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Monitoring Flood Dynamics in Hoa Vang District, Da Nang City Using SAR Remote Sensing and Google Earth Engine

Tran Thi An[1], Le Ngoc Hanh[2,3*], Nguyen Hoang Son[2,4], Le Phuc Chi Lang[2], Nguyen Thi Dieu[3], Nguyen Van An[3]

[1] Thu Dau Mot University, Binh Duong Province, Vietnam.
[2] University of Education, Hue University, Hue City, Vietnam.
[3] The University of Danang - University of Science and Education, Da Nang City, Vietnam.
[4] Institue of Open Education and Information Technology, Hue University, Hue City, Vietnam.
lnhanh.dhsp22@hueuni.edu.vn

Abstract. This study aimed to assess the flood dynamics in Hoa Vang District, Da Nang City using Sentinel 1 radar satellite images on the Google Earth Engine (GEE) platform from 2015 to 2022. Within the study, various functions were established in GEE to accomplish tasks such as selecting the study area, pre-processing data, filtering images, geometric corrections, and employing the Otsu thresholding method to identify flooded and non-flooded regions for each image. The results showed that the Otsu threshold values ranged from -11.663 to -10.874. Additionally, the study has taken the advantage of Digital Elevation Models and hydrological network to extract flooded areas at different time intervals from 2015 to 2022. In order evaluate the accuracy of flood results, the study uses field survey flood data and calculates the Kappa coefficient. Results show that the Kappa index (0.815) is highly reliable. The results show that the communes in Hoa Vang with the largest inundated area and flooding rate are Hoa Phong with 384.5 hectares, accounting for 20.7% of the area and Hoa Tien with 366 hectares, accounting for 25% of the commune's area. The research findings provide the scientific background for evaluating the socio-economic impacts of flooding, particularly in the agricultural sector of the southern region of Hoa Vang District, Da Nang City.

Keywords: Remote sensing, radar, flood mapping, Google Earth Engine, Hoa Vang

1. Introduction

Flooding is one of the most common natural hazards, affecting approximately 170 million people worldwide every year [1, 2]. Inundation events pose multifaceted threats to human mortality, critical infrastructure integrity, and ecosystem dynamics [3]. The distribution of flood-related damage is not uniform globally and shows distinct geographical patterns [4]. Vietnam is a country that suffers from many natural disasters such as storms, tornadoes, floods and droughts [5]. It is estimated that about 60% of the total land area and 71% of the population are at risk of storms and floods. Every year, the average direct economic loss due to storms and floods is estimated to be about 0.8% of gross domestic product (GDP). According to the annual assessment of the countries most affected by extreme weather events in the period 1997 - 2016, Vietnam ranked 5th in the global climate risk index in 2018 and 8th in the 2018 global climate risk index long-term climate risks [5]. Among natural disasters, floods are the most frequent and dangerous. According to estimates, from 1990 to 2010, there were 74 floods in Vietnam's river systems. In particular, in recent years, extreme water disasters have occurred more frequently, causing more loss of life and significantly affecting the country's economy [6].

To prevent and minimize damage from floods, many studies have proven that prevention and response to flood situations is very important. Among the measures that need to be taken in the early stage, flood risk assessment and zoning is identified as the most important step [7]. In particular, generation of flood hazard zonation maps plays an extremely important role. This map is indispensable in assessing the impact of flooding on potentially affected areas [8].

In the field of flood hazard assessment, there are two commonly used methods for creating flood maps were (1) the utilization of hydrological-hydraulic models and (2) the combination of topographic data and historical flood records using Geographic Information Systems (GIS). The hydrological and hydraulic modeling approach involves the use of mathematical models to simulate flow direction, flow accumulation, and water levels based on rainfall data, terrain characteristics, soil permeability, and other relevant information. Hydraulic models typically rely on flow characteristics and hydraulic properties to generate flood depth maps, but uncertainties may arise due to the quality and resolution of the flow properties, as well as assumptions made in the mathematical models [9]. Popular models such as HEC-RAS, MIKE FLOOD, and SWMM are commonly employed for predicting flooded areas [10]. Lea et al. (2019) had conducted a case study on the application of HEC-RAS 1D-2D coupling simulation to model the 2002 flood in Baeksan, Korea. The aim of this study was to assess the feasibility of using HEC-RAS as a 1D-2D hydraulic calculation model for simulating flooding caused by river overflow. To validate the model, the simulation was applied to the breach event of the Baeksan River dyke in South Korea in 2011. The simulation results exhibited similarities to observational data and the outcomes produced by widely-used flood models, demonstrating the applicability of the HEC-RAS 1D-2D coupling method as a robust tool for accurately simulating inundation during flood events [11]. In another study, Ongdas et al. (2020) employed HEC-RAS (2D) to generate flood hazard maps for the Yesil (Ishim) River in Kazakhstan. The study employed HEC-RAS (2D) to simulate various flood scenarios on the Yesil (Ishim) River. The comparison of different mesh sizes (25, 50, and 75 meters) revealed no significant difference in model performance, although a notable difference was observed in simulation time [12]. In Vietnam, researchers have also employed simulation models to construct flood maps. Nguyen Kim Loi and colleagues carried out the project titled "Real-time flood warning support system for Vu Gia - Thu Bon river basin, Quang Nam province," utilizing the HEC-RAS model [13]. The MIKE flood model was also employed by Vu Duc Long and colleagues to forecast floods in the Ben Hai and Thach Han river systems [14].

