MR indices are not superior to those of forecasting equations in other months. Therefore, this equation can be eliminated during the selection of a forecasting option for the Muong Lay area.

Table 12. Thunderstorm forecast results on the independent data series of Muong Lay station (in 2019)

Station	Month	Frequency				Total	Evaluation criteria						
		H	F	M	CN		PC	% Prediction	FBI	POD	FAR	MR	TS
Muong Lay	4	7	7	3	12	29	0.66	66	1.4	0.7	0.5	0.37	0.41
	5	5	12	3	10	30	0.5	50	2.13	0.63	0.71	0.55	0.25
	6	4	5	10	10	29	0.48	48	0.64	0.29	0.56	0.33	0.21
	7	1	4	8	17	30	0.6	60	0.56	0.11	0.8	0.19	0.08
	8	7	8	6	10	31	0.55	55	1.15	0.54	0.53	0.44	0.33
	9	1	4	5	19	29	0.69	69	0.83	0.17	0.8	0.17	0.1

The forecasting equations for July and September have relatively high PC indices, however, the probability of detection (POD) and success index (TS) of these two equations are quite low compared to other equations. The false alarm ratio (FAR) of these two equations is very high, reaching 0.8, indicating that these equations produce significantly more false alarms than correct forecasts. The miss ratio (MR) of these two equations is relatively low, suggesting that the equations perform better in predicting the absence of thunderstorms. However, the relatively good MR score might be due to the tendency of these equations to miss forecasts, as shown by the bias in the failure rate (FBI) which is less than 1, and the frequency table showing more missed forecasts than correct forecasts of thunderstorms.

The forecasting equations for April and August have moderate accuracy but their probability of detection (POD) and success index (TS) are relatively higher compared to other equations. Meanwhile, the false alarm ratio (FAR) and miss ratio (MR) of these two equations are also at a moderate level.

Therefore, the forecasting equation for April and August can be selected for thunderstorm forecasting in the Muong Lay station area. For other months, other approaches should be considered to make the most accurate forecasts

c) Tuan Giao station

The results of the assessment of forecast quality at Tuan Giao station on the dependent data series are presented in Table 13.

Table 13. Thunderstorm forecast results on the data chain dependent on Tuan Giao station

Station	Month	Frequency				Total	Evaluation criteria						
		H	F	M	CN		PC	% Prediction	FBI	POD	FAR	MR	TS
Tuan Giao	4	16	15	32	78	141	0.67	67	0.65	0.33	0.48	0.16	0.25
	5	25	16	29	70	140	0.68	68	0.76	0.46	0.39	0.19	0.36
	6	35	24	25	60	144	0.66	66	0.98	0.58	0.41	0.29	0.42
	7	17	6	8	56	87	0.84	84	0.92	0.68	0.26	0.1	0.55
	8	29	15	39	103	186	0.71	71	0.65	0.43	0.34	0.13	0.35
	9	20	37	2	67	126	0.69	69	2.59	0.91	0.65	0.36	0.34

The PC index of the forecast equations in the Tuan Giao area is also relatively high when calculated with the dependent dataset, with the lowest value of 0.66 for the June forecast equation and the highest of 0.84 for the July forecast equation. Also for the July forecast equation, the TS index is the highest compared to other forecast equations; The POD index is only smaller than the September thunderstorm forecast equation; The FAR and MR indices are the smallest compared to other equations and close to the optimal value. When considering the contingency table, it can be seen that the number of false alarms and missed forecasts is very small.

The FBI index of most forecast equations is less than 1, indicating that the equations tend to produce missed forecasts. However, it can also be seen that some forecast equations have FBI values very close to 1, such as the June and July thunderstorm forecast equations, indicating that the forecast area of these equations almost coincides with the observed area. The FBI index of the September thunderstorm forecast equation reaches 2.57, indicating that the equation produces a lot of false alarms.

As mentioned above, the probability of detection (POD) of the July and September forecast equations is relatively higher compared to other forecast equations. The reason is that these equations produce very few missed forecasts compared to correct forecasts of thunderstorm occurrence. However, for the September thunderstorm forecast equation, the low POD is due to the equation’s tendency to produce false alarms, leading to a very high POD but also the highest FAR and MR indices compared to other equations, and the TS index is relatively low.

The FAR and MR values of the forecast equations are also quite low, except for the September thunderstorm forecast equation. As mentioned above, the lowest MR and FAR are for the July thunderstorm forecast equation and the highest for the September thunderstorm forecast equation.

Similar to the Muong Lay and Dien Bien stations, after calculating the dependent data series at Tuan Giao station, it is necessary to calculate the independent data series in 2019 to examine the forecasting capability of the forecast equations, and then select the optimal forecast equation for this area.

Table 14. Thunderstorm forecast results on the independent data series of Tuan Giao station (in 2019)

Station	Month	Frequency				Total	Evaluation criteria						
		H	F	M	CN		PC	% Prediction	FBI	POD	FAR	MR	TS
Tuần Giáo	4	2	4	7	16	29	0.62	62	0.67	0.22	0.67	0.2	0.15
	5	3	3	7	17	30	0.67	67	0.6	0.3	0.5	0.15	0.23
	6	3	9	6	11	29	0.48	48	1.33	0.33	0.75	0.45	0.17
	7	1	5	6	18	30	0.63	63	0.86	0.14	0.83	0.22	0.08
	8	3	6	9	13	31	0.52	52	0.75	0.25	0.67	0.32	0.17
	9	1	5	2	20	28	0.75	75	2	0.33	0.83	0.2	0.13

Based on the calculations using the independent dataset, the thunderstorm forecast equation for May is the most suitable for selecting as the thunderstorm forecast scheme for the Tuan Giao area. This is because this equation has a relatively high accuracy, with a PC of 0.67, second only to the forecast equation for September (the September thunderstorm forecast equation has a fairly good skill in forecasting the phase where the phenomenon does not occur, but for the phase where the phenomenon occurs, this equation shows a relatively poor forecasting skill). The POD of this equation is at a moderate level; the TS is the largest compared to other forecast equations; and at the same time, the FAR and MR indices are the smallest. The other equations have a relatively low success score, the probability of detecting the phenomenon is not significantly higher, and the FAR index is too high, indicating that false alarms account for a much higher proportion than correct forecasts of the occurrence of thunderstorms. When examining the frequency table, it can be seen that the equations produce many more false alarms and missed forecasts than correct forecasts of the occurrence of thunderstorms. Therefore, this thesis selects the May forecast equation as the thunderstorm forecast scheme for the Tuan Giao station area.

3.3. Results of selection of thunderstorm forecasting equation for Dien Bien area

From the above results, the thesis selects two suitable equations to forecast thunderstorms for the Dien Bien area and its surroundings, including:

a) Dien Bien station

** April*

$$P_i = \frac{e^{z(-171.815 + 0.508*T7 + 0.163*Td19 + 0.165*P7 - 0.179*1BTd12h - 0.194*7SI)}}{1+e^{z(-171.815 + 0.508*T7 + 0.163*Td19 + 0.165*P7 - 0.179*1BTd12h - 0.194*7SI)}}$$

a2) August:

$$P_i = \frac{e^{z(-19.640 + 0.747*T1 + 0.538*7BT24h + 0.162*13BU18h + 0.752*7BP6h - 0.286*19BP12h)}}{1+e^{z(-19.640 + 0.747*T1 + 0.538*7BT24h + 0.162*13BU18h + 0.752*7BP6h - 0.286*19BP12h)}}$$

b) Muong Lay station

** April*

$$P_i = \frac{e^{z(-15.028 + 0.329*Td7 - 0.431*1BT18h + 0.387*1BT24h + 0.228*1BP24h + 0.194*7TT)}}{1+e^{z(-15.028 + 0.329*Td7 - 0.431*1BT18h + 0.387*1BT24h + 0.228*1BP24h + 0.194*7TT)}}$$

b2) August:

$$P_i = \frac{e^{z(-97.175 + 10.722*Td1 + 0.28*U19 - 12.525*1BTd18h + 6.77*1BU18h - 5.659*U1)}}{1+e^{z(-97.175 + 10.722*Td1 + 0.28*U19 - 12.525*1BTd18h + 6.77*1BU18h - 5.659*U1)}}$$

c) Tuan Giao station

** May*

$$P_i=\frac{e^{z(-39.913\,+\,0.961*7SI\,+\,0.276*7K\,+\,0.680*7TT\,-0.182*B7K24H\,+\,0.278*1BT18h)}}{1+e^{z(-39.913\,+\,0.961*7SI\,+\,0.276*7K\,+\,0.680*7TT\,-0.182*B7K24H\,+\,0.278*1BT18h)}}$$

4. Conclusion

From the research, it can be seen that the developed equations have an acceptable level of accuracy and can be applied in practical forecasting activities. Specifically, the thunderstorm forecasting equations for April and August in the Dien Bien area have accuracies of approximately 62 % and 70 %, respectively; The thunderstorm forecasting equations for April and August in the Muong Lay area have accuracies of approximately 71 % and 68 %, respectively; And the May thunderstorm forecasting equation in the Tuan Giao area has an accuracy of approximately 68 %. Most of the equations involve both observed factors and instability indices.

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METHOD OF COLLECTING DOMESTIC SOLID WASTE IN THE URBANIZATION PROCESS IN NAM TU LIEM DISTRICT, HANOI CITY

Le Ngoc Thuan*, Vu Thi Mai, Pham Thi Hong Phuong, Bui Duc Tan

Hanoi University of Natural Resources and Environment, Vietnam

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Abstract

Nam Tu Liem district is a newly established district of Hanoi city, the urbanization process is taking place rapidly, and urban facilities and infrastructure are being developed, on the other hand, it also creates pressure on the environment, increasing the amount of solid waste. This study aims to understand the changes in the management and collection methods of domestic solid waste in residential areas, during the urbanization process. The study uses the field survey method, collects information from residents and management agencies, conducts analysis, and evaluates the effectiveness of waste collection methods currently being implemented in this district. The study results calculated that there are about 330.34 tons of domestic solid waste generated every day, domestic solid waste is collected at fixed locations and times in residential areas. For old apartment buildings, waste is collected at no fixed time, by collection pipes along the height of the building and then led to the ground floor. The collection model has changed in new apartment buildings, solid waste is collected at the garbage collection room on each separate floor, then the garbage collectors will transport it to the garbage collection point. The study found that 70 % of respondents did not classify solid waste at source, 29 % did classify solid waste to extract some recyclable waste components to sell to scrap collectors, and a few people classified organic waste to compost for growing plants at home. Most people understood or had heard of waste classification at source, but only 34 % of respondents were willing to change their habits or spend money to classify waste at source.

Keywords: Nam Tu Liem; Domestic solid waste; Classifying solid waste at source.

***Tác giả liên hệ, Email:** lnthuan@hunre.edu.vn

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1. Introduction

Domestic solid waste (DSW - also known as household waste) is solid waste generated in people's daily activities. DSW is generated from households, public areas, commercial areas, construction areas, hospitals, waste treatment areas, etc. Of which, household waste accounts for the highest proportion. The quantity, composition, and quality of waste in each country and region are very different, depending on the level of economic, scientific, and technical development [1].

The process of rapid economic growth and urbanization with the number of manufacturing and business sectors, industrial parks, and urban services increasingly developing has created a migration flow from rural to urban areas. Economic development and urbanization on the one hand create millions of jobs for workers, on the other hand also create pressure on the environment, increasing the amount of waste generated, especially household waste. The amount of solid waste generated each day in urban areas depends mainly on the population size, urbanization, and industrialization rate of the city [2]. Meanwhile, the urban infrastructure system has not developed synchronously; the level and capacity of management do not meet the development needs of the urbanization process, causing many pressures on the environment and public health. In recent years, environmental pollution from solid waste, especially at landfills, has been a pressing issue for society [3]. DSW in urban areas accounts for more than 50 % of the total amount of solid waste in the country, increasing from 32,000 tons/day in 2014 to 35,624 tons/day in 2019, accounting for 55 % of the total amount of solid waste generated in the country. Hanoi is the city with the second highest amount of solid waste generation in the country, after Ho Chi Minh city [4]. In these two cities alone, the total amount of urban solid waste generated each day is up to 12,000 tons, accounting for 33.6 % of the total amount of urban solid waste generated nationwide. The amount of solid waste generated in the 5 largest cities, namely Hanoi, Ho Chi Minh city, Da Nang, Hai Phong, and Can Tho, accounts for about 40 % of the total amount of solid waste generated from all cities in the country [5, 8]. In urban areas, DWS generated from households is usually collected by units at certain times, manual vehicles are used by collectors to transport waste to collection points, from there they are loaded onto trucks to transport to treatment facilities or to transfer stations, and finally transferred to treatment facilities [4]. The collection rate of domestic solid waste in urban areas of localities ranges from 62 % to more than 90 % [3]. In concentrated apartment buildings, many places do not have the infrastructure to ensure the collection and classification of waste at source, leading to people not having waste classification activities [6]. The urbanization rate of the whole country has increased rapidly from 30.5 % in 2010 to about 40 % in 2020; Creating favorable conditions for socio-economic development, and promoting economic and labor restructuring towards industrialization and modernization, the urban area is expanded [7, 8]. This study may provide more useful information on how solid waste collection practices have changed during urbanization, and some recommendations to improve the efficiency of urban solid waste management.

2. Research methodology

Documents on the urbanization situation and the status of DSW collection and management in Nam Tu Liem district were collected from annual socio-economic development reports of specialized management agencies of the district and Hanoi city. Reference documents released from 2020 to 2022.

Supplementing the current status of solid waste generation through survey activities in 03 wards (My Dinh 1, Phuong Canh, Tay Mo), during the period from February to May 2023. Accordingly, 50 households in the area were randomly selected and then distributed collection bags, weighing the amount of solid waste (wet) generated each day by the family. Solid waste generated during the day was collected from 6.00 AM to 6.00 PM, while solid waste generated at night was calculated from 6.00 PM the previous day to 6.00 AM the following day, data were collected for 10 consecutive days.

Assessing people's awareness through random interviews with 100 people in households participating in the waste collection program of this study, interview information such as waste collection and classification activities, as well as people's willingness to implement waste classification regulations. Other interviews were also conducted with waste collection and transportation service companies, experienced experts, and district environmental management officers on waste management policies, describing the collection and transportation process of domestic solid waste, and the price of waste collection services for different waste generators. The experts made comments based on observations of urban practices in Hanoi.

3. Results and discussion

3.1. Current status of domestic solid waste generation in Nam Tu Liem district

According to statistics of the Hanoi Urban Environmental Company (URENCO) in 2021, on average 330.34 tons of DSW are generated in Nam Tu Liem district every day (Table 1). On weekdays, it ranges from 320 - 325 tons/day. Peak weekend volume can reach 340 - 350 tons/day. The amount of waste generated is about 45 - 50 tons during the daytime and at night about 280 - 290 tons. DSW is generated from households, shops, shopping malls, apartment buildings, and state and private organizations. Nam Tu Liem district is a new district established in 2013, from the old Tu Liem district, so the urbanization process is taking place rapidly, and many businesses have been established. Nam Tu Liem district also welcomes many new residents from many places to settle down, live, and work. The amount of household waste generated from households is greater in the evenings and weekends than during the day [2].

Table 1. Domestic solid waste generated in Nam Tu Liem district in 2021 [8]

No.	Wards	Average waste (tons/day)	Average waste (tons/year)
1	Trung Van	60,800	22.192,18
2	Me Tri	44,275	16.160,38
3	Phu Do	22,183	8.096,98
4	Tay Mo	37,639	13.738,42
5	Dai Mo	44,079	16.089,02
6	Xuan Phuong	24,725	9.024,63
7	Phuong Canh	26,013	9.494,75
8	My Dinh 1	39,870	14.552,73
9	My Dinh 2	46,356	16.920,12
10	Cau Dien	37,536	13.700,64
Total		**333,460**	**121,712,90**

A survey of 50 families with 193 people, for 10 consecutive days, in My

Dinh 1 ward (17 families), Phuong Canh (17 families), and Tay Mo (16 families) showed that on average each person generates 1.065 kg per day, with the most household waste generated on the two weekends, reflecting the living characteristics of urban residents.

The population of Nam Tu Liem district in 2020 was 290,052 people, an increase of 56,562 people compared to 2013, equivalent to 24.22 %. With the standard of domestic solid waste generation through survey research of 1,065 kg/person, the total amount of solid waste generated in the area is estimated at approximately 309 tons/day, this figure reflects a similar reflection to the statistical report on the volume of domestic solid waste published by the URENCO, which is from 320 to 325 tons/day.

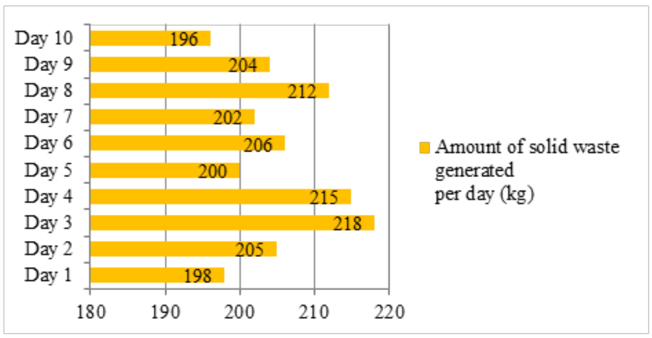


Figure 1: Daily domestic solid waste generation volume of the study area

3.2. Current status of solid waste collection management in Nam Tu Liem district

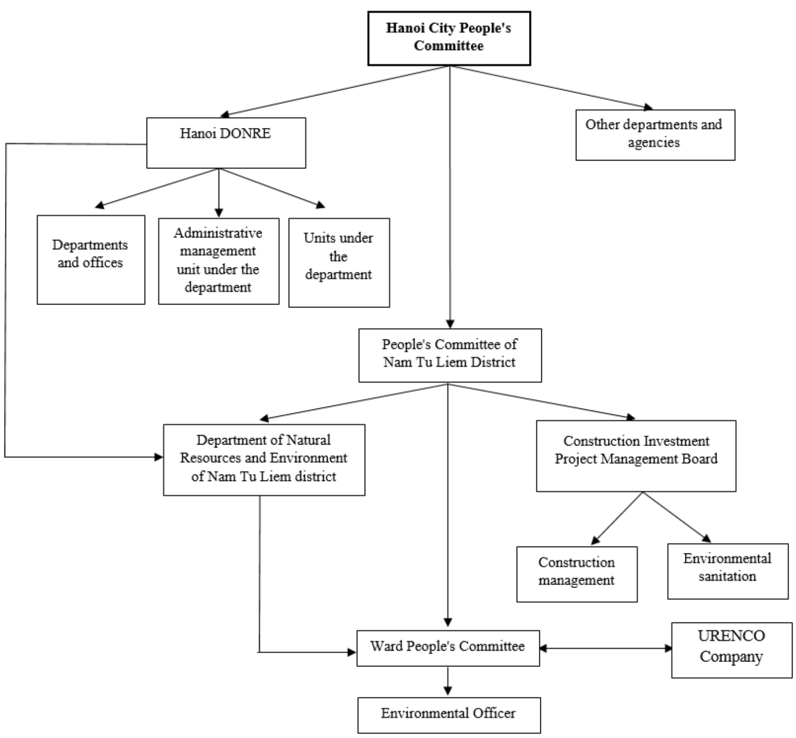


Figure 2: Organizational structure for domestic solid waste management in Nam Tu Liem district

Currently, environmental sanitation work, including DSW collection in the Nam Tu Liem district, is carried out by the URENCO. The solid waste collection and treatment model applied by the URENCO in the Nam Tu Liem district is still manual. Although there is some combination of machinery, it is still limited, the number of manual workers still accounts for the majority. Workers collecting in alleys and lanes mainly still use hand-pushed vehicles, which takes a lot of effort and time.