Meanwhile, the approach of combining terrain data, historical flood data, and GIS involves utilizing digital elevation models (DEMs), historical flood depth measurements, and conducting spatial analysis in GIS to identify areas with elevations lower than observed water levels, thereby delineating the flood extents. Hagos et al. (2022) conducted a researched entitled “flood risk assessment and mapping using integrated GIS with multi-criteria analysis in the upper Awash River, Ethiopia”. The study employed soil data, slope, elevation, drainage density, vegetation cover, and land use as causing parameters for constructing flood maps [15]. In Vietnam, several authors have also applied this method to generate the flood maps. For instance, Le Duc Hanh and colleagues developed a method integrating telecommunication technology, reconnaissance, Real-Time Kinematic (RTK), and GIS, which was experimentally applied to the Tuy Hoa delta in Phu Yen province [16]. Additionally, Le Hoang Tu and colleagues conducted a study in 2013, entitled “integrating Analytic Hierarchy Process and GIS for Flood Risk Zoning in Vu Gia Watershed, Quang Nam Province”. Six factors affecting flood risk areas were identified, including slope, soil, land use, rainfall, river density in the basin, and population density. The flood hazard zonation map was established based on expert opinions, collected data, survey questionnaires, field surveys, and documents from local departments [17].

Remote sensed data, characterized by its wide coverage and the capability of frequent and repeated data acquisition, enables quick and continuous monitoring of ground surface phenomena. This approach proves particularly valuable in surveilling regions that challenges for human access. Although optical satellite images are popular data for water surface extraction [18], it is difficult to apply in tropical areas such as Vietnam where the rainy season coincides with the flood season, characterized by cloudy coverage, making image interpretation impossible or with low accuracy [19]. To overcome the disadvantages of optical remote sensing, radar remote sensing (SAR) was developed, which uses a completely different way to observe the Earth's surface by actively transmitting/receiving microwave signals instead of using sunlight such as optical satellite systems. SAR operates in most weather conditions and has the ability to operate day and night. SAR has been widely used to study flooding, especially in areas with high cloud cover and rainy seasons in tropical climates zone [20]. SAR techniques and multi-temporal image classification can help partially address this challenge by providing information on surface water and flooding under extreme climatic conditions [21].

In this study, the flood dynamics in Hoa Vang district, Da Nang City was tracked using radar Sentinel 1 images taken during times with the largest flooded area of the years during the period 2015-2022. During the research period, the study employed the Google Earth Engine (GEE) platform to collect data, perform calculations, and generate flood maps at various time points. Furthermore, GIS (Geographic Information System) and statistical tools were utilized to assess the progression of flooding in the communes within Hoa Vang district.

2. Methodology

2.1. Overview of Study Area

Hoa Vang district, located in the rural area of Da Nang city, is known for being highly susceptible to severe floods in the Central Region of Vietnam. The district encompasses a varied topography, consisting of mountains, midlands, and plains that extend from the western to the southern parts of Da Nang city. Hoa Vang experiences a typical monsoon tropical climate, characterized by small temperature fluctuations and consistently high temperatures throughout the year. The district observes two primary seasons annually: the rainy season, which spans from September to December, and the dry season, which lasts from January to August. Droughts are frequent occurrences in Hoa Vang district during the dry season.

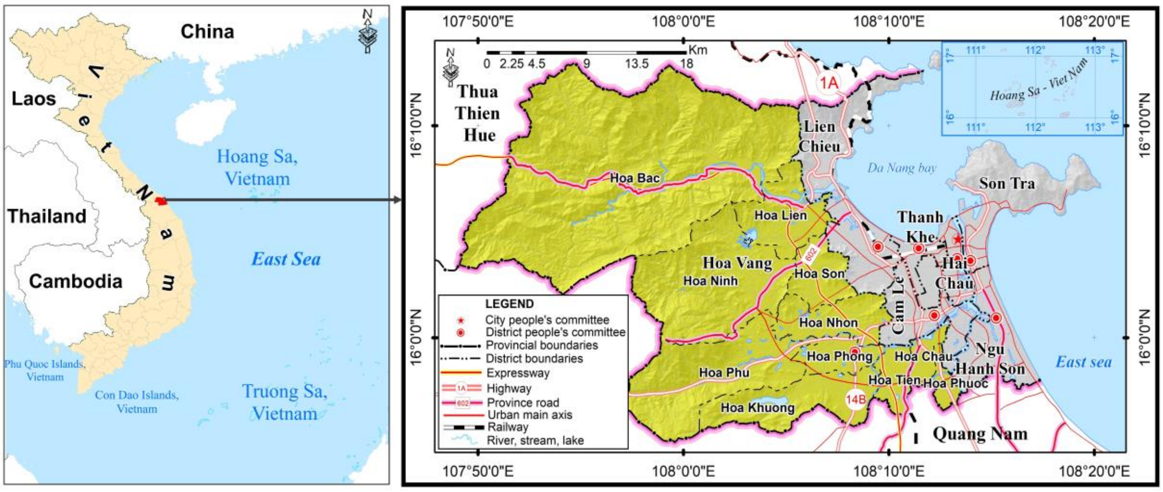

Figure 1. Hoa Vang district and location in Da Nang city.

The average annual temperature in Hoa Vang district is 26.7°C, with the highest temperatures typically occurring in May, June, July and August, averaging 29-30°C, and the lowest in December, January, February, averaging 21-24°C. Notably, the Ba Na mountain forest area, with an altitude of nearly 1,500m, has an average temperature of around 20°C. The average annual sunshine hours in the district is 2,438 hours, most in May and June, averaging 262 to 282 hours/month; while December and January typically have less sunshine, averaging 136 to 152 hours/month.

Hoa Vang has the Cu De river system in the North and rivers such as Tuy Loan and Yen rivers in the South, which are tributaries of the Ai Nghia and Vu Gia rivers. The hydrology of these rivers varies seasonally, leading to flooding in the rainy season and water shortages in the dry season, causing droughts in Hoa Vang district. In recent years, the impacts of climate change have led to increased precipitation, surpassing historical extreme rainfall records and exceeding the design capacities of drainage systems, resulting in frequent localized flooding in numerous residential areas.

2.2. Data Processing and Workflow

Data Collection and Processing

The main data source utilized in this research comprises freely available Sentinel 1 images obtained from the European Space Agency (ESA). These images were selected to coincide with the periods exhibiting the largest flooded areas within Hoa Vang district, Da Nang city, from 2015 to 2022. To achieve the most accurate extraction of flooded areas, the study also incorporated elevation data and hydrological maps obtained from the authorities in Da Nang city. Moreover, the accuracy of the flood map in Hoa Vang district was evaluated by comparing it with field survey data on flooding, using the Kappa index as a metric. Table 1 provides detailed information on the Sentinel 1 radar satellite images employed in this study.

Table 1. Statistics of Sentinel 1 images used in flood mapping in Hoa Vang district.

STT	Time	Scene ID
1	19/12/2015	S1A_IW_GRDH_1SDV_20151219T223528_20151219T223557_009117_00D1B6_FCE4
2	13/12/2016	S1A_IW_GRDH_1SDV_20161213T223538_20161213T223607_014367_01747F_F242
3	22/11/2017	S1A_IW_GRDH_1SDV_20171122T105621_20171122T105646_019377_020DB4_B329
4	11/12/2018	S1A_IW_GRDH_1SDV_20181211T105627_20181211T105652_024977_02C0DE_F3DA
5	31/10/2019	S1A_IW_GRDH_1SDV_20191031T105635_20191031T105700_029702_036252_96C7
6	12/11/2020	S1B_IW_GRDH_1SDV_20201112T105551_20201112T105616_024231_02E10A_CE5D
7	19/12/2021	S1A_IW_GRDH_1SDV_20211219T105645_20211219T105710_041077_04E146_EF62
8	15/10/2022	S1A_IW_GRDH_1SDV_20221015T105653_20221015T105718_045452_056F76_6357

Sentinel 1 radar satellite imagery is capable of providing high-resolution images and a short turnaround time (6 days). Additionally, it is capable of capturing observations both during the day and at night, and it can operate effectively in all weather conditions, including cloudy conditions, as it can penetrate clouds to obtain data. The data acquisition specifications for Sentinel 1 imagery include Ground Range Detected High Resolution (GRDH), a C-band radar sensor operating at 5.405 GHz, Interferometric mode Wide swath (IW), an incident angle ranging from 30.4° to 46.2°, a wide scanning bandwidth of 250 km, and dual polarization (vertical transmit/horizontal receive VH and vertical transmit/vertical receive VV) [22]. These specifications enable the imagery to provide information on the intensity of surface reflectance and achieve excellent discrimination between water and land. Consequently, Sentinel 1 images are highly suitable for flood monitoring applications. In this study, a collection of Sentinel 1 images was conducted, specifically targeting the periods of greatest flooding between 2015 and 2022 in Hoa Vang district, Da Nang city.

Terrain elevation: Elevation is an important factor affecting flooding in an area [23]. Low-lying areas could be inundated more quickly when water flows down from high altitudes. Areas located at high altitudes often have a lower likelihood of flooding than lowland areas [24]. The research collected data on terrain elevation points at a scale of 1:10,000 in the study area. On that basis, we use the inverse distance interpolation (IDW) method in GIS to create a DEM map for the study area. Based on the fact that floods in the study area are all located in areas with elevations less than 20m. Therefore, the study classified altitude into two ranges: >20m and <20m. From this data, we have masked areas from the images that are not flooded.

In addition, to be able to eliminate areas with permanent water, the study uses hydrological maps of the study area. This data is integrated into GEE to proceed with eliminating non-flooded areas. Finally, the study extracted flooded areas at various times in the period 2015 - 2022 in Hoa Vang district, Da Nang city. Figure 2 illustrates the process of data processing.