Currently, the management of domestic solid waste in Hanoi is related to several state management agencies. The Department of Natural Resources and Environment is responsible for managing and advising the City People's Committee to resolve issues related to solid waste in the city; the Department of Construction is responsible for appraising the design of waste treatment facilities; the Department of Finance is responsible for managing the city's budget for collecting, transporting and treating domestic solid waste. The Department of Natural Resources and Environment of Nam Tu Liem district is a specialized agency directly responsible for managing the environmental sector in the district, including the management of domestic solid waste. The district Construction Investment Project Management Board is responsible for managing the collection, transportation, and treatment. URENCO company is the unit that collects and transports domestic waste in the Nam Tu Liem district. Environmental officers of wards are responsible for advising the Ward People's Committee and directly managing the state on environmental issues in the ward under their management.

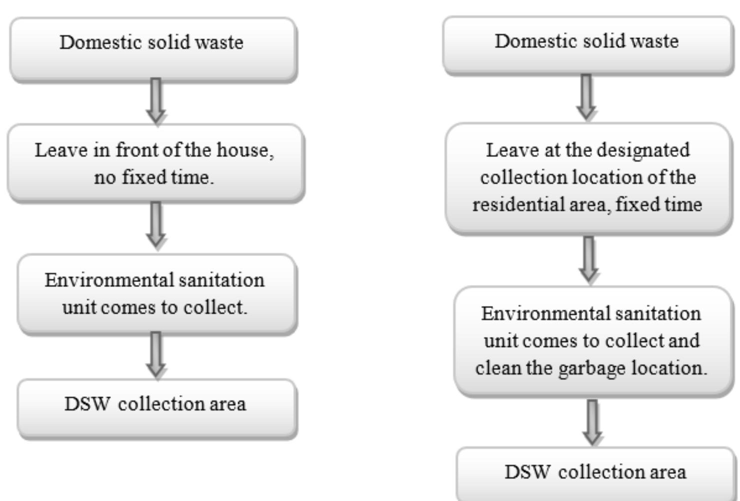
On average, each day the collection unit will collect domestic solid waste with an average transport volume of 330 tons divided into 2 shifts: Day and night shifts. The day shift uses vehicles with a load capacity of 6.5 tons and 10.1 tons with a collection volume of about 46.2 tons. The night shift uses vehicles with a load capacity of 6.5 tons, 9.57 tons, 11 tons, 10.3 tons, and 10.1 tons with a collection volume of about 284.14 tons. In Nam Tu Liem district, average solid waste fees are collected according to customer groups including Individuals, production and business households, administrative agencies and public offices, and other organizations (Table 2). However, the funds collected from households and production and business establishments for domestic solid waste only cover part of the collection or transportation costs, the remaining part of the transportation and treatment costs is paid by the local budget. Funding for domestic solid waste management is taken from the local budget, and allocated according to the proposal of the Department of Finance to the People's Committee and People's Council of Hanoi for annual approval.

Table 2. Environmental sanitation service price for household waste in Nam Tu Liem district

No.	Individual/Organization	Unit	Price
1	**Individual**	VND/person/month	6,000
2	**Production and business households**		
2.1	Households doing business in hotels, restaurants, trading, food and beverage items, construction materials (bricks, sand, stone, gravel,...), vegetables, fruits, fresh food, flower business, village craft		
a	Waste volume ≤ 1 m^3/month	VND/household/month	130,000
b	Waste volume > 1 m^3/month	VND/m^3 VND/ton	208,000 500,000
2.2	Small business, other trade	VND/household/month VND/household/day	50,000 3,000
3	**Organizations (administrative agencies, schools, hospitals...)**		
3.1	Waste volume ≤ 1 m^3/ month	VND/unit/month	130,000
3.2	Waste volume > 1 m^3/ month	VND/m^3 VND/ton	208,000 500,000
4	**Other organizations and establishments**	VND/m^3 VND/ton	208,000 500,000

3.3. Methods of collecting and transporting domestic solid waste in households and residential areas in Nam Tu Liem district

The urbanization process of Nam Tu Liem district has led to significant changes in the living community and residential infrastructure. Old residential areas are characterized by unsynchronized infrastructure, concentrated low-rise housing, narrow roads, and alleys, typically in Me Tri, Phu Do, Tay Mo, and Dai Mo wards. In recent years, many concentrated residential areas and newly built apartments have had more complete infrastructure. The collection and transportation of solid waste from residential areas have also changed a lot.



a. SW collection at households before 2010

b. DSW collection at households in 2021

Figure 3: Domestic solid waste flow chart in residential areas

Before 2010, the waste collection model in Nam Tu Liem district was manual and had no clear regulations. Waste was left in front of the house by people and there was no specific time (Fig. 3). There was always waste scattered on the streets, leading to a lack of urban aesthetics and environmental sanitation, and bad odors appeared in places where people gathered waste. Since 2020, solid waste collection in residential areas has been reorganized and become more reasonable, with regulations on waste locations and the time when households can bring waste to the collection location. At a specific time of the day (depending on the regulations of each residential area), waste is left in designated locations, and the environmental unit is responsible for collecting and cleaning the waste location. The new form of solid waste collection aims to ensure urban aesthetics while keeping the urban area clean and making people more aware of solid waste collection.

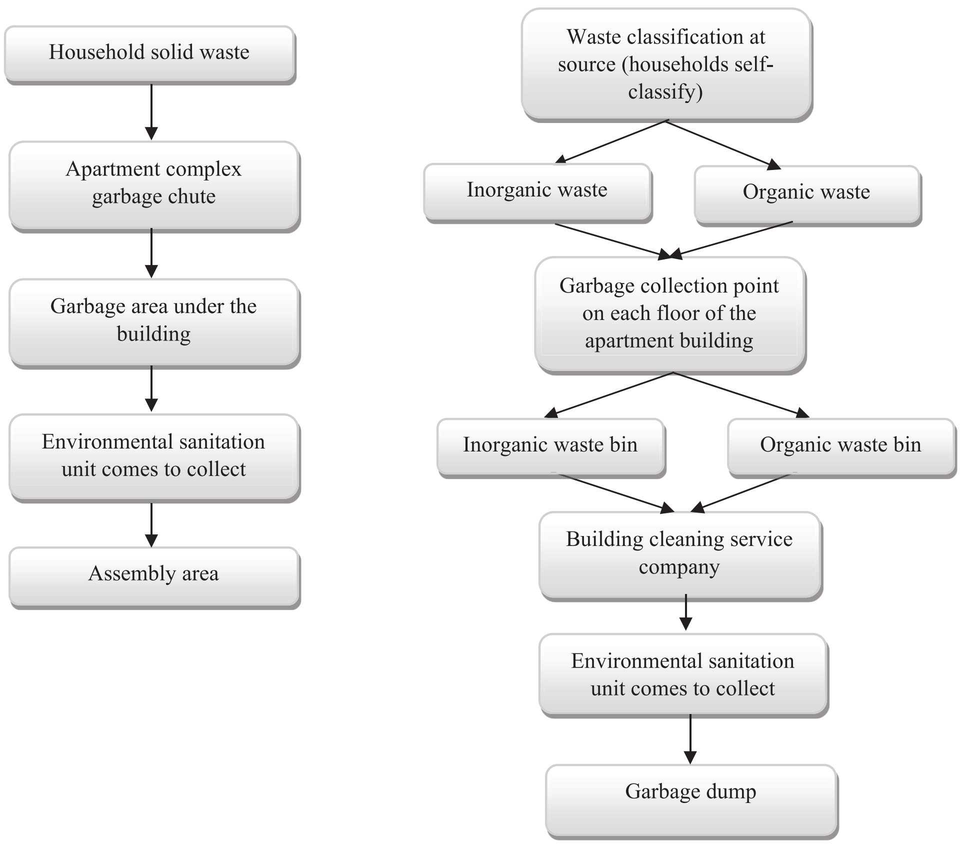


Figure 4: Domestic solid waste flow chart at concentrated apartment buildings in Nam Tu Liem district

Garbage collection in old apartment buildings (used for more than 20 years) in Nam Tu Liem district often uses garbage pipes, a garbage pipe system from the ground floor to the top floor of the building. Residents do not set a time to put garbage into the garbage pipe. Garbage will follow the pipe down to the first floor of the building. At the foot of the building, there will be a garbage collection room with 1 or 2 large garbage bins. The limitation of this collection model is that it can easily cause fire explosions or bad smell, garbage bags in the process of free falling can tear, and burst, causing garbage to fall out, and collecting and processing is very time-consuming and laborious. In new apartment buildings, there has been a change in the garbage collection model, typically at Vinhome Smart City apartments, each floor will have its garbage room, equipped with 2-layer doors to prevent odors from spreading outside, the garbage room will have 2 garbage bins to classify organic and inorganic garbage. At a certain time of the day, the sanitation unit of the apartment management board will be responsible for collecting the garbage from each floor and bringing it to the garbage collection location of each building. Next, the unit responsible for garbage collection in the district will transport the garbage to the collection point. This collection model can both classify garbage at the source and clean the garbage collection area. Although each building's garbage collection room has inorganic and organic garbage bins, households have not yet classified their garbage. This is only an encouraged action, not a mandatory one. Nam Tu Liem district has not yet had a successful pilot model of waste classification at the source.

3.4. Assessment of people's awareness in Nam Tu Liem district on current domestic solid waste management

The interview results show that 91 % of people surveyed feel satisfied with the current solid waste collection model, 3 % of people feel dissatisfied with the reason for the delay of the collection unit in the area, and 6 % of people feel acceptable.

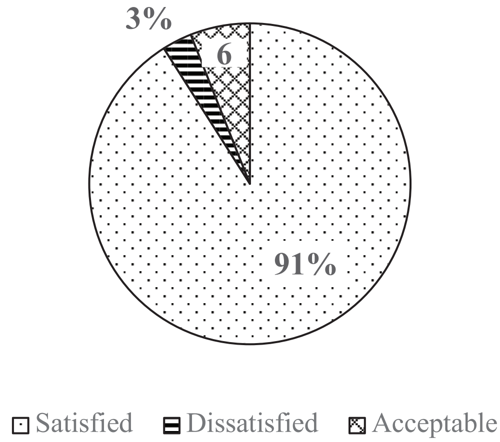


Figure 5: Evaluation of domestic solid waste collection activities

According to the interview results, 83 % of the interviewees know how to classify solid waste at source, but 70 % of the respondents do not classify it at source, 29 % of people classify solid waste to get recyclable materials such as paper, plastic, metal, beer cans,…to sell to scrap collectors, only 1 % classify at source to compost organic waste for home plants. 96 % of the respondents know the phrases "Sort solid waste at source", and "Waste classification" through the media and social networks, but only 34 % are willing to change their habits or spend money to classify waste at source

4. Conclusion

The results of the research and field survey show that the model of collecting and transporting solid waste in the Nam Tu Liem district has changed during the urbanization process. The total amount of solid waste generated in Nam Tu Liem district is estimated at an average of 333.46 tons/day. The collected solid waste reached 100 % in 2021, URENCO is responsible for maintaining environmental sanitation in the entire district, but there is no waste sorting at the source. In residential areas, solid waste is collected at fixed locations and times. For old apartment buildings, waste is collected by collection pipes along the height of the building and then led to the ground floor. The collection model has changed in new apartment buildings, solid waste is collected at the garbage collection room on each separate floor, then the garbage collectors will transport it to the garbage collection point. The study found that 70 % of respondents do not separate their waste at source, 29 % do separate their waste to extract some recyclable waste components to sell to scrap collectors, and a small number of people separate organic waste to compost for growing plants at home. The majority of people understand or have heard of source separation, but only 34 % of respondents are willing to change their habits or spend money to separate waste at source.

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RESEARCH ON FACTORS AFFECTING LAND PRICES IN THANH MIEN DISTRICT, HAI DUONG PROVINCE

Nguyen Thi Hang*, Nguyen Thanh Ton
Hanoi University of Natural Resources and Environment, Vietnam

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Abstract

The study was conducted based on the application of exploratory factor analysis (EFA) and multi-linear regression models to analyze factors affecting land prices in Thanh Mien district, Hai Duong province. The authors used a 5-level Likert scale to design a questionnaire to assess the level of influence of factors on land prices in Thanh Mien district. Surveying 150 households with land use rights transfer transactions and officials related to land valuation with the questionnaire. SPSS software is used to process data, and the results after testing the scale with Cronbach's Alpha coefficient and EFA exploratory factor analysis identified 20 factors belonging to 5 groups of factors affecting land prices in the district. The results of the linear regression model analysis show that 74.283 % of the fluctuations in residential land prices are explained by factors affecting land prices, of which the group of factors with the greatest influence is the group of location factors (27.6 %), followed by the group of economic factors (26.93 %), followed by the group of social factors (20.76 %), the group of other factors (14.88 %) and finally the group of factors with the least influence is the group of policy factors (9.81 %).

Keywords: Residential land prices; Influencing factors; Linear regression model; Thanh Mien district.

***Corresponding author, Email:** nthang.qldd@hunre.edu.vn

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1. Introduction

Land price is the connecting bridge in the relationship between land - market - state management. The land valuation must be consistent with the actual land use right transfer price on the market under normal conditions. When there is a difference compared to the actual land use right transfer price on the market, it must be adjusted accordingly [1]. Good land price management will be an effective tool in land finance policy, ensuring a stable long-term source of revenue for the State budget, the healthy development of the real estate market, and overcoming weaknesses in land management and use, ensuring economical and effective land use.

However, land prices are affected by many different factors. The Land Law 2013, Decree No. 44/2014/ND-CP regulating land prices, and Circular No.36/2014/TT-BTNMT have detailed regulations on land valuation methods, construction and adjustment of land price tables, specific land valuation, and land price consultation. However, in reality, there is always a difference between land prices regulated by the State and land prices traded on the market because land prices in general and residential land prices in particular are affected by many factors.

Thanh Mien district, Hai Duong province has made great strides in economic, cultural, and social development in recent years. Many projects have been implemented and completed, such as the Co Island expansion project; investment projects to build residential areas, road expansion projects, etc., leading to increasingly vibrant land-related activities in the locality, and land prices in the district always tend to increase. Although land valuation has been carried out under state regulations, there are still limitations that affect land recovery and make it difficult to determine land use fees and land rents. Therefore, understanding the factors affecting land prices helps the government and investors make reasonable decisions, promoting economic and infrastructure development. At the same time, this study also helps land management agencies have an overview of the real estate market, thereby being able to develop appropriate policies for effective land management and use.

2. Research methods

2.1. Method of selecting research locations

Based on the land price list regulated by the People's Committee of Hai Duong province (2020) [10] and the actual conditions of Thanh Mien district, the authors divided the research location into 3 areas and selected routes that reflect the city's socio-economic development and the difference in land prices as follows:

- Area 1 includes 3 routes: the section from Neo bridge flower garden and the section from Neo Intersection to Nguyen Luong Bang street flower garden, Thanh Mien town, belonging to group A - Type I street; the section from the turn to Doan Tung commune People's Committee to the 3-way turn to Nguyen Luong Bang memorial house. This is an area of great importance in connecting different areas and has a large traffic volume as well as a highly regulated price.

- Area 2 includes 4 routes: Tue Tinh street, Thanh Mien town; Chu Van An street, Thanh Mien town; Residential area of Chuong, Lam Son commune, along Provincial Road 392; Land along National Highway 38B, Thanh Mien town. Area 2 is the area that plays a role in connecting residential areas, with main traffic routes, and has a regulated price at an average level.

- Area 3 includes 3 routes: The section through Thanh Giang, Tu Cuong, Ngu Hung, and Tien Phong communes - land along Provincial Road 392B; Dang Tu Te street, Thanh Mien town; The remaining streets within Thanh Mien Town. Area 3 is the area that plays an important role in connecting residential areas and supporting internal trade and has a regulated price at a low level (Table 1).

2.2. Method of collecting secondary data

The authors collected data on socio-economic development and the transfer of land use rights from 2021 to 2023, at the Department of Natural Resources and Environment and the Registration Office for Land use Rights of Thanh Mien district.

2.3. Method of collecting primary data

The research team conducted a survey of 20 officials working in land management in Thanh Mien district, Hai Duong province on factors affecting land prices regulated by the state and land prices in the market in 3 years 2021, 2022, and 2023. The results identified 5 groups of factors representing 21 independent variables affecting land prices to be included in the research model (Table 2).

The authors collected primary data from a survey of 150 households and individuals who transferred land use rights at the study sites. The sample size was determined based on the sampling method of Hair, Anderson, Tatham & Black (1998) [3]. Accordingly, the minimum sample size is 5 times the total number of observed variables:

$$n = 5 \times m$$

in which: n: Number of samples to be investigated; m: Number of observed variables understood as a measurement question in the survey [3].

In this study, it is expected that there will be 21 influencing factors, so the minimum sample size to be investigated is greater than or equal to $21 \times 5 = 105$. To ensure the requirements, the number of samples selected for investigation in this study is 150, the sampling method is random.

The authors use a 5-level Likert scale to assess the level of influence of the factors [7]: (1) No influence; (2) Little influence; (3) Normal; (4) Influence; (5) Very influential.

2.4. Exploratory factor analysis method

The collected data were entered into SPSS software for exploratory factor analysis. The data processing and analysis process includes 2 main steps:

Step 1: Verify the scale using Cronbach's Alpha index.

In the study, the measurement of factors is done using many observation questions. Therefore, when creating the questionnaire, the observed variables are sub-variables of a created factor. To assess the suitability of the sub-variables with the parent factor, the study conducted a scale verification using Cronbach's Alpha index and the total item correlation coefficient (Corrected Item - Total Correlation). The data ensures reliability when Cronbach's Alpha coefficient is in the range (0.6 - 0.95), and the total item correlation coefficient > 0.3 [3].

Step 2: Exploratory Factor Analysis (EFA)

The main goal of EFA is to describe the relationship between a set of observable variables k (smaller number) and unobservable variables. Factor analysis works on the principle of measurability and reduction of variables with common variance, unobservable. Variables are only accepted when the appropriate coefficient KMO (Kaiser - Meyer - OlKIN) is in the range (0.5 - 1) and the loading weights > 0.35 [5] or the distance between 2 loading weights (Factor Loading) of the same variable in 2 different factors > 0.3 [3], if the loading weight > 0.3 then the sample size must be at least 350, if the sample size is about 100 then the loading weight should be > 0.5 and if the sample size is about 50 then the loading weight must be > 0.75. For this study, the loading weight was chosen to be > 0.5 because the number of samples investigated was 150. In addition, the scale was only accepted when the total variance explained (Total Variance Explained) > 50 %; Bartlett's coefficient with a significance level of sig < 0.05 to ensure that the factors are correlated with each other; Eigenvalue coefficient has a value ≥ 1 to ensure that the factor groups are different.

2.5. Regression analysis

The authors use a multiple regression model in the form $Yi = \beta o + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \ldots + \beta nXn + e$ to determine the level of influence on land prices of the factors. In which:

Yi is the dependent variable representing the price of the land plot;

X1, X2... Xn are independent variables representing the factors affecting land prices;

βo is a constant, the value of Y when all values of X are 0;

β1, β2... βn are regression coefficients;

e is the standard error.

3. Research results

3.1. Land prices regulated in Thanh Mien district

a. Urban residential land

Location 1: Land located next to roads and streets (frontage);

Location 2: Land located next to alleys of roads and streets, with an alley cross-section Bn ≥ 3 m and an alley depth calculated from the construction boundary close to the edge of the main road sidewalk to the beginning of the land plot < 200 m;

Location 3: Land located next to alleys (sidewalks) with an alley cross-section 2 m ≤ Bn < 3 m and an alley depth calculated from the beginning of the alley to the beginning of the land plot < 100 m or located next to alleys with an alley cross-section Bn ≥ 3 m and an alley depth calculated from the construction boundary close to the edge of the main road sidewalk to the beginning of the land plot ≥ 200 m;

Location 4: Land with remaining location, with less favorable conditions for production, business, and living.

b. Rural residential land

- Land on the outskirts of urban areas, along main traffic routes (national highways, provincial roads, district roads), traffic hubs, commercial and tourist areas and residential areas:

+ *Location 1:* Land adjacent to main traffic routes, commercial and tourist areas, and residential areas, with favorable conditions and the highest land price;

+ *Location 2:* Land adjacent to roads and alleys leading to main traffic routes, with alley cross-section Bn ≥ 3 m and alley depth calculated from the construction boundary to the beginning of the land plot D < 200 m;

+ *Location 3:* Land adjacent to main roads and alleys leading to main traffic routes, with alley cross-section Bn ≥ 3 m and alley depth calculated from the construction boundary to the beginning of the land plot 200 m ≤ D < 400 m; Adjacent to alleys with a cross-section of 2 m ≤ Bn < 3 m and an alley depth calculated from the construction boundary of the main traffic road to the beginning of the plot of land D < 200 m;

+ *Location 4:* Land adjacent to main alleys leading to main traffic roads with a cross-section of Bn ≥ 3 m and an alley depth calculated from the construction boundary to the beginning of the plot of land 400 m ≤ D < 600 m; Adjacent to alleys with a cross-section of 2 m ≤ Bn < 3 m and an alley depth calculated from the construction boundary of the main traffic road to the beginning of the plot of land 200 m ≤ D < 400 m;

+ *Location 5:* Land adjacent to main alleys leading to main traffic roads with a cross-section of Bn ≥ 3 m and an alley depth calculated from the construction boundary to the beginning of the plot of land 600 m ≤ D < 800 m; Adjacent to alleys with an alley cross-section of 2 m ≤ Bn < 3 m and an alley depth calculated from the main road construction boundary to the beginning of the plot of land of 400 m ≤ D < 600 m;

+ *Location 6:* Land located adjacent to main alleys leading to main roads with an alley cross-section of Bn ≥ 3 m and an alley depth calculated from the construction boundary to the beginning of the plot of land of 800 m ≤ D < 1,000 m; Adjacent to alleys with an alley cross-section of 2 m ≤ Bn < 3 m and an alley depth calculated from the main road construction boundary to the beginning of the plot of land of 600 m ≤ D < 800 m; Land at the next location of the plot of land has a depth greater than 100 m;

- Land in the remaining locations in rural areas

+ *Location 1:* Land located in the center of the commune, near schools, markets, and medical stations, adjacent to main traffic routes or traffic hubs of the commune, with favorable conditions and the highest land price;

+ *Location 2:* Land located adjacent to main traffic routes, inter-commune roads with favorable conditions and lower land prices than location 1;

+ *Location 3:* Land located adjacent to inter-village roads, with favorable conditions and lower land prices than location 2;

+ *Location 4:* Land located adjacent to alleys leading to main traffic routes, district roads, inter-commune roads, and land located along other roads of the commune, with favorable conditions and lower land prices than location 3;

+ *Location 5:* Land in the remaining locations, with the lowest land prices;

+ In case the land location has just been determined according to the suburban area, along the main traffic routes (national highways, provincial roads, district roads), traffic hubs, commercial and tourist areas, and residential areas;

and the location has been determined according to the remaining area in the countryside, the land price is calculated according to the method of determining the location with the higher land price.

Land prices on the research routes in Thanh Mien district have differences between routes and locations. Land prices at location 1 are always the highest, being the center of the district, convenient for traffic, and suitable for family business purposes. Land prices gradually decrease and also have quite a difference between locations.

Market research results show that land prices on the market have large fluctuations and are many times higher than the land prices in the regulated price list (Table 1).

Table 1. Regulated land prices and market land prices in Thanh Mien district, Hai Duong province

Area	Route	Location	Regulated land prices (1000 VND/m^2)	Market land prices (1000 VND/m^2)			Difference (times)		
				2021	2022	2023	5/4	6/4	7/4
1	2	3	4	5	6	7	8	9	10
Area I	Nguyen Luong Bang Street, Thanh Mien Town (from the flower garden to Neo Bridge)	1	14000000	2850000	33000000	45500000	0.20	2.36	3.25
		2	7000000	19500000	24000000	35500000	2.79	3.43	5.07
		3	5000000	12000000	19200000	28000000	2.40	3.84	5.60
		4	3000000	10500000	12500000	15000000	3.50	4.17	5.00
	Nguyen Luong Bang Street, Thanh Mien Town (section from Neo intersection to flower garden)	1	14000000	28000000	32500000	46000000	2.00	2.32	3.29
		2	7000000	15500000	22500000	24500000	2.21	3.21	3.50
		3	5000000	9200000	14700000	15800000	1.84	2.94	3.16
		4	3000000	6800000	9500000	9200000	2.27	3.17	3.07
	Land along Provincial Road 392, Doan Tung Commune (from the turnoff to Doan Tung Commune People's Committee to the 3-way intersection to Nguyen Luong Bang Memorial House)	1	10000000	28500000	32800000	38000000	2.85	3.28	3.80
		2	5000000	18000000	20000000	24200000	3.60	4.00	4.84
		3	4000000	135000000	15800000	14200000	33.75	3.95	3.55
		4	3000000	7800000	8300000	7800000	2.60	2.77	2.60
Area II	Tue Tinh Street (from the flower garden to Phuong Hoang Ha)	1	8000000	12200000	15000000	20000000	1.53	1.88	2.50
		2	4000000	7500000	9700000	16600000	1.88	2.43	4.15
		3	2500000	5400000	7000000	9800000	2.16	2.80	3.92
		4	1600000	2700000	3500000	4000000	1.69	2.19	2.50
	Chu Van An Street (from Neo Intersection - to Dong Trang culvert)	1	8000000	11000000	13000000	16000000	1.38	1.63	2.00
		2	4000000	7500000	9200000	11800000	1.88	2.30	2.95
		3	2500000	5400000	7000000	9000000	2.16	2.80	3.60
		4	1600000	2200000	3000000	4000000	1.38	1.88	2.50
	Land along provincial road 392 (section belonging to the residential area of Chuong, Lam Son commune)	1	7000000	18800000	20000000	31700000	2.69	2.86	4.53
		2	3500000	10500000	14100000	22200000	3.00	4.03	6.34
		3	2800000	7800000	8800000	10700000	2.79	3.14	3.82
		4	2100000	4000000	5700000	8800000	1.90	2.71	4.19

Area	Route	Location	Regulated land prices (1000 VND/m²)	Market land prices (1000 VND/m²)			Difference (times)		
				2021	2022	2023	5/4	6/4	7/4
1	2	3	4	5	6	7	8	9	10
Area II	Hoang Xa Street (from Agricultural Bank to Tran Van Giap Street)	1	6000000	8000000	10000000	12000000	1.33	1.67	2.00
		2	3000000	5500000	7200000	8500000	1.83	2.40	2.83
		3	2000000	3400000	5300000	7300000	1.70	2.65	3.65
		4	1200000	2100000	3200000	4500000	1.75	2.67	3.75
Area III	Land along provincial road 392B (section through Thanh Giang, Tu Cuong, Ngu Hung, Tien Phong communes)	1	5000000	25000000	33500000	36000000	5.00	6.70	7.20
		2	2500000	15100000	28800000	29600000	6.04	11.52	11.84
		3	2000000	10200000	14500000	16500000	5.10	7.25	8.25
		4	1500000	7800000	9100000	10500000	5.20	6.07	7.00
	Dang Tu Te street, Thanh Mien town	1	5000000	7600000	8500000	10800000	1.52	1.70	2.16
		2	2500000	4100000	6600000	7700000	1.64	2.64	3.08
		3	1300000	2000000	3200000	4500000	1.54	2.46	3.46
		4	1000000	1200000	3500000	4500000	1.20	3.50	4.50
	The remaining streets within Thanh Mien town	1	2500000	4200000	7500000	8000000	1.68	3.00	3.20
		2	1500000	2000000	3000000	4000000	1.33	2.00	2.67
		3	800000	1300000	1500000	2000000	1.63	1.86	2.50
		4	600000	1100000	1200000	1500000	1.83	2.00	2.50

3.2. Factors affecting land prices in Thanh Mien district

Based on the investigation and interviews with 6 staff of the Department of Natural Resources and Environment, 6 staff of the Thanh Mien District Land Registration Office, and 8 land officials of communes in Thanh Mien district. The results show that land prices here are affected by many factors including 21 factors affecting land prices, divided into 5 groups of factors, specifically:

i) Location factors: Different locations will lead to differences in land prices, at the same time, land prices change according to road sections and areas [5];

ii) Economic factors: Land prices are affected by issues such as economic growth rate in the area; income and consumption of residential areas as well as bank interest rates [11];

iii) Social factors: Land prices are affected by social factors such as urbanization speed, population density, living environment, public awareness, social security, and land speculation [9];

iv) Group of policy factors: Factors affecting land prices include planning policies, land price policies, tax policies [9];

v) Group of other factors: Including shape, area, width, and depth of the land plot, these are factors affecting the value of the land plot [4].

After identifying 5 groups of factors affecting land prices, a survey was conducted on 150 households and individuals who received and transferred land use rights in 2021, 2022, and 2023 on selected routes according to the survey form. The specific results were:

Table 2. Results of household and individual surveys on factors affecting land prices in Thanh Mien district

Factors affecting land prices	Total number of questionnaires	Influence		No Influence	
		Number of questionnaires	Ratio (%)	Number of questionnaires	Ratio (%)
I. Location factors					
(1) Distance to administrative center	150	131	87.3	19	12.7
(2) Distance to school	150	132	88	18	12
(3) Distance to hospital	150	120	80	30	20
(4) Distance to market	150	126	84	24	16
II. Economic factors					
(5) Economic growth rate in the region	150	150	100	0	0
(6) Income and consumption of residents	150	150	100	0	0
(7) Bank interest rates	150	150	100	0	0
(8) Income generating capacity of the land plot	150	146	97.3	4	2.7
III. Social factors					
(9) Urbanization rate	150	150	100	0	0
(10) Population density	150	150	100	0	0
(11) Living environment	150	150	100	0	0
(12) Education level	150	150	100	0	0
(13) Social security	150	150	100	0	0
(14) Land speculation	150	150	100	0	0
IV. Legal factors					
(15) Legal status of the land plot	150	134	89.3	16	10.7
(16) Restrictions on land use rights	150	132	88	18	12
(17) Planning restrictions	150	131	87.3	19	12.7
V. Other factors					
(18) Plot shape	150	150	100	0	0
(19) Plot area	150	150	100	0	0
(20) Plot frontage width	150	150	100	0	0
(21) Plot depth	150	150	100	0	0

3.3. The level of influence of factors affecting land prices in Thanh Mien district

3.3.1. Reliability analysis of survey data

The authors analyzed the reliability of survey data using SPSS software, through Cronbach’s Alpha coefficient and the Corrected Item - Total Correlation (Table 2). The results of Cronbach’s Alpha testing for 21 independent variables in the research model showed that the survey variable “The ability to generate income of the land plot” (KT4) had a Corrected Item - Total Correlation of 0.193, less than 0.3 (not reliable enough), so it had to be removed from the research model. Thus, 20 survey variables are eligible to continue with exploratory factor analysis.

Table 3. Results of reliability analysis - Cronbach's Alpha

Observation variable	Symbol	Corrected Item - Total Correlation	Cronbach's Alpha coefficient
Location factors (Cronbach's Alpha = 0.825)			
Distance to the administrative center	VT1	0.590	0.805
Distance to school	VT2	0.704	0.759
Distance to hospital	VT3	0.656	0.779
Distance to market	VT4	0.662	0.773
Economic factors (Cronbach's Alpha = 0.700)			
Economic growth rate in the area	KT1	0.425	0.677
Income and consumption of residents	KT2	0.683	0.511
Bank interest rates	KT3	0.733	0.482
Income generating capacity of the land	KT4	0.193	0.807
Social factors (Cronbach's Alpha = 0.939)			
Urbanization rate	XH1	0.855	0.922
Population density	XH2	0.780	0.932
Living environment	XH3	0.833	0.925
Public awareness	XH4	0.830	0.926
Social security	XH5	0.767	0.934
land speculation	XH6	0.837	0.925
Policy factors (Cronbach's Alpha = 0.885)			
Economic policy	CS1	0.766	0.846
Tax policy	CS2	0.794	0.821
Planning policy	CS3	0.770	0.843
Other factors (Cronbach's Alpha = 0.834)			
Land plot shape	KB1	0.528	0.850
Land plot area	KB2	0.840	0.706
Land plot frontage width	KB3	0.571	0.828
Land plot depth	KB4	0.736	0.756

3.3.2. Exploratory factor analysis

Exploratory factor analysis (EFA) is used to reduce a set of k survey variables into a set F (with F < k) of more meaningful factors. In this study, instead of studying 20 factors affecting land prices, the authors studied 5 groups of factors, each of which includes factors that are correlated with each other to save time and research costs.

The results of the test of the suitability of factor analysis showed that the KMO coefficient (Kaiser - Meyer - Olkin) = 0.792, satisfying the condition 0.5 < KMO < 1 (Table 3). Thus, exploratory factor analysis is suitable for real data. In addition, the Barlett's test has a value of Sig. = 0.000 < 0.05, showing that the real data is completely consistent with EFA analysis and the survey variables are linearly correlated with the representative factor.

Table 4. Results of KMO and Bartlett's Test

Index		Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.792
Bartlett's Test of Sphericity	Approx. Chi-Square	2503.349767
	df	190
	Sig.	0.000

The evaluation results of the survey variables in the model with the required factors, because the total explained variance of the independent variable is 74.283 > 50 % (Table 4). The results show that 74.283 % of the change in the result factor is due to the factors (variables) given in the model, that is, the survey variables in this study explained 74.283 % of the variation in land prices in Thanh Mien district.

Table 5. Total explained variance and factor loading of the rotation matrix for independent variables

Factors	Eigenvalues			Total explained variance		
	Total	Variance (%)	Cumulative (%)	Total	Variance (%)	Cumulative (%)
1	6.570	32.851	32.851	6.570	32.851	32.851
2	3.372	16.859	49.711	3.372	16.859	49.711
3	2.439	12.196	61.907	2.439	12.196	61.907
4	1.325	6.627	68.534	1.325	6.627	68.534
5	1.150	5.749	74.283	1.150	5.749	74.283
6	0.837	4.185	78.468			
7	0.707	3.534	82.002			
8	0.677	3.387	85.389			
9	0.569	2.846	88.235			
10	0.473	2.365	90.599			
11	0.369	1.844	92.444			
12	0.354	1.771	94.214			
13	0.319	1.593	95.807			
14	0.251	1.255	97.062			
15	0.218	1.091	98.153			
16	0.111	.556	98.709			
17	0.099	.497	99.206			
18	0.085	.427	99.633			
19	0.053	.265	99.897			
20	0.021	.103	100.000			

Table 6. Factor loading results of the rotation matrix

Variables	Component				
	1	2	3	4	5
XH1	0.878				
XH6	0.862				
XH5	0.857				
XH3	0.857				
XH2	0.854				
XH4	0.852				
VT3		0.812			
VT4		0.795			
VT2		0.785			
VT1		0.711			
KB2			0.820		
KB3			0.779		
KB1			0.712		
KB4			0.712		
CS3				0.851	
CS2				0.809	
CS1				0.808	
KT2					0.923
KT3					0.899
KT1					0.647

The rotation matrix determining the factor loading shows that 5 groups of factors with 20 survey variables are arranged in a non-original order. The factor loading of all variables have values >0. According to Hair & CS (1998), a factor loading >0.3 is considered to be at the minimum level; a factor loading >0.4 is considered important; a factor loading >0.5 is of practical significance (Table 5). Thus, it can be affirmed that each element in each factor is correlated with the factor of which it is a component and has practical significance.

Thus, the exploratory factor analysis confirmed the following 5 groups of factors: Location factors, economic factors, social factors, policy factors, and individual factors were included in the regression analysis.

3.4. Regression analysis and determination of the level of influence of factors on land prices

3.4.1. Regression analysis

After conducting the steps of testing and factor analysis, eligible factors are included in the regression analysis to determine the linear regression equation between land prices and influencing factors as well as to determine the level of influence of those factors on land prices. The adjusted R2 value is 0.63, so 63 % of the variation in land prices is caused by the influence of independent variables in the model. The Durbin-Watson value (d) is a test value used to detect the presence of correlation in regression analysis. The value of d is always between 0 and 4. If $1 < d < 3$ then the model does not correlate, if $0 < d < 1$ then the model has a positive correlation, if $3 < d < 4$ then the model has a negative correlation. Therefore, it can be assumed that there is no first-order linear correlation in the multiple linear regression data because the Durbin-Watson coefficient value of 1.925 is very close to the value of 2.