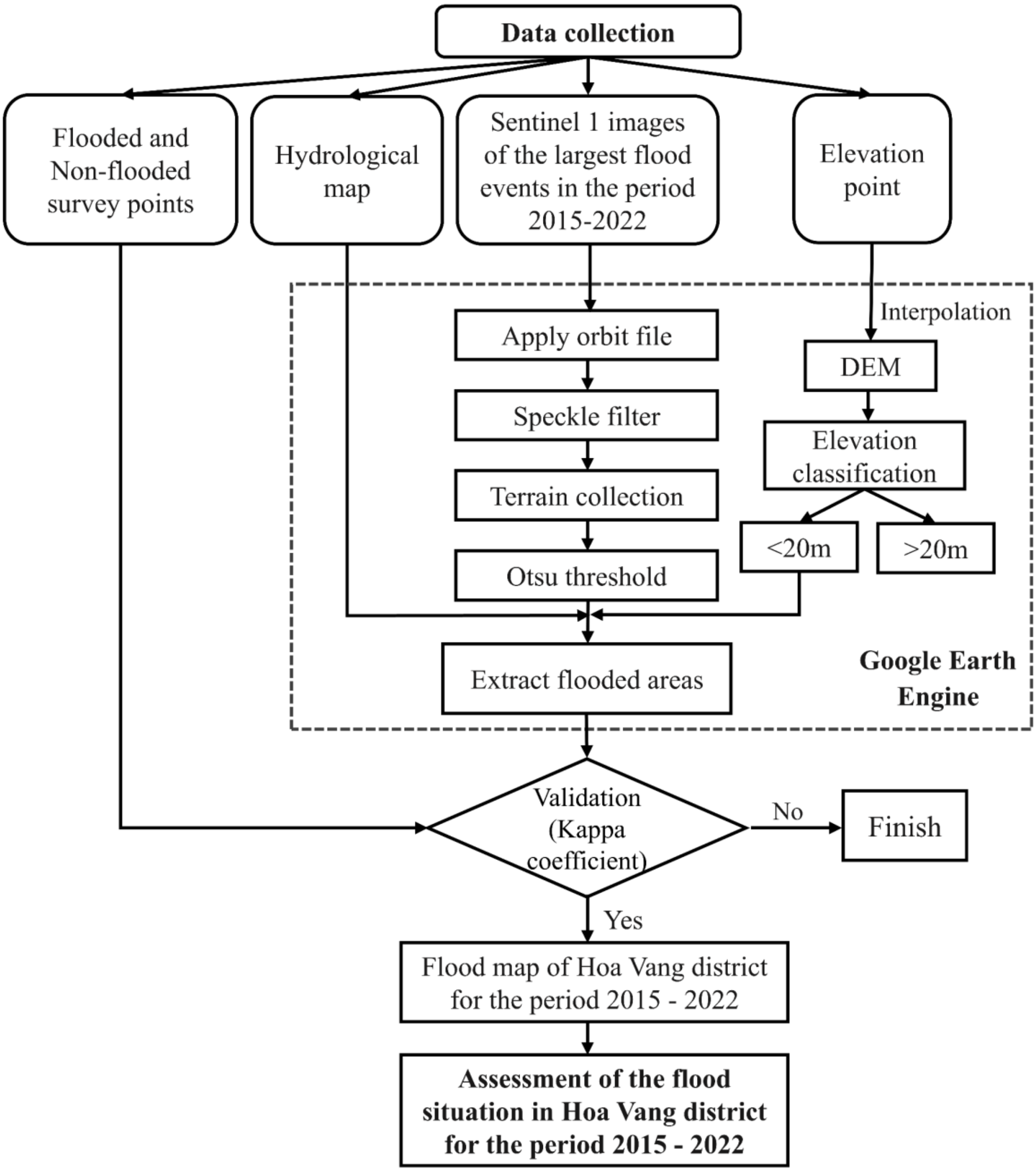

Figure 2. Flowchart of assessing flood dynamics in Hoa Vang district using radar remote sensing and Google Earth Engine.

Flood Mapping on GEE

In this study, a number of functions on the GEE platform have been applied to calibrate images, filter images, terrain correction and use the Otsu thresholding method.

Image preprocessing on GEE: First, we upload to GEE the research area which is the boundary of Hoa Vang district. Once the study area boundary is uploaded, it can be used to locate satellite images (Sentinel 1 data). Subsequently, we set up functions on GEE to calibrate the Sentinel 1 images. This is a necessary step to normalize the values in the images into backscatter values, allowing us to make comparisons of images in a time series. Continuing, the study conducted image noise filtering to remove thermal noise generated by the sensor from Sentinel 1 images to eliminate possible causes of error during

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the analysis process. The final step in image preprocessing is terrain correction. This step helps ensure all pixels are positioned correctly.

Otsu thresholding method: When all image preprocessing is finished, the next step is to distinguish flooded areas from the remaining areas. In digital image processing, one of the common approaches to distinguish two objects with different spectral characteristics is called histogram thresholding [25]. The goal of this method is to determine a value to distinguish two objects and use that threshold value to classify the image into two categories. Since in the VV and VH polarized flooded area, there is a low backscatter value between different earth objects, pixels below the defined threshold will be applied to classify the flooded area. The best situation for determining a threshold value is when the histogram has a multinomial distribution with two peaks separated by a valley. One mode is for pixels in flooded areas, which have low backscatter values due to specular reflection on the water surface, and the other mode is for pixels with higher backscatter in non-flooded areas [26]. On the other hand, the Otsu threshold algorithm is a known technique for automatically determining the optimal threshold t (Equation 1), which maximizes the variance between two classes from a gray-level histogram. Additionally, Otsu thresholding has been proven to be the simplest and most effective thresholding method for mapping surface water areas [27]. Therefore, in this study, water pixels on each Sentinel-1 image were detected using an automatic Otsu thresholding algorithm with Equation (1). The weights of the water and non-aqueous classes are the probability of these two classes being separated by each threshold. This procedure is performed for each Sentinel-1 image, hence the algorithm allows us to find different optimal thresholds for different images.

Pixels with backscattering values less than the estimated Otsu threshold value t are classified as water, and greater than or equal to the estimated Otsu threshold value t are classified as non-water. The Otsu threshold is estimated as follows:

$$\sigma^2(t) = P_w(t) \times \sigma_w^2(t) + P_{nw}(t) \times \sigma_{nw}^2(t) \tag{1}$$

where σ is the weighted sum of variances of water and non-water classes. P_w, σ_w, P_{nw}, and σ_{nw} are the probabilities and variances of the water (w) and non-water (nw) classes separated by a threshold t, respectively [21].