Table 7. Regression coefficients

Model	Unstandardized regression coefficient beta	Standardized regression coefficient beta	Sig.	Multicollinearity statistics	
				Acceptability	VIF
Constant	-2.616		0.000	0.683	1.463
VTtb	0.703	0.332	0.000	0.808	1.238
KTtb	0.406	0.324	0.000	0.628	1.592
CStb	0.256	0.250	0.000	0.863	1.158
XHtb	0.170	0.118	0.032	0.667	1.499
KBtb	0.280	0.179	0.004	0.683	1.463

From the regression coefficient results, the authors consider the unstandardized regression coefficients in the beta coefficient column. Thereby, the authors can provisionally estimate the sample regression model before testing, the model is represented as follows:

$$Y= -2{,}616 + 0{,}703VT + 0{,}406KT + 0{,}256CS + 0{,}170XH + 0{,}281KB + \epsilon$$

In Table 6, the significance level Sig. of the variables in the regression model, all have a value of 0.000, which is smaller than the maximum value of 0.05. Therefore, all variables have an impact on land prices. The VIF values of all variables have an impact on land prices. The VIF values of all variables are greater than 1, indicating that there is a multicollinearity phenomenon in this analysis.

Analysis of variance ANOVA to re-test the reliability of the regression analysis (Table 8) shows that the transformed F value = 49.033, the significance level Sig = 0.000, the results of the regression analysis ensure reliability.

Table 8. Analysis of variance ANOVA

	Total variance	df	Mean-variance	F	Sig.
Regression	35.955	5	7.191	49.033	<.001b
Remainder	21.118	144	0.147		
Total	57.073	149			

3.4.2. Assess the level of influence of factors on residential land prices

Table 9. Level of influence of factors on land prices

Group of influencing factors	Standard beta	Ratio (%)	Order of influence
VT - Location	0.332	27.60	1
KT - Economy	0.324	26.93	2
XH - Social	0.250	20.78	3
CS - Policy	0.118	9.81	5
KB - Others	0.179	14.88	4
Total	**1.203**		

Thus, the results of the analysis of the influence of factors on land prices in Thanh Mien district show that the location factor has the highest influence at 27.6 %, followed by the economic factor at 26.93 %, followed by the social factor at 20.78 %, other factors at 14.88 % and finally the policy factor at 9.81 %.

The location factor and economic factors have the highest influence on land prices in the Thanh Mien district. This is consistent with the fact that when regulating land prices in the land price frame, as well as the regulated price list, the location factor is the basis for building land prices. If the land plot is more conveniently located near the center, schools, hospitals, etc., the price will always be higher than other plots. In addition, the group of economic factors (economic growth rate, income and consumption, bank interest rates) is also a factor that greatly affects land prices.

Thus, the results of the analysis of the influence of factors on land prices in Thanh Mien district show that the location factor has the highest influence at 27.6 %, followed by the economic factor at 26.93 %, followed by the social factor at 20.78 %, other factors at 14.88 % and finally the policy factor at 9.81 %.

From the above research results, it can be recommended that when valuing residential land in Thanh Mien district, it is necessary to consider more carefully the location and economic factors to set land prices in accordance with market prices, while contributing to socio-economic development and improving the effectiveness of state management of land.

4. Conclusion

Land prices in the Thanh Mien district market in the period of 2021 - 2023 are always higher than the regulated price, the difference also fluctuates according to each location in each section of a route

Land prices in Thanh Mien district are affected by five groups of factors, including location factors, social factors, economic factors, policy factors, and other factors. The results of the linear regression analysis determined the linear regression equation as $Y = -2.616 + 0.703VT + 0.406KT + 0.256CS + 0.170XH + 0.281KB + \epsilon$

In which, the group of factors that have the greatest influence on the land price of Thanh Mien district is the group of location factors (27.6 %), followed by the group of economic factors (26.93 %), followed by the group of social factors (20.78 %), the group of other factors (14.88 %) and finally the group of policy factors (9.81 %).

5. Recommendation

During the implementation process, the authors identified the location factor group and the economic factor group as the two groups of factors that have the greatest impact on land prices in Thanh Mien district. Therefore, when determining land prices in Thanh Mien district, it is necessary to consider more carefully the location and economic factors so that the land price is consistent with the market price while contributing to socio-economic development and improving the effectiveness of land management.

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MANAGEMENT AND USE OF CEMETERY LAND IN THAI BINH CITY: CURRENT SITUATION AND SOLUTIONS

Nguyen Ngoc Hong*, Dao Dinh Duc, Tran Thi Hoa

Hanoi University of Natural Resources and Environment, Vietnam

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Abstract

Thai Binh city - is the provincial capital and the political, economic, and socio-cultural center of Thai Binh province, one of the 04 satellite cities of the Southern Red River delta region, currently a Type 2 city under Thai Binh province. In more than 20 years of construction and development, Thai Binh city has had a high growth rate and is striving to become a Type 1 city under the province by 2025. Along with the development process, the city always pays attention to environmental protection issues, striving to build Thai Binh city to develop quickly and sustainably, in which the city mentions the issue of planning and managing cemetery land in the area - one of the sources that can cause environmental pollution in the city. The research will evaluate the current status of land use and management as well as propose solutions to improve the efficiency of land use management of cemeteries and graveyards, contributing to ensuring the needs of society as well as ensuring environmental factors for sustainable development in the research area.

Keywords: Cemetery land; Cemetery; Thai Binh city; Environmental protection.

***Corresponding author, Email:** nnhong@hunre.edu.vn

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1. Introduction

Thai Binh city is the economic, cultural, social, scientific, and defense center of the province and is also one of the 8 cities in the Northern coastal region. Located 110 km from Hanoi's capital, it is also the traffic hub of the province. In more than 20 years of formation and development, Thai Binh city has had significant changes and developments. With the growth rate of economy, culture, and society, Thai Binh city is currently an area attracting many workers to live and work, the pressure on socio-economic infrastructure is increasing, and the issue of environmental protection is also an urgent issue for sustainable city development, especially in the context of the city striving to become a Type 1 city under the province.

A cemetery (graveyard) is a public land used to bury the dead (according to the Vietnamese Dictionary, page 656). In Vietnam, the concept of cemetery land and graveyard is not clearly defined but is often referred to as the resting place of the deceased. Cemeteries are places where the deceased are buried in different burial forms and are managed and built according to planning (according to Clause 1, Article 2, Decree No. 23/2016/ND-CP on construction, management, and use of cemeteries and crematoriums). However, while cemetery land is a concept that refers to land areas that are centrally planned to serve burial purposes, cemetery land is land that, although having the same purpose, is not planned, and is still scattered, fragmented, and spontaneous.

Cemetery land, NTD cemetery land is an important and top concern issue in urban areas in Vietnam, including Thai Binh city. As the economy develops under the influence of urbanization and industrialization, people's needs increase, and the issue of etiquette is increasingly important and urgent. According to the orientation, Thai Binh city 2030 will expand by nearly 2 times compared to the present, and the demand for land in general and land for cemeteries, funeral homes, and crematoriums; Land for ash storage facilities is also very large to serve the people. If the management and planning of cemeteries are not synchronized and not strictly managed, the risk of environmental pollution in the city is very high. The study will assess the current situation and propose solutions to improve the effectiveness of cemetery land management, associated with the goal of sustainable development and environmental protection in the study area.

2. Methodology

2.1. Investigation methods, document, and data collection

Secondary data: Collect data on natural conditions, socio-economic conditions, land management, and use in 2023 at state management agencies and public service units in Thai Binh city.

Data on current land use status in 2023: Including investigation and collection of data on cemetery land and cemeteries in Thai Binh city. Data on planning, land use plans; technical infrastructure, environmental landscape, etc.

2.2. Method of data synthesis, comparison, analysis, and processing

The collected data will be analyzed and synthesized using Microsoft Excel software. The data after being synthesized will be used as a basis for comparison, evaluation, and discussion, especially for evaluating the current status of cemetery land use and management, thereby providing a basis for proposing solutions to improve the effectiveness of cemetery land management and use in the research area.

3. Results and discussion

3.1. Current status of cemetery land management and use

According to land statistics in 2023, Thai Binh city has 87.5 hectares of cemetery land with 650 cemetery locations distributed in 16/19 wards and communes. Specifically as follows:

Table 1. Current status of cemetery land use in Thai Binh city

No.	Administrative unit	Current status of cemetery land use		Number of Cemetery Areas
		Land area (ha)	Percentage (%)	
1	Bo Xuyen ward	0	0.0	0
2	De Tham ward	0	0.0	0
3	Hoang Dieu ward	6.8	7.8	47
4	Ky Ba ward	3.8	4.3	09
5	Le Hong Phong ward	0	0.0	0
6	Phu Khanh ward	3.6	4.1	01
7	Quang Trung ward	0.6	0.7	03
8	Tien Phong ward	2.5	2.9	05
9	Tran Hung Dao ward	2.1	2.4	01
10	Tran Lam ward	5.7	6.5	14
11	Dong Hoa commune	5.2	5.9	36
12	Dong My commune	4.2	4.8	15
13	Dong Tho commune	3.0	3.4	09
14	Phu Xuan commune	16.3	18.6	134
15	Tan Binh commune	6.9	7.9	72
16	Vu Chinh commune	8.7	9.9	163
17	Vu Dong commune	4.0	4.6	49
18	Vu Lac commune	5.5	6.3	43
19	Vu Phuc commune	8.6	9.8	49
Total		**87.5**	**100.0**	**650**

Source: Collected and compiled data

Through the synthesis of collected statistical data, the number of cemeteries in Thai Binh city is 650, of which 01 city-level cemetery is located in Phu Khanh ward (City People's cemetery); 01 provincial-level cemetery is the provincial martyrs' cemetery (Tran Lam ward); The remaining 26 are commune and ward-level cemeteries scattered in 16/19 wards and communes. According to the data table, the communes and wards with high cemetery areas are Phu Xuan commune with 16.3 hectares, accounting for 18.6 % of the total cemetery area of the city with 134 cemetery points; Quang Trung ward has the lowest area of 0.6 hectares, accounting for 0.7 % of the cemetery area of the city. 03 inner-city wards without any cemeteries are Bo Xuyen ward, De Tham ward, and Le Hong Phong ward.

Up to now, 70 % of cemeteries have had surrounding walls and drainage infrastructure built such as in Tran Hung Dao, Tran Lam, Phu Khanh, Phu Xuan wards,... However, many communal cemeteries have not yet had surrounding walls built such as Hoang Dieu, Quang Trung, Tan Binh, Vu Dong, Vu Phuc,... More or less causing environmental pollution affecting the surrounding environment.

Regarding the supervision work, currently, basically communal cemeteries have a management board to supervise and ensure security in these areas.

Through the results of the actual survey, in the general planning content, in the current status section, most of the projects only stop at the level of stating the name, location, and area of the existing people's cemeteries, completely not mentioning the current status of planning management and construction of cemeteries. The construction of cemetery land use planning is integrated into the general land use planning, the norms for this type of land are not specific, so it mainly relies on the implementation results of previous years, and previous periods to calculate the area for the next period, without analyzing the effectiveness of land use. Therefore, the planning is often broken, leading to the situation that cemetery land planning is almost only a formality.

3.2. About funeral homes

Regarding funeral homes, the city currently has 01 funeral home located at the Tran Lam ward Medical Center, which is solidly and modernly invested in accordance with regulations with a scale of 0.81 hectares, exploited and operated by Truong Duong Funeral Services Company Limited.

3.3. About assigning investors to build and operate cemetery infrastructure

Regarding the work assigned to enterprises, currently, there is only 01 city-level cemetery in Phu Khanh ward that has been assigned land to invest in building and operating cemetery infrastructure, with regulations on operations, synchronous infrastructure, and ensuring environmental hygiene.

In general, the cemetery areas in the area have been invested in and built, but they are quite scattered. Some communes have 2 - 3 cemeteries, causing waste of land funds and difficulty in ensuring environmental hygiene conditions. Not to mention the small cemeteries that have not been relocated to centralized cemeteries for a long time are also potential sources of environmental pollution and loss of urban beauty. In addition to the martyrs' cemeteries of the province, communes, and wards, the remaining public cemeteries still practice cremation, which greatly affects the environment.

3.4. The concept of cremation is still promoted

Currently, people have not fully accepted the method of cremation due to the concept of customs and practices. Therefore, the choice of cremation is still widely used. According to the City People's Committee, the current rate of cremation in the area is only about 27 % (meeting the standards of Type 2 urban area according to Resolution No. 1210/2016/UBTVQH13 dated May 25, 2016 of the National Assembly Standing Committee on urban classification), but it is still quite low compared to the current trend and when the city is upgraded to a Type 1 urban area, according to regulations, this rate must reach at least 30 %. With the above situation, there is a risk of greatly affecting the environment around the cemetery area, especially the water and air environment [1].

3.5. Planning for the future

According to the general planning until 2035 with a vision to 2050 approved in 2023 and the land use planning until 2030 Thai Binh city approved until 2030, the city will maintain the current status of cemeteries and cemetery sites with an area of 87.5 hectares, not opening new or expanding new cemeteries and sites. Gradually close the cemeteries when they are full, and only accept burial cases. According to the planning, the city's burial needs will be transferred to 2 cemeteries planned for the province in Kien Xuong district and Quynh Phu district, and the aim is to use cremation methods.

For the city funeral home, it is expected to invest in an additional funeral home located in the northern hospital campus near Long Hung Street with a scale of 1 ha and by the criteria of Type 1 urban area (according to Resolution No. 1210/2016/ UBTVQH13 dated May 25, 2016 of the National Assembly Standing Committee on urban classification, a Type 1 urban area must have 2 funeral homes) [3].

4. Forecasting demand and proposing solutions to improve the efficiency of cemetery land management and use in Thai Binh city

4.1. Forecasting demand

According to the general planning, by 2035, Thai Binh city will expand and merge 10 more communes from Vu Thu, Kien Xuong, and Dong Hung districts with an expected total area of 570 thousand people, and by 2050 it will be 700 thousand people. Thus, the demand for cemetery land is also very large, so it is necessary to have fundamental measures to solve the needs of the people while ensuring environmental sanitation according to the criteria of a Type 1 urban area. The forecast demand for cemetery land is 0.06 ha/1000 people [2]. Thus, if the population increase by 2035 (currently 208,162 people) is converted to 361,838 people, the demand for cemetery land will increase by 21.71 hectares, and by 2050, the increase will be 491,838 people, the demand for cemetery land will have to increase by 29.51 hectares.

4.2. Proposing solutions to improve the efficiency of cemetery land management and use in Thai Binh city

a. Propaganda and mobilization work

The City People's Committee needs to strengthen propaganda and mobilization work so that people better understand their responsibilities in environmental protection, and not carry out burials at small, unplanned, and spontaneous locations. Promote the use of modern burial methods such as cremation to increase the rate to about 50 % or more by 2035 and over 90 % by 2050. At the same time, raise people's awareness of environmental protection at cemeteries.

b. Regarding planning

The City People's Committee does not plan to expand and add new cemeteries and recommends that the Thai Binh Provincial People's Committee accelerate the planning and construction of provincial-level cemetery projects to reduce pressure on cemeteries in the city.

At the same time, the City People's Committee is considering closing cemeteries in inner-city wards early before 2035, only accepting burials until the occupancy rate reaches 100 %.

With the urgent need for burial land for the deceased in Thai Binh city today, it is necessary to quickly implement the general cemetery planning and supplement the detailed planning of 1/500. In parallel with the addition of the 1/500 detailed planning, it is necessary to supplement and promulgate regulations on construction management according to the cemetery planning. The content of the proposed management regulations provides specific and clear solutions for landscape architecture management such as regulations on burial forms in the entire cemetery and in each component area: Unification of architectural style, height, finishing materials, and color; Regulations for each type of burial (burial, sand burial, cremation, etc.).

c. Regarding the specialization of management and exploitation

The City People's Committee develops a policy mechanism and assigns enterprises to bid and manage, exploit, and trade cemetery infrastructure in areas without synchronous infrastructure, water supply and drainage infrastructure, and surrounding walls.

d. Strengthening management

Enhance the State's management role in the management of people's cemeteries: The State management agencies directly performing the function of managing people's cemeteries are the Department of War Invalids and Social Affairs, People's Committees of communes.

Strengthen the inspection and handling of violations of construction planning and environmental sanitation at commune-level people's cemeteries.

Perfecting unified and appropriate economic policies (fees, collection fees) in the management, use, and operation of people's cemeteries. In addition to legal regulations, the People's Committee needs to study and issue specific regulations on management and operation fees, sanitation fees for commune-level people's cemeteries;

Improve the capacity of cadres and cemetery management boards to manage people's cemeteries; Thai Binh province and functional departments need to learn from cemetery management experiences in other urban areas in and outside the country.

The City People's Committee and the People's Committees of communes and wards in the area shall strengthen the inspection and handling of violations related to the use of cemeteries to avoid affecting the surrounding environment.

Issue regulations on the management of local people's cemeteries to effectively manage and exploit cemeteries.

5. Conclusion

The entire Thai Binh city has 87.5 hectares of cemetery land with 650 cemetery points, some cemeteries have been invested in synchronously and spaciously, but there are still some cemeteries that have not been built with surrounding walls, water supply, and drainage infrastructure; There are no general regulations on operating regulations; The cremation rate in the area is about 27 %, meeting the standards of Type 2 urban area but is still not high compared to the general trend. The people's cemeteries in the city lack long-term planning, leading to consequences such as environmental pollution, affecting land use planning,... due to loose management, messy arrangement of graves, many levels, arbitrary burial areas not according to regulations. The city has planned to move cemetery land needs to provincial cemeteries according to the direction and orientation of the Provincial People's Committee and gradually closed inner-city cemeteries according to the roadmap, which is also a highlight in environmental protection actions. Therefore, it requires synchronous solutions, from many different perspectives, to manage public cemeteries to minimize negative impacts on the economic, social, and environmental development of the surrounding area.

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ASSESSMENT OF TOURISM ACTIVITIES AND ENVIRONMENTAL IMPACTS ON ECOSYSTEMS IN HA LONG BAY WORLD NATURAL HERITAGE SITE

Nguyen Huu Viet Truong[1], Bui Thi Thu Trang[2,*], Le Van Manh[3], Nguyen Khac Thanh[2]
[1]Graduate student, Hanoi University of Natural Resources and Environment, Vietnam
[2]Hanoi University of Natural Resources and Environment, Vietnam
[3]Institute of Biotechnology, Vietnam Academy of Science and Technology

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Abstract

Ha Long Bay, a UNESCO World Natural Heritage site, has become a globally renowned tourist destination, attracting millions of visitors annually. However, the rapid growth of tourism poses significant challenges to managing and preserving this heritage site. The study reveals that tourism activities have notable impacts on the ecosystem, with 32.5 % reporting minor effects on mangroves, 36.4 % on coral reefs, and 34.4 % on beach activities. Despite progress in waste management and biodiversity conservation, Ha Long Bay's ecosystem continues to face negative impacts from environmental pollution caused by boats, tourist waste, and pressures on endemic flora and fauna. The lack of sufficient financial resources, technological capabilities, and inadequate management measures have hindered effective conservation efforts. The research highlights the critical role of local communities and tourists in mitigating these negative impacts and emphasizes the need for increased investment, stringent management, and heightened awareness to ensure the sustainable protection of this natural heritage site.

Keywords: Ha Long Bay; Natural heritage; Tourism activities; Impact on ecosystem; SWOT model method.

[*]**Corresponding author, Email:** btttrang@hunre.edu.vn

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1. Introduction

In Vietnam, overexploitation and encroachment have significantly reduced natural ecosystems such as forests, coral reefs, and seagrass beds, leading to a decline in biodiversity and increasing environmental pollution, particularly in coastal and marine areas. Ha Long Bay (Quang Ninh), a renowned natural heritage site, faces immense pressure from human activities including maritime transport, tourism, mining, and waste disposal. With unique ecosystems comprising caves, semi-enclosed water zones, and lagoons nestled among islands, Ha Long Bay boasts exceptional biodiversity. However, its coral reefs, sensitive to water quality, are at high risk of degradation. In response, the Ha Long Bay Management Board has implemented various measures to conserve and restore ecosystems while safeguarding the sustainable value of this heritage site against the adverse impacts of exploitation and pollution.

Natural heritage is a typical relic, scenic spot created by nature and has special aesthetic value. This is an ecosystem with beautiful landscape, is home to a large number of species of organisms, brings many values, contributes to society, has outstanding global value in terms of science, conservation or aesthetics. Depending on their scientific or aesthetic significance, such sites can achieve international recognition as world natural heritage. Representing the nation's image on the global stage, these sites hold immense cultural, aesthetic, and economic value. Thus, conserving these treasures and protecting their environments is a collective responsibility. Vietnam's Environmental Protection Law 2020 emphasizes the duty of all citizens to safeguard natural heritage. Article 21, Clause 3, mandates that organizations, communities, households, and individuals must participate in protecting natural heritage, while also granting them benefits under the ecosystem service payment framework as stipulated by law. Article 138 elaborates on payments for natural ecosystem services, where users compensate providers for the value of services like forest environments, wetlands, marine ecosystems, and geological formations for tourism, recreation, or aquaculture, as well as carbon storage for greenhouse gas mitigation. Organizations or individuals engaging in activities such as water surface exploitation, recreational services, or tourism must pay for ecosystem services to ensure the protection and sustainable development of these natural systems [1].

In addition, the Vietnamese government has introduced regulations to safeguard the environment in natural heritage sites. Article 21, Clause 7, of Decree 08/2022/ND-CP specifies measures for environmental protection within natural heritage areas: core zones are regulated as strictly protected zones, while buffer zones are managed as restricted-emission zones. Natural ecosystems must be prioritized for preservation and restoration, while polluted or degraded soil and water environments must be rehabilitated. Core values of biodiversity must remain intact, and ecosystem services should be developed sustainably. Geological, ecological, and biodiversity indicators must be surveyed, monitored, and reported regularly. In emergency cases of significant environmental threats, the Ministry of Natural Resources and Environment will recommend emergency measures to the Prime Minister, including limiting discharge volumes and specifying implementation zones and timeframes.

In fact, there have been a number of studies on the impact of tourism activities on the environmental landscape. The study by Tran Thi Huong and colleagues assessed the impact of tourism activities on the natural and social environment in Ban Lac, Chieng Chau commune, Mai

Chau district, Hoa Binh province. The main research method is to survey and investigate along the route to determine the causes of impacts on the natural and social environment, combined with analysis of water quality and environmental components and calculation of solid waste and wastewater from tourism activities to assess the pressure of tourism on the environment of the area. The research results show that the amount of waste generated from tourism activities is 1,302 kg/day, accounting for 40.77 % of the total amount of solid waste in the whole area. The amount of wastewater from tourism is 10,055.75 m^3/year. The source of the waste affects the surface water quality of the area. In addition, local culture is disrupted and conflicts arise in sharing benefits within the community. To reduce negative impacts and move towards sustainable ecotourism development, local authorities need to apply long-term solutions such as: Environmental planning; Raising awareness for people and tourists; Support activities from stakeholders are needed. This study has provided important information for the management and development of sustainable ecotourism in Ban Lac, while emphasizing the need for cooperation and coordination from stakeholders to ensure the protection of the environment and local society [3].

The study of author Truong Sy Vinh (2019) has shown that the increase in tourism activities here has caused many problems for the ecological environment. The results show that, on normal days, the environmental carrying capacity of Cuc Phuong National park mostly does not exceed the carrying capacity, even at a very slight level. However, on peak days or holidays, the number of visitors exceeds the carrying capacity of the ecosystem, causing problems with clean water supply and transportation systems. Based on these results, the study proposes a number of solutions such as limiting the number of visitors during peak seasons, organizing reasonable tour programs, upgrading infrastructure and equipment for tourism. These measures aim to protect the ecological environment and ensure sustainable development of tourism in Cuc Phuong National park [4].

Thus, our state has issued regulations on environmental protection for natural heritage and has also conducted studies on the impact of tourism activities on the environmental landscape. However, sub-regulations and practical guidelines for assessing the environmental impacts of tourism on natural heritage remain underdeveloped, lacking a robust scientific and practical foundation for effective implementation. Furthermore, quantifying these impacts is challenging due to the non-market characteristics of tourism activities. To address these issues, it is imperative to develop accessible, scientifically robust tools to enhance the management of tourism in natural heritage areas, thereby improving local economic and social development outcomes.

This article presents research findings on the current state of tourism and its management within Ha Long Bay, a UNESCO World Natural Heritage site. It also evaluates the extent to which tourism activities impact the ecosystem of this natural heritage area, as managed by the Ha Long Bay Management Board.

2. Methodology

2.1. Secondary data collection method

This study selectively inherits and utilizes secondary data from previously published research, reports, and official documents related to the study area, including:

- Natural and socio-economic conditions of Ha Long.
- Reports on tourism activities in natural heritage areas.
- Reports on the current state of natural heritage management.
- Biodiversity reports of natural heritage areas.
- Information from existing legal documents on waste management in Ha Long Bay.
- Data from scientific studies on the collection, classification, and disposal of hazardous and recyclable waste in Vietnam and globally.

Information from programs on waste sorting at the source, is obtained through newspapers, television, and the internet.

2.2. Field surveys combined with sociological investigation

Field surveys and investigations are conducted across multiple routes. Planned surveys took place in May and June of 2024, along six tourist routes currently operational within Ha Long Bay's World Natural Heritage area:

- Route 1: Tourist port - Van Canh park area
- Route 2: Tourist port - Cave park area
- Route 3: Tourist port - Marine culture park area
- Route 4: Tourist port - Marine entertainment center area
- Route 5: Cruise tourism exploration route
- Route 6: Coastal port areas: Tuan Chau, Vinashin, SunGroup

The sociological investigation method requires high levels of enthusiasm and rigor from researchers to accurately achieve the study's objectives. This involves verifying the accuracy of collected data, filling gaps in information, and supplementing existing materials. To gather specific and reliable data, survey subjects are selected based on local social conditions. Before conducting interviews, the study surveyed Ha Long's demographics, including age, gender, household size, occupation, education level, and income. This method is crucial for the study as it enables direct interviews with tourists visiting the heritage site, tourism managers, and service providers. These interactions help identify the impacts of tourism activities on Ha Long Bay's ecosystem, the responsibilities of stakeholders, and their willingness to contribute financially to ecosystem conservation.

- The sample size for the survey, when the total population is unknown, is calculated using Yamane's formula (1967) [5]:

$$n = Z^2 \frac{p\ x\ (1-p)}{e^2}$$

in which:

- n: The required sample size to be determined.

- Z: The Z-score value from the Z-distribution table is based on the selected confidence level. Commonly, a 95 % confidence level is used, corresponding to Z=1.96.

- p: The estimated proportion of success for the sample size *n*. According to Yamane's formula, p=0.5 is chosen to maximize p(1−p), ensuring the most conservative estimate for sample size determination.

- e: The allowable margin of error. Typical values for *e* include ±0.01 (1 %), ±0.05 (5 %), and ±0.1 (10 %), with ±0.05 being the most widely used.

Using the sociological investigation method, two survey forms were developed:

- One targeted at tourists.
- One targeted at accommodation providers.

These surveys aim to assess the willingness to pay for an ecosystem conservation fund in Ha Long Bay. The total number of samples calculated by the formula is approximately 200 votes.

Survey structure:

- Section 1: Information on tourism activities within Ha Long Bay World Natural Heritage site.
- Section 2: Evaluation of the ecological impacts of tourism activities on the World Natural Heritage site.

2.3. SWOT model method

Using SWOT analysis, the study evaluates the current state of tourism, highlighting strengths, weaknesses, opportunities, and challenges in managing Ha Long Bay as a World Natural Heritage site.

Based on statistical results and interview results, through the SWOT tool (S - Strengths, W - Weaknesses, O - Opportunities, T - Challenges) analyze the strengths and weaknesses of biodiversity and ecosystem values, and tourism activities at the world natural heritage site of Ha Long Bay; analyze opportunities and challenges for biodiversity conservation, resource exploitation and environmental protection associated with ecotourism at the world natural heritage site of Ha Long Bay.

3. Research results

3.1. Evaluation of tourism activities and management at Ha Long Bay World Natural Heritage site

3.1.1. Strengths in tourism management

According to interviews with the Ha Long Bay Management Board, the tourism industry in Ha Long Bay demonstrated a remarkable recovery post-COVID-19, attracting 7.13 million visitors and generating revenue of 14.491 trillion VND in 2022. By early 2024, the bay welcomed over 610,000 tourists, including 529,000 international visitors, reinforcing its global appeal. The management board has implemented stringent environmental protection measures, such as waste control and regular water quality monitoring, contributing to preserving the bay's natural environment. Furthermore, new tourism products like ecotourism, MICE tourism, and cultural and sports events have been introduced to enhance service quality and evenly distribute tourist traffic.

In addition, policies have been reviewed and adjusted to address practical management needs. Natural landscapes, geological formations, and ecosystems are well-preserved, with community outreach and education yielding positive results. Water quality is monitored periodically, waste sources are controlled effectively, and international cooperation has been strengthened. Revenue from entrance fees has increased annually, providing essential resources for management and conservation efforts. Tourism development activities are aligned with the principles of heritage conservation, ensuring safety and enriching the visitor experience.

3.1.2. Weaknesses in tourism management

Despite positive growth, the rapid expansion of tourism presents significant challenges. Overcrowding, pollution from tourist boats, and socio-economic pressures are critical issues. Waste disposal, wastewater management, and ecosystem conservation require ongoing efforts from authorities and tourism businesses. Service quality remains uneven, with significant disparities between different tourism routes. While Routes 1 and 2 attract the largest number of visitors, other routes remain underutilized. Additionally, infrastructure requires upgrading to meet growing demands; for example, out of 505 tourist boats, 13 are still under repair, and other facilities need improvement.

Although measures like limiting the number of tourist boats and designating restricted areas have been implemented, enforcement and monitoring remain insufficient. This is compounded by a lack of coordination among agencies and inconsistent application of regulations. Limited resources in terms of personnel, finances, and technology hinder effective oversight, leading to non-compliance and negative environmental impacts. Addressing these issues requires enhanced inter-agency collaboration, adequate resource allocation, and greater community awareness of environmental protection and sustainable tourism practices.

3.1.3. Opportunities in tourism management

The Ha Long Bay Management Board has outlined plans for synchronized management mechanisms, including regulations on tourist boat operations, quality improvement plans, and guidelines for managing service activities like kayaking and rowboats. Since 2016, the number of operational boats has been reduced from 533 to 505, with a focus on improving quality and efficiency. Wooden boats have been replaced with steel-hulled or equivalent materials to ensure safety and meet tourism demands.

To optimize visitor distribution, Quang Ninh province has introduced new routes and attractions. Three premium cruise routes have been piloted, enhancing connectivity and reducing visitor congestion in core heritage areas. Scientific studies since 2017 have highlighted the unique values of Ha Long Bay, providing effective management and conservation solutions.

Furthermore, initiatives such as relocating fishing village residents to onshore housing since 2014 and banning fishing in strictly protected zones since 2018 have supported biodiversity preservation. Promotional activities have diversified through social media and international media partnerships. Tour guides, boat staff, and multimedia tools such as signage, CDs, and videos are leveraged to inform tourists and raise community awareness about ecosystem conservation.

3.1.4. Challenges in tourism management

Interviews with the Ha Long Bay Management Board reveal ongoing challenges that must be addressed to ensure sustainable ecosystem conservation. Climate change poses significant threats, including rising sea levels and altered habitats for various species. Effective preventive and adaptive measures are essential to address these challenges.

Tourism management and monitoring require strict and continuous enforcement to ensure all activities comply with environmental regulations. This necessitates close cooperation among local authorities, tourism businesses, and local communities. Additionally, enhanced research and impact assessments of human activities are crucial for developing effective conservation strategies. These studies provide insights into the effects of tourism and climate change on ecosystems, enabling the proposal of appropriate measures to protect and sustain the natural heritage of Ha Long Bay.

3.2. Assessment of the impacts of tourism activities on ecosystems in the Ha Long Bay World Natural Heritage site

3.2.1. Survey results from tourists

Ha Long Bay attracts a large number of tourists every year, including both domestic and international visitors. The frequency of tourists visiting this world natural heritage site varies from first-time to second-time visitors. This reflects the desire of visitors to explore and experience new things in the bay. First-time visitors to Ha Long Bay are often attracted by the magnificent natural landscape and cultural values, while those who return for the second time want to enjoy more of the interesting experiences they have had. Most tourists stay in the Ha Long Bay World Heritage site for 2 to 3 days (accounting for 51.6 % and 20.8 % of the total survey). This shows that tourists often choose a sufficient amount of time to explore and enjoy the experiences in Ha Long Bay, from sightseeing, cultural experiences to participating in entertainment and relaxation activities.

The average cost of a trip to Ha Long Bay usually ranges from 500,000 VND to 3,800,000 VND, depending on the length of stay, food costs and type of accommodation chosen by visitors. Ha Long Bay stands out with its natural beauty and diverse caves, attracting a large number of visitors. Therefore, the number of tourists to Ha Long Bay is always high and tourism activities are constantly developing. However, along with the growth of sea tourism, Ha Long Bay is also facing many negative environmental problems, affecting the natural landscape and ecosystem here.

* *Assessment of current status of domestic solid waste*

Table 1 provides detailed information on the types of solid waste commonly found in Ha Long Bay and the percentage of impact of each type. Accordingly, plastic bottles account for the highest proportion at 17.6 %, followed by tissue paper and cans at 16.7 % and 16.6 %, respectively. These are common types of waste and have a great impact on the marine environment. Plastic bags, at 11.5 %, and cigarette butts, at 11.1 %, are also significant sources of pollution, negatively affecting the marine ecosystem. Food waste and disposable plastic waste account for 8.5 % and 9.5 %, respectively, indicating the need to control and manage waste from tourism and daily activities. Styrofoam waste, at 8.2 %, and other household solid waste, although only at 0.3 %, also contribute to the total amount of waste and need to be effectively treated. Analysis of Table 1 clearly shows that plastic bottles, tissues and cans are the types of solid waste that have the greatest impact on the environment of Ha Long Bay. This raises an urgent need to reduce the use of plastic products and increase recycling measures. Waste such as plastic bags, cigarette butts, leftover food and single-use plastic waste also need to be strictly managed to minimize negative impacts on the ecosystem.

Table 1. Percentage of solid waste from tourists common in Ha Long Bay

Solid waste	Percentage of impact (%)
Plastic bags	11.5
Plastic bottles	17.6
Cans	16.6
Tissues	16.7
Cigarette butts	11.1
Food waste	8.5
Disposable plastic wast	9.5
Styrofoam wast	8.2
Other household solid wast	0.3

* *Impact of tourism activities on coral reef ecosystems*

Coral reefs in Ha Long Bay are an important part of the marine ecosystem, however, they are facing some serious problems:

• *Devastation due to tourism activities*: Many coral areas are destroyed by unsustainable tourism activities, such as kayaking, illegal diving, or destructive fishing methods.

• *Water pollution:* Improperly treated waste discharge from residential areas and tourist facilities, along with increased pollutants from tourism activities, have reduced water quality, causing damage to coral reefs.

• *Climate change:* Warming seawater and ocean acidification are major threats to coral reefs. These changes make corals susceptible to bleaching and death, seriously affecting marine biodiversity.

The degree to which tourism activities affect coral reef ecosystems in the Ha Long Bay World Natural Heritage Site is presented in Table 2.

The survey results from Table 2 indicate that 36.4 % of tourists believe tourism activities in Ha Long Bay have little to no significant impact on coral reef ecosystems. This reflects the effectiveness of environmental protection measures and monitoring efforts implemented by the Ha Long Bay Management Board. The 24/7 monitoring system and strict environmental regulations have successfully mitigated many negative impacts of tourism. Additionally, tourist awareness of environmental protection has improved, supported by informational signs and announcements placed at key stops throughout the bay, fostering a greater appreciation for the natural beauty of coral reefs.

Table 2. Impact of tourism activities on coral reef ecosystems in Ha Long Bay World Natural Heritage site

Impact level	Percentage (%)
No impact	13.2
Minimal impact	23.2
Minor impact	36.4
Moderate impact	19.2
Significant impact	8.0

However, 8.0 % of respondents expressed concerns about significant negative impacts on coral reefs, highlighting potential risks associated with littering, uncontrolled tourism activities, and non-compliance with environmental regulations. While most impacts are perceived to be mild or moderate, continued efforts and strengthened environmental protection measures are crucial to minimize any negative effects, ensuring the preservation and sustainability of Ha Long Bay's unique ecosystems.

** Impact levels of tourism activities on mangrove ecosystems*

Mangrove forests are a very important ecosystem for the environment, playing a role in protecting the coast, creating habitats for many animals and helping to regulate the climate. However, mangrove forests in Ha Long Bay are currently facing a number of problems:

• *Area reduction:* Land exploitation for tourism development, infrastructure projects and climate change have reduced the area of mangrove forests.

• *Environmental pollution:* Waste from residential areas and tourist areas near mangrove areas also contributes to the decline in the quality of the living environment of the mangrove ecosystem.

The degree to which tourism activities affect mangrove ecosystems in Ha Long Bay World Natural Heritage site is illustrated in Table 3.