Generation of flood maps: Based on the values of thresholds calculated by the Otsu method combined with hydrological maps and masked areas with elevations less than 20m in Hoa Vang district, research has been conducted to extract the flood inundation areas in the period 2015 - 2022. On that basis, the research conducted to create maps and evaluate flood dynamics in Hoa Vang district, Da Nang city.

Evaluate the accuracy of flood maps

In this study, the accuracy of the flood mapping results is evaluated using the Kappa index [28]. The Kappa coefficient is a statistical measure that assesses the agreement between predicted flood extents generated by a model or mapping method and observed flood extents. The calculation of the Kappa coefficient involves the use of the following formula:

$$K = \frac{(P_o - P_e)}{(1 - P_e)} \tag{2}$$

Where:

K is the Kappa coefficient;

P_o: Observed Accuracy [28];

P_e: Expected Accuracy [28].

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Using the Kappa coefficient provides a more robust measure of the agreement between the observed and predicted flood extents, accounting for the possibility of agreement occurring by random chance. This is especially crucial for flood mapping, where the cost of false predictions (both false positives and false negatives) can be high in terms of planning, response, and resource allocation.

Table 2. Interpretation of Kappa [29]

Value of Kappa	Level of Agreement	% of Data that are Reliable
0 - 0.20	None	0 - 4%
0.21 - 0.39	Minimal	4 - 15%
0.40 - 0.59	Weak	15 - 35%
0.60 - 0.79	Moderate	35 - 63%
0.80 - 0.90	Strong	64 - 81%
Above 0.90	Almost perfect	82 - 100%

3. Results and Discussions

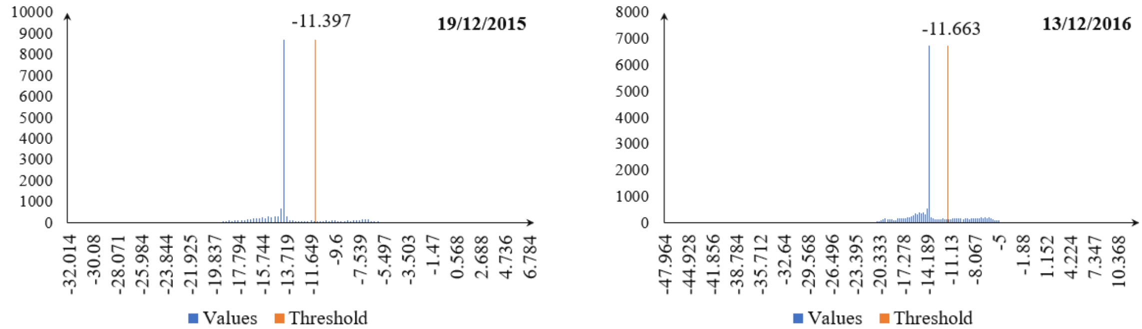
3.1. Flood mapping using the Otsu method and accuracy assessment

3.1.1. Determination of thresholds for flood mappings using the Otsu method

In this study, the Otsu method was applied on the GEE platform to perform thresholding and identify flooded areas within Sentinel 1 images. Specifically, a thresholding chart was generated for the time of the years exhibiting the highest flood value within the period from 2015 to 2022. This analysis is presented in Table 3, while Figure 3 visually represents the results of thresholding by Otsu method.

Table 3. Threshold values to determine flooding at the greatest times by year in the period 2015-2022.

STT	Time	Calculated threshold	STT	Time	Calculated threshold
1	19/12/2015	-11.397	5	31/10/2019	-11.651
2	13/12/2016	-11.663	6	12/11/2020	-11.013
3	22/11/2017	-10.874	7	19/12/2021	-10.888
4	11/12/2018	-11.647	8	15/10/2022	-11.652