Table 3. Impact levels of tourism activities on mangrove ecosystems in Ha Long Bay World Natural Heritage site

Impact level	Percentage (%)
No impact	12.7
Minimal impact	21.3
Minor impact	32.5
Moderate impact	26.5
Significant impact	7.0

The research results indicate that 34.0 % of surveyed tourists believe tourism activities have little to no significant impact on mangrove ecosystems. Specifically, 12.7 % reported no impact, while 21.3 % believed the impact was minimal. This suggests that the environmental protection and monitoring measures implemented by the Ha Long Bay Management Board have been effective to a certain extent. Strict environmental regulations, combined with a 24/7 monitoring system, have significantly reduced the negative effects of tourism activities. A notable proportion of respondents, 32.5 %, considered the impact of tourism to be minor, indicating that while tourist presence and activities exist, their impact on mangrove ecosystems remains manageable. This can be attributed to increased environmental awareness among tourists and effective coordination from the management board in maintaining and safeguarding the ecosystems.

However, some respondents pointed out that tourism does have certain adverse effects on mangroves. This highlights the need for the management board to further enhance protective measures, strengthen monitoring efforts, and raise awareness among both tourists and residents about the importance of environmental preservation. From this analysis, it is clear that while most surveyed tourists perceive the impacts of tourism on mangrove ecosystems as mild or moderate, there is still a need for continued environmental protection efforts. To ensure sustainable development and the best possible preservation of this valuable ecosystem, ongoing initiatives to protect the environment must remain a priority.

3.2.2. Impact levels of different tourism activities on ecosystems in Ha Long Bay World Natural Heritage site

The levels of impact of tourism activities on ecosystems in Ha Long Bay World Natural Heritage site are illustrated in Figure 1.

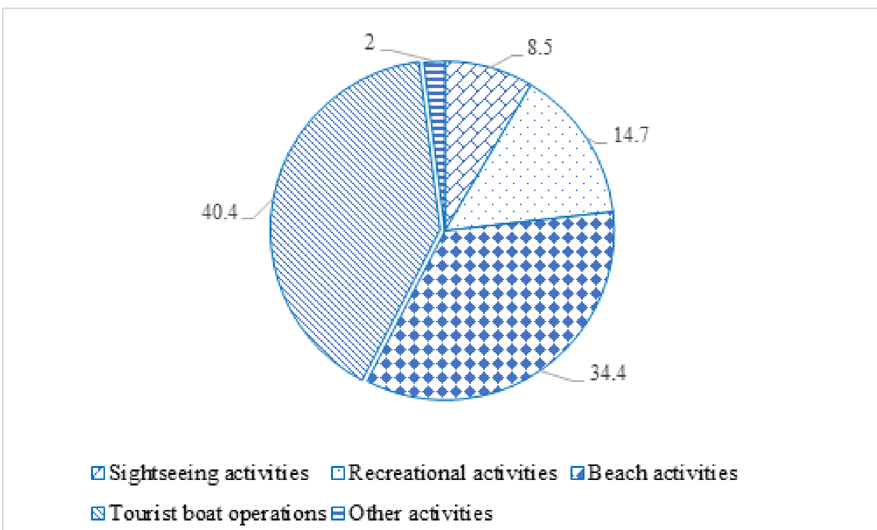

Figure 1: Impact levels of tourism activities on ecosystems in Ha Long Bay World Natural Heritage site

Figure 1 highlights that the operation of tourist boats is the most significant factor affecting Ha Long Bay's ecosystems, accounting for 40.4 %. Continuous boat activities contribute to noise pollution and degrade water quality, particularly impacting marine species sensitive to environmental changes. Beach activities follow at 34.4 %, reflecting the popularity of renowned beaches like Bai Chay and Minh Chau. While these activities provide substantial economic benefits, the increasing number of visitors and the use of personal care products contribute to a large amount of plastic waste and other pollutants, necessitating strict environmental management measures to ensure sustainability. Recreational activities, including adventure sports and cultural events, make up 14.7 % of the impact. These activities diversify tourism experiences and promote local economic growth but consume significant resources, generate waste, and pose risks to the habitats of local flora and fauna. Sightseeing activities, which account for 8.5 %, mainly focus on exploring the natural beauty of the bay and have a lower environmental impact. However, they still carry risks of soil erosion and damage to sensitive ecosystems. Additional activities like fishing and diving also have negative impacts, particularly when overexploitation or non-compliance with conservation regulations occurs.

Overall, tourism activities in Ha Long Bay are closely tied to the marine environment, offering both opportunities and challenges for its ecosystems. To achieve sustainable development, stringent management measures must be implemented, alongside the promotion of ecotourism and community awareness campaigns to emphasize the importance of protecting the natural values of this heritage site.

4. Conclusion

Ha Long Bay is celebrated for its pristine environment and stunning natural landscapes, underpinned by diverse and rich ecosystems, especially its well-preserved forests with minimal human impact. These attributes make it a prime destination for tourists seeking recreation and relaxation. However, research reveals that uncontrolled tourism activities, including boat pollution, visitor waste, and pressure on endemic flora and fauna, have negatively impacted the bay's ecosystems. Key ecosystems like mangroves and coral reefs are affected, with 32.5 % and 36.4 % of surveyed participants respectively rating their impact levels as low. Beach activities, contributing 34.4 % of the impact, also place considerable strain on these ecosystems.

Despite efforts in biodiversity conservation and waste management, current measures remain insufficient to prevent environmental degradation. Raising awareness and fostering responsibility among stakeholders is vital for protecting Ha Long Bay. While many tourists and locals recognize the importance of environmental protection, some still lack full awareness of their roles in preserving the bay. A shortage of information about tourism's ecological impacts further complicates conservation efforts. Innovative educational programs and communication strategies are crucial to improving community awareness, driving behavioral changes, and ensuring the sustainable development and long-term protection of this World Natural Heritage site.

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

Bui Thi Thuy Dao*, Ninh Thi Kim Anh

Hanoi University of Natural Resources and Environment, Vietnam

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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.

***Corresponding author, Email:** bttdao@hunre.edu.vn

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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.

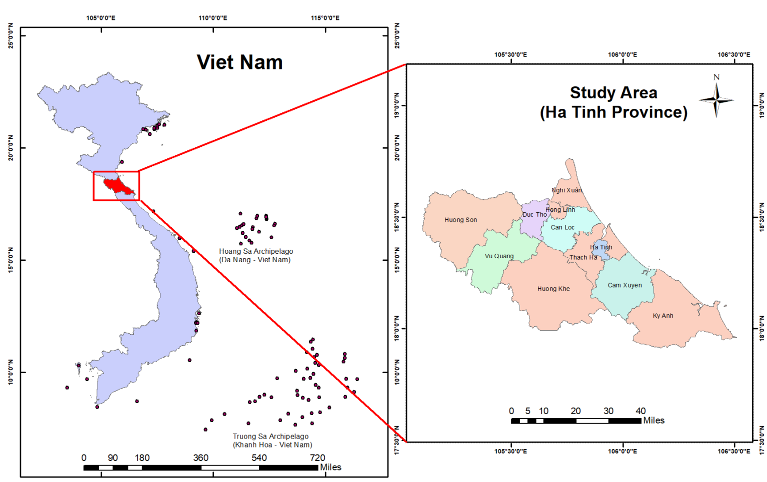

Figure 1: Geographical location of Ha Tinh province

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:

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

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.

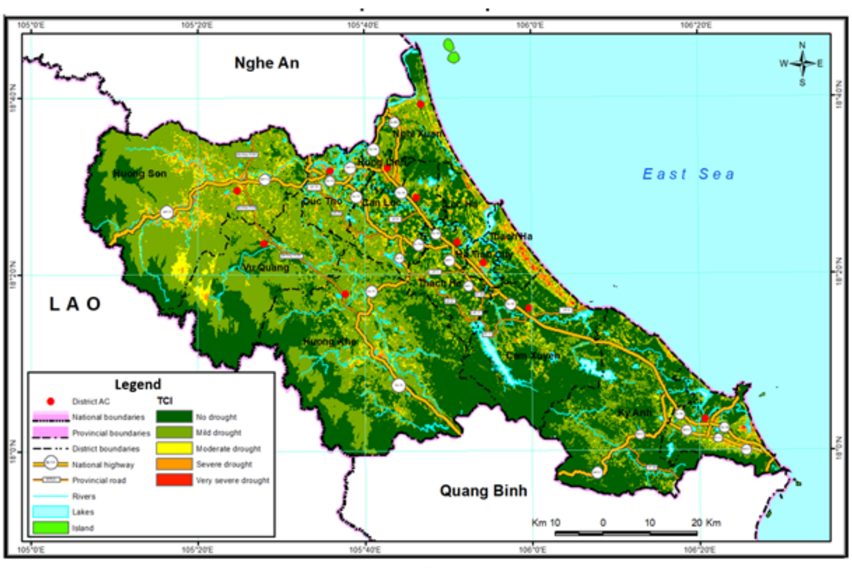

Figure 2: TCI index map of Ha Tinh province

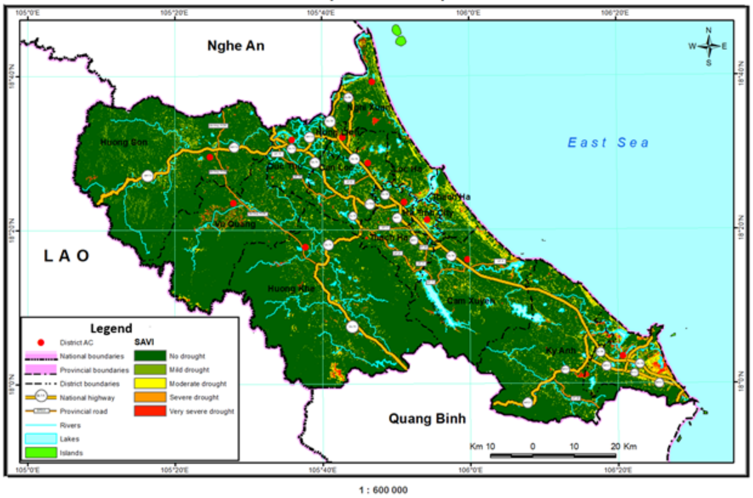

Figure 3: SAVI index map of Ha Tinh province

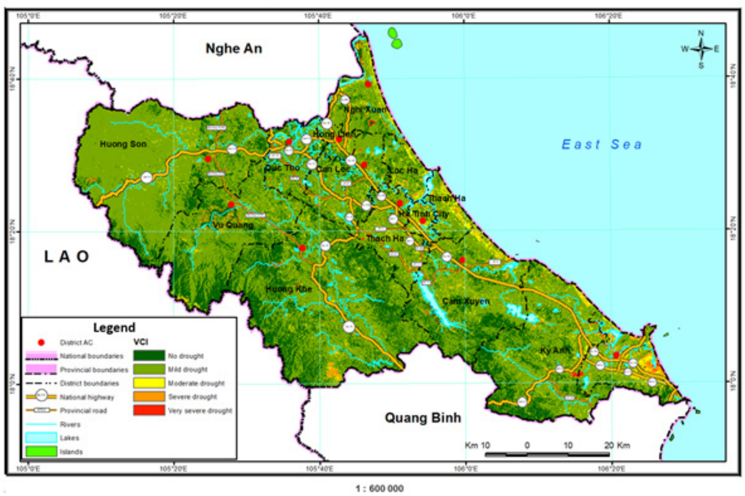

Figure 4: VCI index map of Ha Tinh province

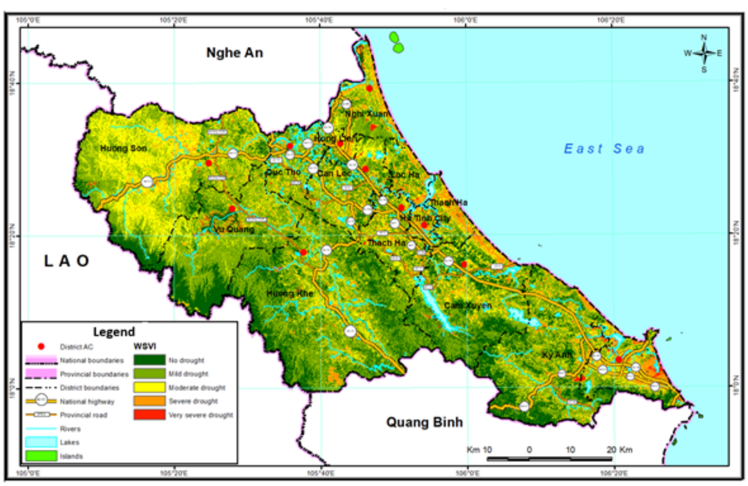

Figure 5: WSVI index map of Ha Tinh province

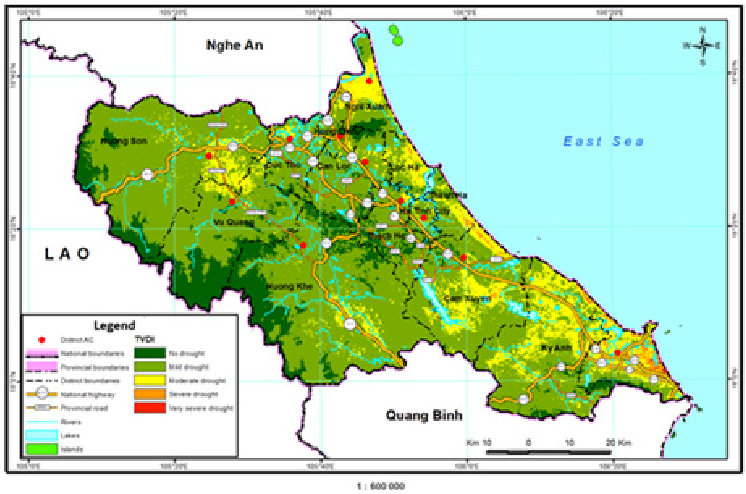

Figure 6: TVDI index map of Ha Tinh province

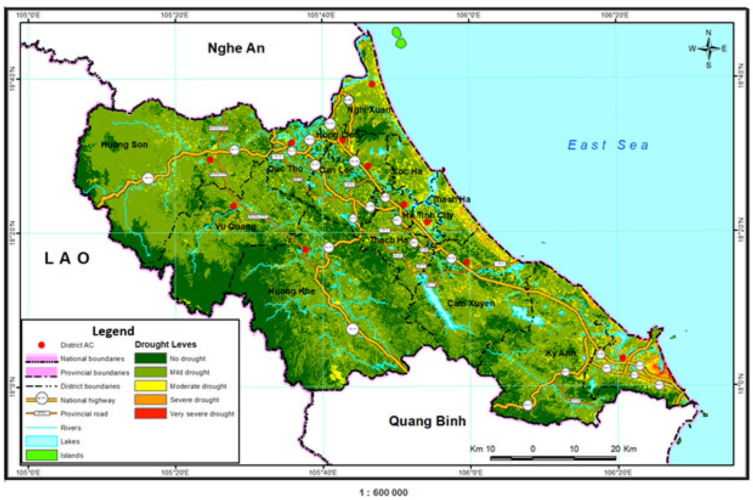

Figure 7: General drought map of Ha Tinh province

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:

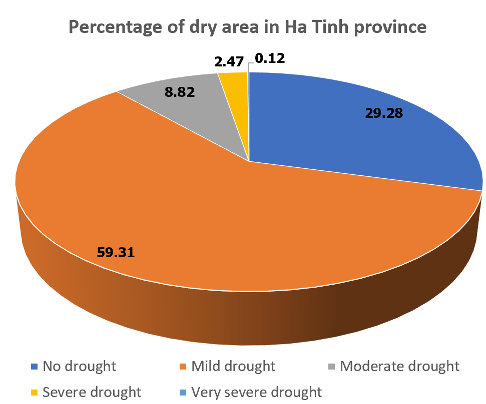

Figure 8: Dry zoning chart of Ha Tinh province

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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AIR QUALITY PREDICTION IN HANOI USING A DEEP LEARNING APPROACH

Dang Thi Khanh Linh*, Vu Van Huan
Hanoi University of Natural Resources and Environment, Vietnam

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Abstract

Air pollution is becoming a serious global crisis, threatening human health, disrupting the balance of the environment, negatively affecting ecosystems, and contributing to climate change. Accurate long-term air quality prediction plays a key role in building early warning systems to mitigate these negative impacts. Efforts to forecast air quality through the combination of knowledge from environmental science, statistics, and computer science have attracted much attention. Among them, deep learning and advanced machine learning have demonstrated an outstanding ability to detect complex non-linear patterns from environmental data. However, the application of deep learning to air quality prediction is still quite new. This paper proposes a deep-learning model using the LSTM (Long Short-Term Memory) network to predict air quality in Hanoi. The research results demonstrate that the proposed model is capable of predicting the air quality index with high accuracy, close to actual values from monitoring data.

Keywords: Air quality index; Deep learning; LSTM.

***Corresponding author, Email:** dtklinh@hunre.edu.vn

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1. Introduction

Air pollution is the biggest environmental threat, mainly due to toxic emissions from rapid industrialization and population growth. Air quality has deteriorated significantly, seriously affecting human health. The AQI index is used to measure pollution levels, based on 12 parameters such as PM2.5, PM10, O_3, NO_2, SO_2, CO, NH_3, Pb, Benzene, Toluene, and Arsenic. Typically, six major substances (PM10, PM2.5, SO_2, CO, and O_3) are used to calculate the AQI, depending on the target, data, and monitoring technique. A high AQI indicates severe pollution with a high health risk. AQI data is monitored in real-time and collected daily at many weather stations [1].

Accurately predicting air quality is a significant challenge due to the spatial and temporal heterogeneity of data from sources such as ground monitoring stations, satellites, and aircraft. Ground monitoring stations are particularly important as they are strategically located near highly polluted areas, providing valuable data for analyzing air quality fluctuations. However, many regions still lack comprehensive monitoring systems, leading to sparse and limited data. Additionally, the complexity of chemical processes involved in air pollution, combined with their spatial and temporal variability, makes it challenging to rely on fixed formulas for predictions. As a result, achieving accurate air quality predictions remains a demanding task [2].

Today, two main methods have been used to predict air quality: traditional methods based on hand-crafted features and machine learning algorithms based on deep learning. Traditional methods include basic numerical, statistical, and machine-learning models. Numerical models are based on atmospheric dynamics and chemical processes, using meteorological data to simulate pollution. Meanwhile, statistical models focus on integrating meteorological data with historical air quality data but have limitations in handling nonlinear problems [3]. To overcome this, researchers have applied nonlinear machine learning such as SVR and RFR, which have better performance. However, these methods still have difficulty capturing complex time series patterns and modeling the long-term impact of pollution, leading to reduced prediction accuracy [4, 5, 6].

In recent years, deep learning techniques have emerged and attracted considerable attention in various fields. These methods are effective in recognizing complex patterns and extracting high-level features, achieving great success in fields such as computer vision, speech processing, and natural language processing. However, there is still a lack of systematic reviews on the application of deep learning to air quality prediction [2].

Recently, Artificial Intelligence (AI) algorithms have been widely applied in air quality prediction. Thanks to the advancement of computational technology and algorithms, deep learning models have been deployed to analyze and predict non-linear relationships between data variables. These models have demonstrated outstanding effectiveness in improving the accuracy and reliability of data analysis results [7]. The Random Forest Regression (RFR) and Support Vector Regression (SVR) algorithms were applied to build a regression model to predict the air quality index (AQI) in the study of Liu H et al., [8]. Data related to nitrogen oxide concentrations in a city in Italy, obtained from a public data source, were analyzed. The performance of the models was evaluated based on the correlation coefficient, Root Mean Square Error (RMSE), and coefficient of determination R2. The results show that both methods provide superior prediction performance.

Similarly, Wu Q et al., proposed a hybrid and optimal method that combines secondary analysis (SD) with an AI optimization algorithm [9]. AQI data collected from China during 2016 - 2018 were used to validate the prediction model. Wavelet analysis was performed on high-frequency, low-frequency, and variable modes, and sample entropy was used to smooth the analysis. Then, a Neural Network (NN) based on Long Short-Term Memory (LSTM) was deployed to predict AQI [10].

In addition, the parameters of the least squares support vector machine (LS - SVM) were optimized using the BAT algorithm, taking into account factors related to air pollutants. The results show that this method effectively models the characteristics of AQI data, contributing to improved prediction ability.

Air pollution data, a typical form of time series data, has the potential to be improved through the integration of dynamic data [11], which is an important direction in real-time forecasting. Current deep learning models often have many parameters, resulting in high computational complexity. However, due to the time-sensitive air quality prediction requirements, the models must ensure fast and accurate prediction. Therefore, reducing the computational complexity of deep learning models is an important challenge for future research.

In addition, many factors significantly affect air pollution data. For example, high wind speed can reduce PM2.5 concentrations, while high humidity often increases pollution levels. High atmospheric pressure is also often correlated with improved air quality. These meteorological features play an important role in building air quality prediction models, emphasizing the importance of incorporating weather factors into the analysis and forecasting process.

To address the challenges in enhancing the accuracy of air quality prediction, this study makes the following key contributions:

i) Propose extended features to improve the accuracy of air quality predictions in Hanoi, Vietnam.

ii) Development of a predictive model for the AQI index using the LSTM deep learning algorithm.

2. Data and method

2.1. The dataset

The datasets reflect various environmental conditions associated with air pollutant concentrations. Data on six pollutants - PM2.5, PM10, NO_2, O_3, SO_2, and CO - were collected from multiple monitoring stations in Hanoi, the capital of Vietnam. These pollutants served as predictors for the analysis and were recorded over the period from July 5, 2016, to July 1, 2020.

The raw dataset from the Hanoi monitoring stations consists of 2,115 rows, stored in a CSV file. This dataset is divided into two subsets: The first 2,005 rows are used for training, while the remaining 110 rows are reserved for testing. Before the training phase, data preprocessing is performed to address missing or invalid values in the raw dataset. Missing values are handled through an imputation process, which replaces them with the nearest data points. This approach is applied when the percentage of missing values is below 16 % for a row or 1 % for a column within the station datasets.

2.2. Feature selection

In Vietnam, pollution levels are assessed using parameters such as PM2.5, PM10, NO_2, O_3, SO_2, and CO. In this study, we forecast the values of PM2.5 and PM10 based on data from the preceding 15 days. To enhance forecasting performance, we incorporate extended features into the dataset in addition to the raw parameters from the collected data.

Since Particulate Matter (PM) can be directly emitted from sources or formed in the atmosphere through chemical reactions involving gases such as SO_2, NO_x, and certain organic compounds, and as pollutants often interact with one another, we propose an extended feature set. This set includes the following: the total measured values of pollutants for a given day, the average daily values of PM10 and PM2.5, and the average daily values of NO_2, CO, SO_2, and O_3. The extended features are detailed in Table 1.

Table 1. Description of extended features

No	Feature	Type	Description
1	S_Data	Numeric	Total of value data on day (Sum of PM2.5, PM10, NO_2, O_3, SO_2, and CO values)
2	A_PM	Numeric	Median of PM2.5 and PM10 values
3	A_O	Numeric	Median of NO_2, O_3, SO_2, and CO values
4	S_PM10	Numeric	Total of PM10 values 15 days earlier (Sliding window size = 15)
5	A_PM10	Numeric	Average of PM10 values in 15 days earlier

2.3. Sliding window

The sliding window method is a technique that utilizes prior time steps to predict the next time step. By applying this method, the input data is restructured into segments based on a defined window size. In this study, the window size was set to 15, meaning that data from the previous 15 days is used to predict the value for the subsequent day. After restructuring, the data resembles a supervised learning dataset, allowing it to be used with any machine learning algorithm for time series modeling [12]. If the dataset consists of m input time series, denoted as X, and an output series, denoted as Y, then:

$$X = \{x_t^i\} \ t \in \mathrm{T}=\{1,2,\ldots,n\} \text{ and } i = 1,2,\ldots,m \quad (1)$$
$$Y = \{y_t\} \ t \in \mathrm{T}$$

The sliding window transformation process generates the following dataset:

$$X = \{\{x_{t-1}^1, x_{t-2}^1, \ldots, x_{t-w}^1\}, \{x_{t-1}^2, x_{t-2}^2, \ldots, x_{t-w}^2\} \ldots, x_{t-1}^m, x_{t-2}^m, \ldots, x_{t-w}^m\}, \{y_{t-1}, y_{t-2}, \ldots, y_{t-w}\}, y_t\} \ with \ t \in \mathrm{T} \quad (2)$$

w: represents the window size.

2.4. Performance evaluation

Similar to the previous study, the performance of the models is evaluated using the metrics RMSE (Root Mean Squared Error) and MAE (Mean Absolute Error) [12]. These metrics are calculated based on the differences between the predicted results and the true values. Additionally, R2 (R-squared) is used to quantify the strength of the relationship between the predictive models and the target variables [13]. The mathematical expressions for these metrics are defined as follows:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|y_i - \hat{y}_i\right| \tag{3}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(y_i - \hat{y}_i\right)^2} \tag{4}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(y_i - \hat{y}_i\right)^2}{\sum_{i=1}^{N}\left(y_i - avg(y)\right)^2} \tag{5}$$

Where $\hat{y}_i$ is the i^{th} predicted value, y_i is the i^{th} obsered value.

2.5. Model for predicting AQI

After preprocessing the data, the next steps involve preparing it for training and testing. In deep learning methods, model construction is typically achieved through experimental processes. In this study, we focus on utilizing a multi-step LSTM model. The proposed model for predicting AQI is shown in Fig 1.

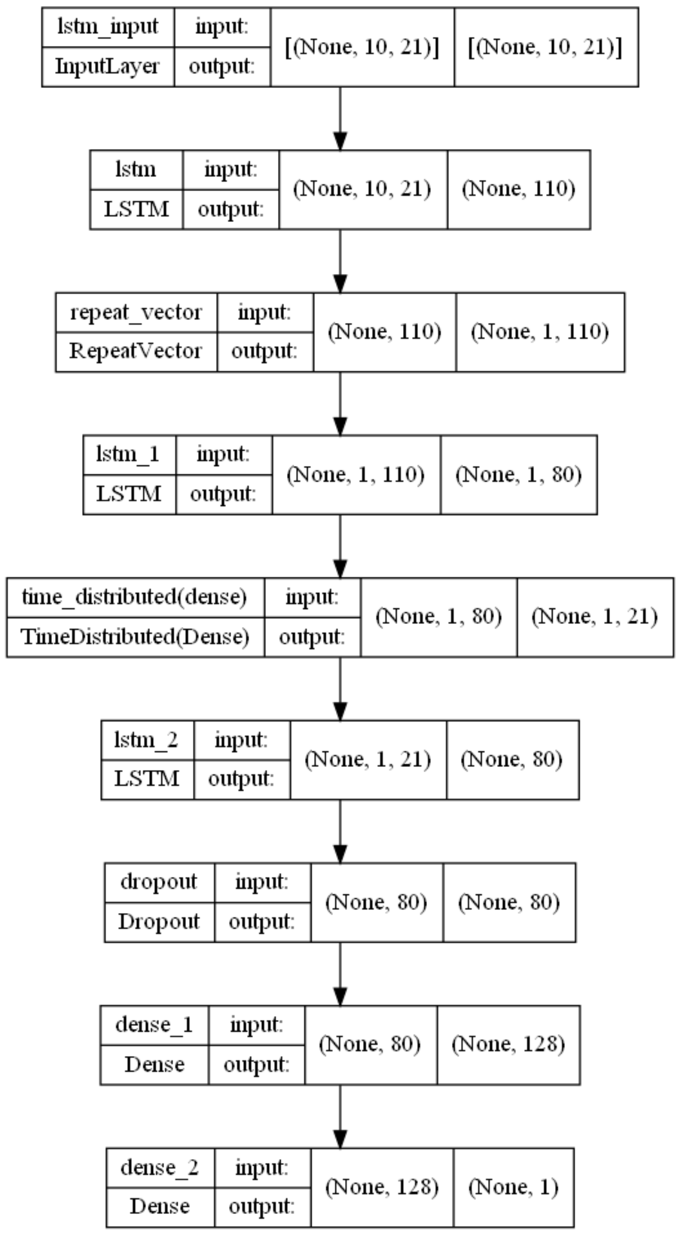

Figure 1: The proposed model for predicting AQI

3. Results and discussion

The models were trained on a Lenovo X270 computer with 8GB of RAM, using Python 3.9 in an integrated development environment (IDE).

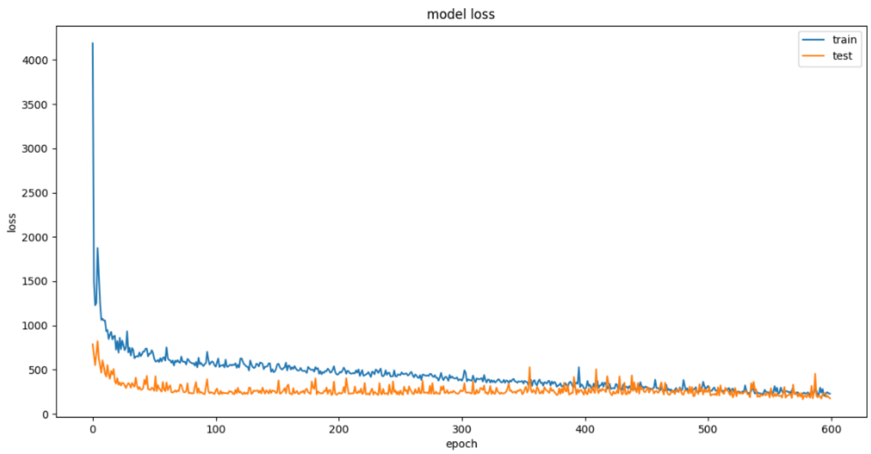

Figure 2: The loss model graph

Fig. 2 illustrates the loss graph for both the training and test sets. The loss on the training set decreases progressively with each epoch, indicating that the model is effectively learning from the data and improving its accuracy on the training set. Beyond epoch 450, the losses on the training and test sets converge, demonstrating that the proposed model adequately fits the data and aligns well with the prediction target.

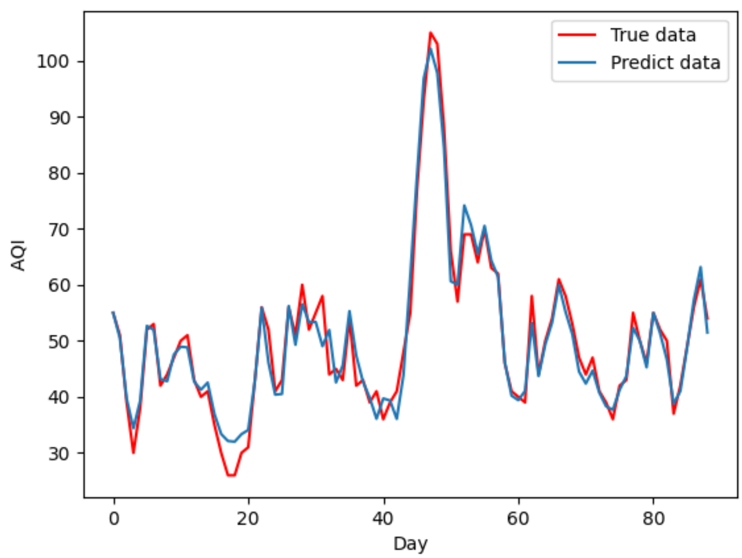

Figure 3: The trend of AQI real value and predicted value

Fig. 3 describes the trends of actual and predicted values for the AQI index in Hanoi during April, May, and June 2020, as modeled by our proposed approach. We employed the Encoder LSTM algorithm with a sliding window size of 15. The results demonstrate that our model effectively captures and predicts the trend of the AQI index.

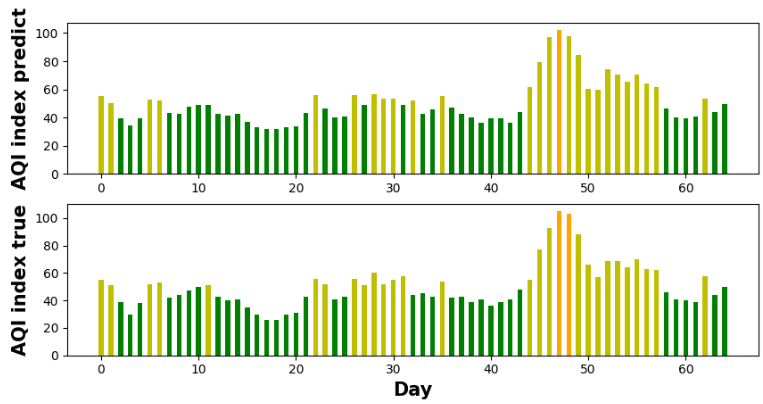

Figure 4: The true AQI values and AQI values from April to June 2020 in Hanoi

Fig. 4 shows the actual AQI values alongside the predicted AQI values in Hanoi from April to June 2020. The colors represent different levels of health concern: green indicates good air quality, yellow signifies moderate conditions, and orange or red denotes unhealthy levels [15].

Table 2 presents the detailed evaluation results of the prediction of the Air Quality Index (AQI) in Hanoi for the next three days, using the LSTM algorithm. The prediction was made based on the data of the previous 15 days, using the LSTM model with a sliding window. The results show that the machine learning algorithms achieved high performance in predicting the AQI index for the first day, with evaluation indices including MAE = 2.456, RMSE = 3.243, and $R2$ =0.96. This proves that the proposed model is suitable for the initial training data and target, demonstrating good learning and generalization ability.

However, when predicting the AQI index for the second and third days, the accuracy of the model tends to decrease. The reason is that the input data for the following days is taken from the prediction results of the previous days. This leads to an accumulation of errors over each prediction step, which gradually reduces the accuracy over time. However, the overall performance of the model is still reliable, showing potential for application to time-series AQI prediction problems, especially in applications requiring short-term forecasting.

Table 2. Performance of the LTSM AQI predicted model

The step ahead	MAE	RMSE	R2
1 day ahead	2.456	3.243	0.96
2 day ahead	6.782	8.587	0.723
3 day ahead	7.235	9.111	0.693

4. Conclusion

In this paper, we proposed a deep learning model to predict air quality based on AQI. The effectiveness of this method has been verified through the criteria: high accuracy with small MAE, short training time, and simple model structure. To evaluate the performance of the model, we use the MAE, RMSE, and R2 indices. The results show that the deep learning method with the LSTM algorithm, using a 15-day sliding window, is capable of predicting 1 day in advance with high reliability. Our experimental results achieved R2 = 0.96, based on a dataset collected over 4 years in Hanoi, Vietnam. This shows the potential application of the model not only in research but also in real-time air quality forecasting systems. This method can be used to assist managers in taking timely measures to protect public health and minimize the impacts of air pollution.

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CALCULATING THE INFLOW TO TUYEN QUANG RESERVOIR BY HEC-HMS MODEL USING DIFFERENT LULC MAPS AND BASIN DIVISIONS

Nguyen Tuan Anh*, Nguyen Chinh Kien, Duong Thi Thanh Huong, Do Thanh Hang, Nguyen Thi Hang, Tran Thi Thanh Huyen

Institute of Mechanics, Vietnam Academy of Science and Technology

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Abstract

For mathematical models in general and hydrological models in particular, the accuracy of input data and the detail in using that data greatly affect the calculation results. For each specific requirement, how detailed the input data needed to ensure the accuracy while still meeting the requirements of real-time tasks is an issue that needs to be surveyed and researched. In this paper, the authors use HEC-HMS model with two types of LULC (Land use-Land cover) maps and different ratios of basin division to calculate Tuyen Quang reservoir inflow for August 2023 and July 2024 floods. The results show that the Jaxa LULC map gives better results than the Microsoft and Esri LULC map and divides Tuyen Quang basin into 29 sub-basins is more suitable than 09 and 49 sub-basins. From there, the influence of LULC map as well as the ratio of basin division on the accuracy and calculation time are commented.

Keywords: LULC map; Tuyen Quang reservoir; HEC-HMS.

***Corresponding author, Email:** ntanh@imech.vast.vn

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1. Introduction

In distributed or semi-distributed hydrological models such as Marine (France), WetSpa (Belgium), TopModel (UK), HEC-HMS (USA) [1], detailed data on basin characteristics (Topography data, Land use-Land cover map, Soil map,...) greatly affect the calculation results of basin inflow. However, these data are difficult to accurately measure on a large scale because of the very high cost. Thanks to remote sensing technology and artificial intelligence, several types of LULC maps are built and provided for free with a good accuracy, synchronized over time on large scale and continuously updated annually. Two types of LULC maps are free and the best today.

The LULC map has resolution of 10 × 10 m including 12 layers built by analyzing images taken from the advanced ground observation satellite ALOS-4 of the Japanese aerospace agency (Jaxa). The collected data were validated by using random sampling stratification, following the procedure for assessing the accuracy of LULC changes proposed by Olofsson et al. Accordingly, 600 points are randomly distributed on 12 layers corresponding to 12 layers of LULC map. The error matrix of the samples is created based on the actual validation data. Then, the error matrix of the area ratio is calculated by multiplying each row by the area ratio of that row [3].

LULC map has resolution of 10 × 10 m from Microsoft & Esri including 9 layers built by analyzing Sentinel-2 satellite images based on artificial intelligence models trained with billions of pixels labeled images. This dataset, produced by Impact Observatory, (Microsoft & Esri) displays a global map of LULC for the years 2017 - 2023. Each map is a composite of LULC predictions for 9 classes throughout the year in order to generate a representative snapshot of each year. This dataset used billions of human-labeled pixels (curated by the US National Geographic Society) to train a deep learning model for land classification. Each global map was produced by applying this model to the Sentinel-2 annual scene collections from the Microsoft Planetary Computer. Each of the maps has an assessed average accuracy of over 75 %.