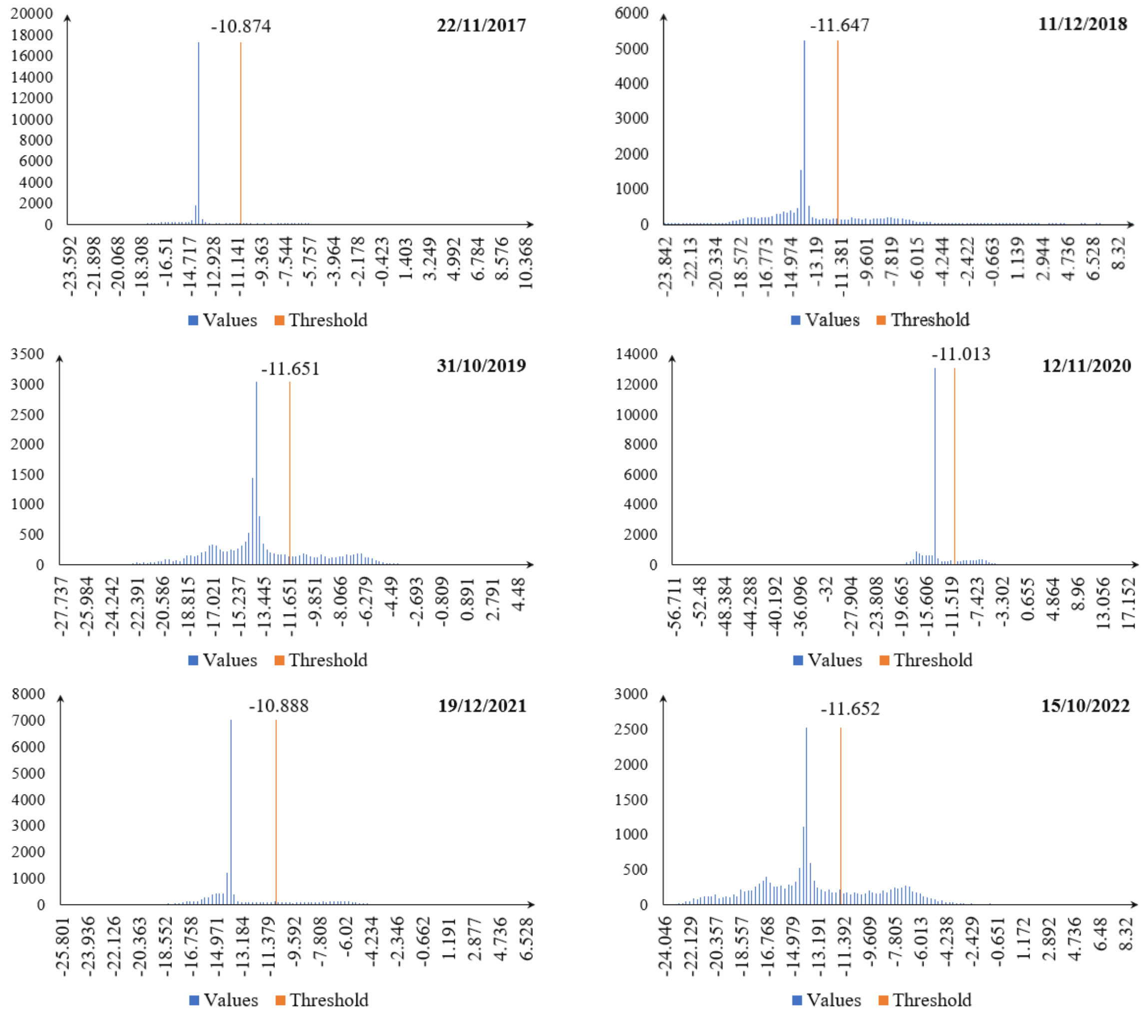


Figure 3. Thresholding at the largest flooded periods by year in the period 2015-2022 in Hoa Vang district.

Based on the Table 3 and Figure 3, we can see that the threshold values according to the Otsu method of the images are different. This enables classify flooded and non-flooded areas with greater accuracy than simply determining a fixed threshold for all images.

3.1.2. The results of accuracy assessment based on the Kappa coefficient

The study used the Kappa index to evaluate the accuracy of flood maps derived from Sentinel 1 imagery on the GEE platform (Figure 4). Based on the results of field survey on the flood situation after the historical flood on October 15, 2022 in Hoa Vang district, Da Nang city, the study applied the formula to calculate the Kappa index. A number of flood inventory data including 192 surveyed points which indicated both flood and non-flood signs have been investigated in the accuracy assessment process. As the results, the Kappa coefficient calculated from the satellite-derived flood map and the field surveyed flood point data is 0.815. This Kappa index is relatively high, which shows that the flooding results established using Sentinel 1 images are reliable. Based on this analysis, we generated a flood map at different times and assessed flood dynamics by communes of Hoa Vang district in the period 2015 - 2022.