These maps have been improved from Impact Observatory's previous release and provide a relative reduction in the amount of anomalous change between classes, particularly between "Bare" and any of the vegetative classes "Trees," "Crops," "Flooded Vegetation," and "Rangeland". This updated time series of annual global maps is also re-aligned to match the ESA UTM tiling grid for Sentinel-2 imagery [4].

High resolution and detailed maps will help the model reflect the basin characteristics of the study area better. In distributed hydrological models the more detailed the data, the larger the calculation volume and requiring more time for processing. It also leads to the phenomenon of errors accumulation and poor results. For the semi-distributed model, if the area of the sub-basin is too large, it will not be able to describe all the characteristics of the region but if it is too small it will take a long time to adjust and calculate the model. It is also encountered the phenomenon of error accumulation if the model is not established well.

In Vietnam, the author Bui Dinh Lap [2] has studied how to divide and index the basin with the aim of mitigating the spatial impact of input factors such as soil, LULC map as well as the influence of spatial rainfall distribution,...

In this paper, the authors calculate Tuyen Quang reservoir inflow using two types of free and best available LULC maps from the Japan Aerospace Agency (Jaxa) and Microsoft & Esri. Furthermore, in order to study the influence of detail in basin division on the results and calculation time the authors divided the Tuyen Quang basin into sub-basins with different numbers.

2. Data collection

The authors collected the following data for calculating the Tuyen Quang reservoir inflow (The rainfall runoff throughout Tuyen Quang basin called Tuyen Quang reservoir inflow).

Digital Topographic map (DEM) has 30 × 30 m resolution data, provided free of charge by the Japan Aerospace Agency (Jaxa) in 2022 [5].

Soil map has 250 × 250 m resolution provided by FAO in 2020.

LULC map has 10 × 10 m resolution from the Japan Aerospace Agency and Microsoft & Esri in 2023.

Measured rainfall data in Tuyen Quang basin at the rain stations: Bac Me, Bao Lac, Chiem Hoa, Cho Ra, Dau Dang, Dong Van, Ha Giang, Ham Yen, Na Hang in 2023, 2024 from the National Center for Hydrometeorological Forecasting, General Department of Hydrometeorology (Figure 2, 3). Tuyen Quang reservoir inflows in 2023 and 2024 from Vietnam Electricity (EVN) [6].

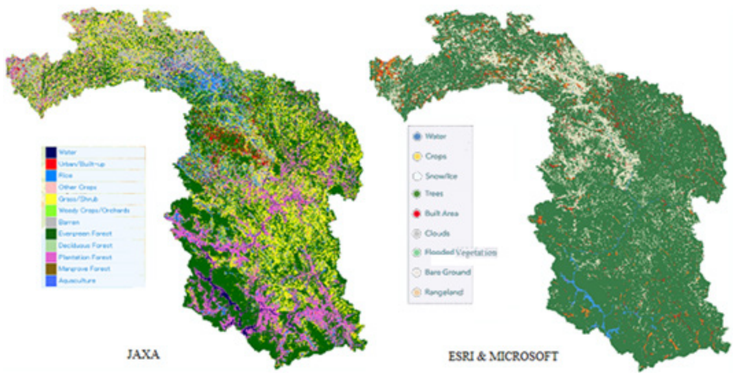

Figure 1: LULC map

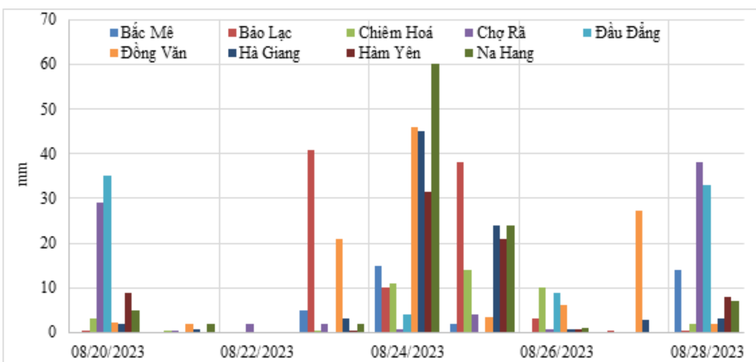

Figure 2: Rain data on Tuyen Quang basin in 2023

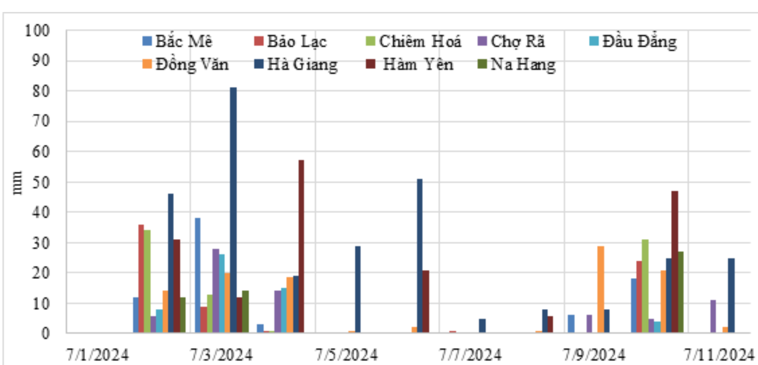

Figure 3: Rain data on Tuyen Quang basin in 2024

3. Model setup

The HEC-HMS hydrological model [7] stands for Hydrologic Engineering Center - Hydrologic Modeling System, built by the American Society of Military Engineers to calculate the process of converting rain into runoff on each sub-basin, then routing the flow on the river system [8]. In this model, the process of converting runoff from rain is calculated according to the following processes: Rain on the sub-basins will be collected on each sub-basin after infiltration process into the soil (Loss), then these flows are routed along the river branches concentrated at the outlet point of the basin. In this entire process, the loss greatly affects the final result. These processes are modeled by many different methods through average parameters of time and space. These parameters are adjusted to suit the characteristics of each studied basin.

3.1. Loss method

In HEC-HMS, loss can be calculated by many methods, to use the characteristics of the LULC map the model offers two methods: "Grid Curve Number" or "Curve Number" (CN). The CN method is more often used because it is simpler, more stable, easier to use and more useful, especially in river basins with little or no measuring stations. The CN method was introduced by the United States Land Conservation Agency (USDA) to calculate surface runoff from a certain amount of rainfall in river basins. It is a method constructed from a set of experimental equations and parameters. Its core is to determine the characteristics that hold or store the maximum amount of water in the soil according to its depth. These characteristics depend on factors: LULC, Soil types, Initial moisture conditions,...

The CN method [9] is built on the water equilibrium equation with two basic hypotheses:

- Hypothesis of balance between total rainfall and total surface water and permeability (1).

- Hypothesis of the relationship between initial permeability and maximum retention or penetration (2).

Therefore, the CN method will include:

- Water balance equation:

$$P = I_a + F + Q \qquad (1)$$

- Proportional equilibrium hypothesis:

$$\frac{F}{S} = \frac{Q}{P - Ia} \qquad (2)$$

in which: P is the total rainfall; I_a is the initial permeability (mm); F is cumulative permeability; Q is the Surface Water Level (mm); S is the maximum retention or penetration capacity (mm).

Combining equations (1) and (2) would have:

$$Q = \frac{(P - Ia)^2}{P - Ia + S} \qquad (3)$$

I_a is taken as 0.2S based on experimental research, S is calculated from soil and LULC map.

- The formula to calculate CN is as follows:

$$\mathrm{CN} = \frac{25400}{254 + S} \qquad (4)$$

The “Curve Number set” (CNs) is calculated and used in the HEC-HMS model according to the following steps:

- The author counted the LULC classification from the two types of collected maps. Because these LULC maps have different ways in dividing data layers according to different land cover types, a full classification system is needed to serve as a standard for calculation. The authors chose the TR-55 Technical Release, the most widely used hydrological approach in the US since 1975, using the “Soil Conservation Service” flow equation so that the flow rate, the total volume, the hydrological flows is maximum. On the TR-55 Technical Release to refer to the estimated value of the CNs for different land use situations on hydrological land groups for each map, the authors have grouped and classified according to the common standard table (Table 1) on each grid cell.

- Use DEM data, soil map, LULC maps and sub-basins to calculate the CNs for each sub-basin using GIS software.

- At last, the CNs is used in the HEC-HMS model in the form of losses including: CN; Initial Loss (%); Impervious (%).

Table 1. Curve index reference table of maps with Technical Release TR-55

No.	MICROSOFT & ESRI	JAXA	SCS TR-55	A	B	C	D
1	Water, Flooded vegetation, Snow/Ice	Water - Aquaculture	-	0	0	0	0
2	Crops	Rice/Other Crops	Row crops	64	75	82	85
3	Tree	Woody, Crops/Orchards, Evergreen Forest, Deciduous Forest, Plantation Forest, Mangrove Forest	Woods	30	55	70	77
4	Built Area	Urban/Built-up	Residential districts by average lot size	54	70	80	85
5	Clouds	-	-	100	100	100	100
6	Bare Ground	Barren	Fallow: Bare soil	77	86	91	94
7	Rangeland	Grass/Shrub	Pasture, grassland, or range-continuous forage for graving	39	61	74	80

3.2. Sub-basin division

The authors divided the Tuyen Quang basin into different numbers of sub-basins (09, 29 and 49) to study the impact of the basin division on the Tuyen Quang reservoir inflow (Figure 4).

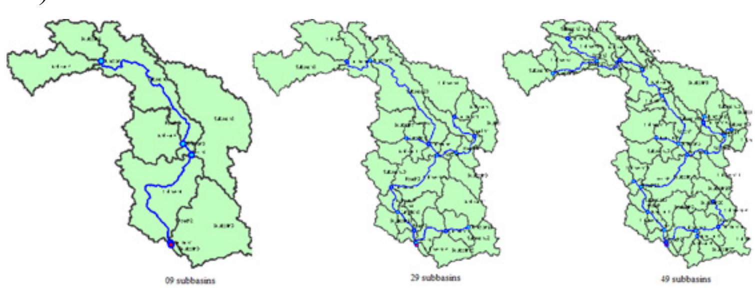

Figure 4: Basin division into 09, 29, 49 sub-basins

In addition to the loss method according to the CNs mentioned above, which are calculated with fixed values, other parameters of each sub-basin and reach need to be optimized such as time of water concentration, flow transmission parameters,… Based on the error between the calculated basin outflow and the observed value, these parameters need to be optimized so that the error is minimum.

Table 2. Number of optimization parameters

Number of sub-basin	Parameters
09	22
29	65
49	122

In the HEC-HMS model, each sub-basin and reach has its own parameters that need to be optimized. Therefore, the number of sub-basins divided will directly affect the accumulated error as well as time of parameter optimization.

3.3. Parameter optimization method

In the HEC-HMS model, there are two automatic parameter optimization methods. Simplex and Differential Evolution methods:

- The Simplex method is a parameters optimization method that uses a Simplex (a set of parameter values) to move to a peak (a position in multidimensional space) at which the value of the objective function (usually the root mean square error) is minimal. This is a direct optimization method (based on geometric operations such as reflection, expansion, contraction) and is often applied to non-linear optimization problems where the derivative may not be known.

- The Differential Evolution method by maintaining a population of the problem's solutions and creating new solutions by adding weighted distribution components randomly to the components of the existing solutions in order to create new solutions to the population. After each generation, the best fit solution (the objective function is the smallest) is kept.

In the previous publication of the authors, the parameter optimal tool of HEC-HMS is used to calculate Ban Chat reservoir inflow [10]. The Differential Evolution method has shown its superiority and was chosen to optimize time of water concentration, flow transmission,... for Tuyen Quang basin. Using the ending condition of iterations (tens of thousands) and a small tolerance (0.01 m^3/s) to ensure the convergence of the method.

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4. Calculation and results

4.1. Assessment of LULC map influence on calculation of Tuyen Quang reservoir inflow

Using 2 types of collected LULC map and dividing Tuyen Quang basin into 9 sub-basins the authors calibrating and verifying using CNs according to empirical values that references to equivalent values of other basins (User), LULC map from Jaxa (Jaxa LULC) and LULC map from Microsoft & Esri (ME LULC) for the same division plan. Tuyen Quang basin is divided into 9 sub-basins, the authors calibrated and verified the HEC-HMS model to calculate the Tuyen Quang reservoir inflow with floods in August 2023 and July 2024. The calculation results are shown in Figure 5, 6 and evaluated by the Nash-Sutcliffe Efficiency indexes (NSE).

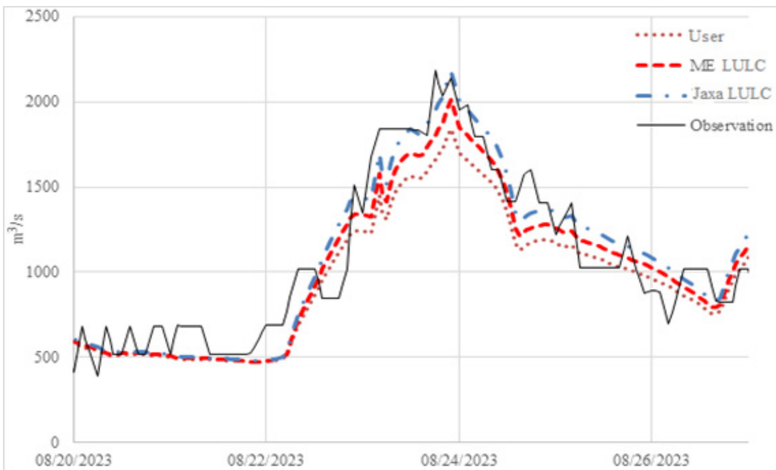

Figure 5: Calibration of Tuyen Quang reservoir inflow in 07/2024

Figure 6: Verification of Tuyen Quang reservoir inflow in 07/2024

Table 3 is the assessment table of the results according to the NSE index. The results show that Jaxa's LULC map gives the best results with the NSE index reaching 0.82 for the calibration and 0.66 for the verification.

Table 3. NSE index

Plan	NSE	
	Calibration	Verification
KN	0.61	0.58
ME	0.75	0.62
JX	0.82	0.66

4.2. Assessment of basin division influence on calculation of Tuyen Quang reservoir inflow

In this article, the authors have not yet attempted to find the optimal number of sub-basins in Tuyen Quang, Just only tested and evaluated 03 ways to divide the basins gradually increasing in number. Starting from the default division of the HEC-HMS model of 09 (JX-09) sub-basins, the authors increase the number of sub-basins (corresponding to the increase in parameters and calculation time) to 29 (JX-29) and 49 (JX-49) sub-basins (To suit existing research conditions as computer system and research time).

The results of calibration and verification in 8/2023 and 7/2024 are shown in Figure 7, 8.

The calculation time and NSE index are shown in Table 4.

Table 4. NSE index and calculation time

Plan	NSE		Cal Time (s)
	Calibration	Verification	
JX-09	0.82	0.66	163
JX-29	0.85	0.69	455
JX-49	0.75	0.63	1130

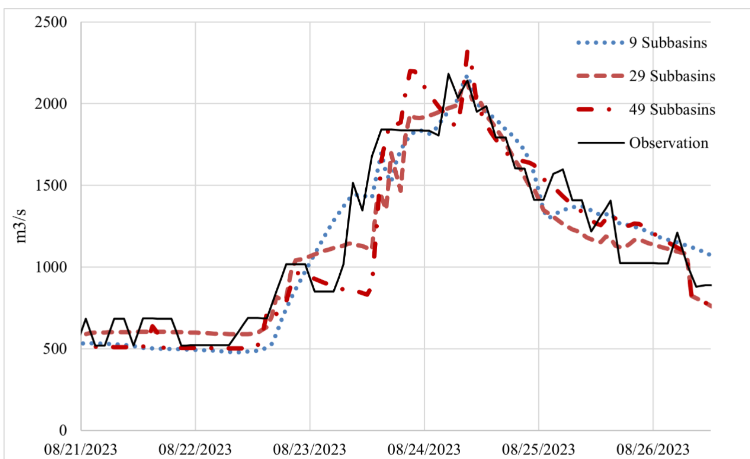

Figure 7: Calibration of Tuyen Quang reservoir inflow in 08/2023

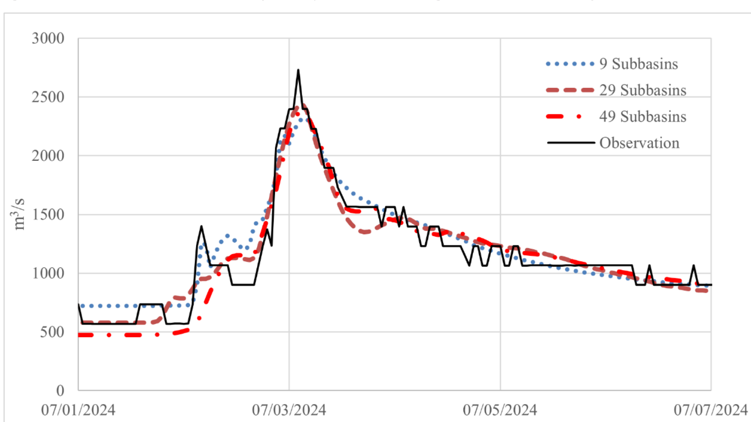

Figure 8: Verification of Tuyen Quang reservoir inflow in 07/2024

Through this table, we can see that the plan to divide Tuyen Quang basin into 29 sub-basins gives the best NSE index. In addition, the calculated flow and the measured data of this plan is also the most similar in both phase and amplitude. About calculation time, the JX-29 plan does not increase too much compared to JX-09, but it is faster than JX-49, and has a much better result.

5. Conclusion

Through the calculation results of Tuyen Quang reservoir inflow using different LULC map and different basin division the authors draw the following conclusions:

For Tuyen Quang basin, using Jaxa's LULC map to calculate loss gives better results than using Microsoft & Esri LULC map;

The division of the basin into 29 sub-basins is more suitable than the division of the basin into 09 or 49 sub-basins. It not only gives best results (NSE Calibration: 0.85 and NSE verification 0.69) but also reduces the calculation time compared with 49 sub-basins plans. That is effective in real-time forecasting Tuyen Quang reservoir inflow.

However, these are initial comments on the use of the available LULC maps and reasonable basin division. It is necessary to continue experimenting with more accurate LULC maps such as the map of the General Statistics Office of Vietnam, Vietnam Department of Survey, Mapping and Geographic Information with field-verified data information, in order to obtain a better model. This study may be used to support managers in regional planning and development (afforestation) as well as in optimally operating hydro-electric reservoirs for power generation and natural disasters mitigation.

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Address: 41A, Phu Dien road, Phu Dien ward, North - Tu Liem, Ha Noi
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