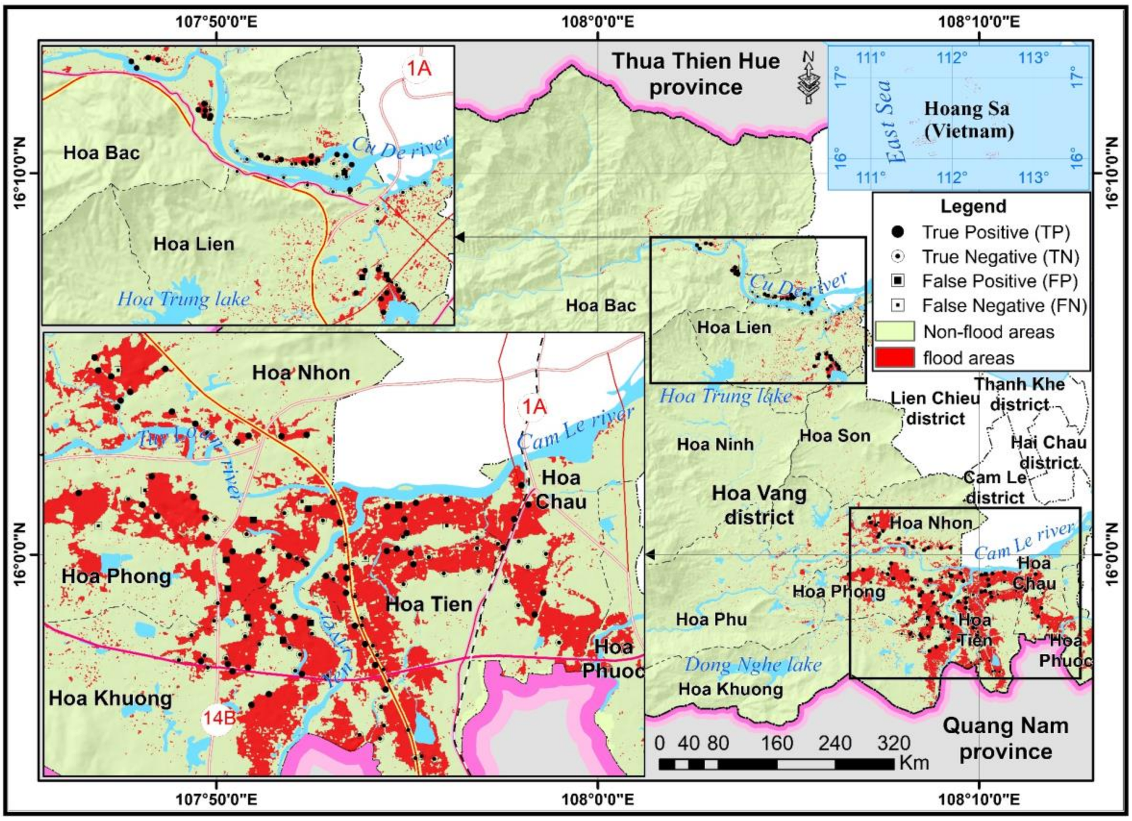


Figure 4. The locations of the surveyed flood points in the study area.

3.2. Assessing the flood situation in Hoa Vang district, Da Nang city in the period 2015 - 2022

The results of generating flood maps for times in the period 2015-2022 using Sentinel 1 images and Otsu method on the GEE platform are shown in Figure 4. We have extracted the maximum flood extent of each year to generate the time-series flood maps in Hoa Vang district for the period of 2015-2022 (Figure 5). The comparison between these flood maps was carried out to analysis the temporal flood dynamic for the study area. The statistical results of inundated areas by the years are shown in Figure 6.

Based on Figure 5 and Figure 6, we can see that the maximum flooded area has changed over the years. However, the trend of inundated area may gradually increase in the period 2015 - 2022. According to the Table 4 and Figure 5, we can see that the times with the significant maximum flooded area are December 13, 2016 (2349 hectares), November 12, 2020 (2520.4 hectares) and October 15, 2022 (2562.6). The years 2015 and 2019 have the maximum flooded extent at relative level and the years 2017, 2018 and 2021 have the flooded coverage area at medium level.

It is obvious that Hoa Vang district is experienced seriously flooded annually with the largest area ranging from 1253.7 hectares to 2562.6 hectares. The year with the largest flooded area is 2022 (October 15, 2022) with 2562.6 hectares. This is a time of historical flooding in many places Da Nang city as well as Hoa Vang district due to the sudden concentrated rainfall on October 2022. The year with the second largest flooded area is 2020 (November 12, 2020). This is the year when many places in Central Vietnam were severely affected by widespread floods. 2019 was recorded as the year with the minimum flooded extent in the period 2015 - 2022. This is the year when the El Nino phenomenon was recorded in Vietnam.

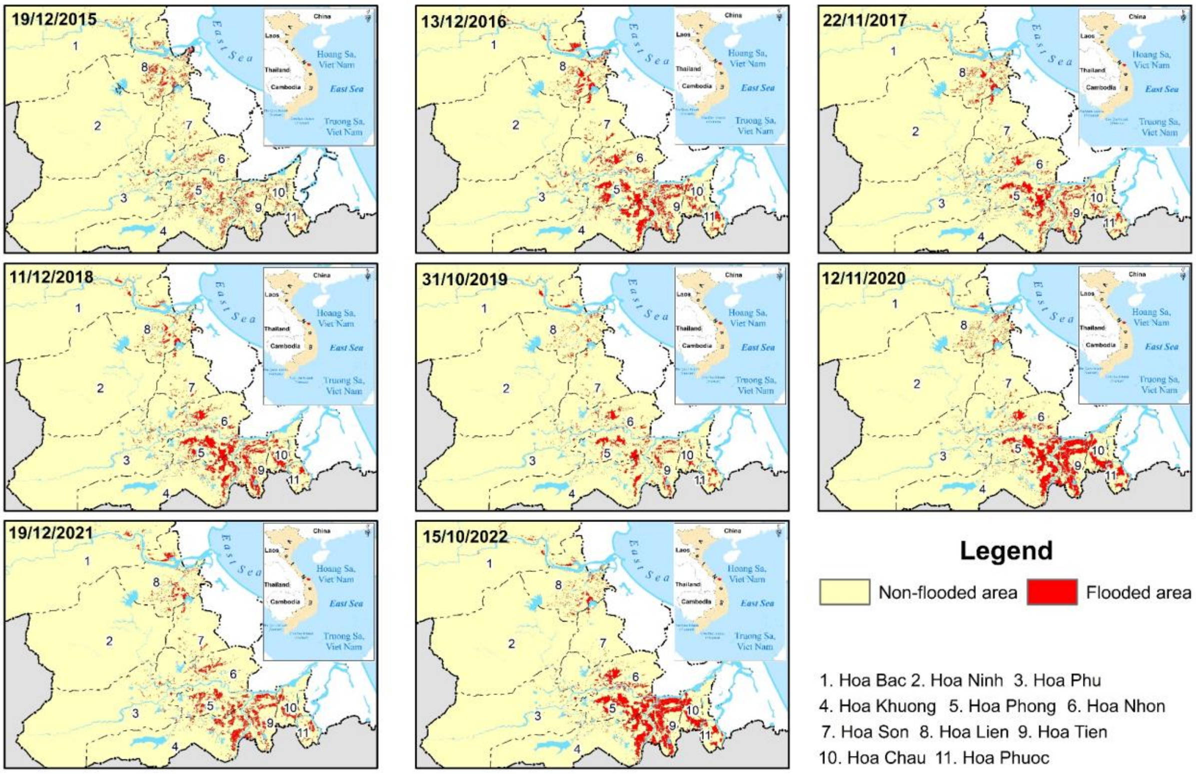


Figure 5. Time-series flood maps in Hoa Vang district for the period of 2015-2022.

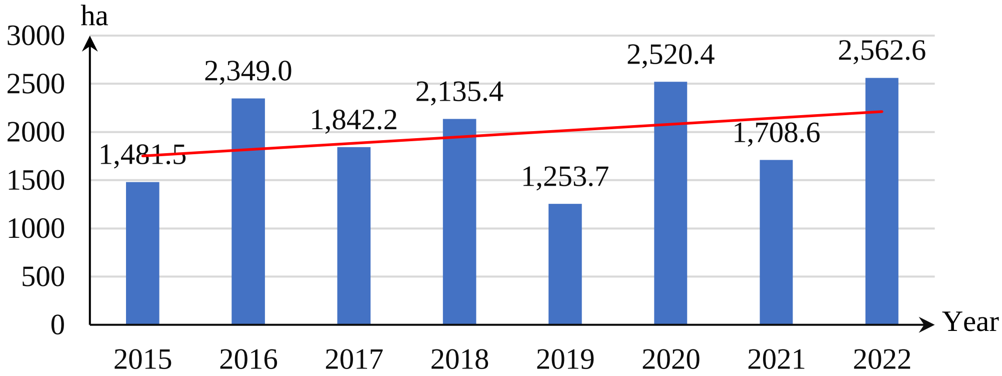


Figure 6. Maximum flooded extent (ha) by year in the period 2015 - 2022.

In general, the largest annual flooded area is over 1200 hectares, showing that the flooding situation in Hoa Vang is serious. Especially in 2020 (2520.4 hectares) and 2022 (2562.6 hectares), there were significant inundated areas. This will strongly affect the local production activities, especially agricultural production. In general, the times with the largest flooded area each year are varied. This can be explained because in addition to the impact of the region's typical rain patterns, a specific year may be affected by other phenomena such as El Nino (little rain) in 2019 and La Nina (heavy rain) in 2020 or due to the combined impact of many factors causing rain such as the historical flood of 2022 (October 15, 2022) in Da Nang city and Hoa Vang district.

Through the Figure 5, it is obvious that two communes with large flooded areas are Hoa Tien and Hoa Phong. In particular, the flooded area of Hoa Tien commune has increased rapidly in recent years. In the period from 2015 to 2019, the average flooded area of Hoa Tien commune (271.4 hectares) was lower than that of Hoa Phong commune (359.9 hectares). However, during the period from 2000 to

2022, the average inundated area of Hoa Tien commune (523.6 ha) is much larger than Hoa Phong commune (425.5 ha). In addition to reasons such as being located in low-lying areas, downstream of rivers flowing through Hoa Vang district, the urbanization process with the construction of many transportation systems, including many roads blocking the flow direction such as Hoa Tien ADB road, Hoa Phuoc - Hoa Khuong ring road and especially the Da Nang - Quang Ngai highway have greatly affected the natural flood drainage ability of these areas, especially in the area of Hoa Tien commune in Hoa Vang district.

In general, the utilization of Sentinel 1 images on the Google Earth Engine platform for flood dynamics maping in Hoa Vang district has effectively depicted the prevailing flood conditions in the area from 2015 to 2022. Sentinel 1 images possess the capability to overcome the weather conditions and exhibit high sensitivity to variations between dry and wet land surfaces. Flooded regions typically exhibit weaker radar reflections compared to dry land due to the flat water surface. Moreover, the Sentinel 1 image acquisition cycle is relatively short, occurring every 6 days, ensuring a consistent supply of data for continuous flood monitoring and surveillance. Additionally, the study area encompasses diverse terrain characteristics. The northern parts of the district generally feature relatively steep topography, resulting in rapid fluctuations of floodwaters compared to the southern region. Consequently, the extent and severity of flooding in these areas are often lower compared to the southern communes, characterized by gentle slopes, flat terrain, and longer durations of flooding.

4. Conclusions

Using Sentinel 1 images on the GEE platform can quickly extract flooded areas. The study used Sentinel 1 images to create a flood map for the period from 2015 to 2022 in Hoa Vang district, Da Nang city on the GEE platform. The classification of flooded and non-flooded areas in this study is based on the Otsu thresholding method. In addition, the study also used topographic and hydrological map data to accurately extract flooded areas. In order to evaluate the accuracy of flood maps, the study uses the Kappa coefficient index which considers the agreement between field survey inundated points and the flood map extracted from the Sentinel 1 radar imageries. The results show that the Kappa index has high reliability (0.815). Based on the results of flood extraction from radar satellite data, the study conducted an assessment of flood dynamics in Hoa Vang district. The results show that flooding in the district has fluctuated strongly over the years. In general, the trend of flooding in the study area is increasing. Especially, the recent years (2020 and 2022) have had a larger flooded area than the first period.

In conclusion, Sentinel 1 images provide an effective solution for rapidly assessing flood conditions, particularly in areas with gentle terrain slopes and prolonged flooding periods, such as the southern communes of Hoa Vang district, including Hoa Tien, Hoa Phong, Hoa Chau, Hoa Nhon, and Hoa Khuong.

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