APPLICATION OF GOOGLE EARTH ENGINE IN FLOOD MONITORING AND ASSESSMENT OF FLOOD-AFFECTED AGRICULTURAL LAND IN THE BUI RIVER BASIN, HANOI CITY

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ABSTRACT

Tropical storms accompanied by heavy rain often appear and cause severe floods from May to November every year in the Bui river basin, seriously affecting the local agricultural production. Therefore, a quick assessment of the agricultural land area affected by inundation is very important for the people and local government officials. In this study, we propose a new method to quickly estimate the agricultural land area affected by floods using Sentinel 1A (S1A). Firstly, the flood map estimated from the S1A image on Google Earth Engine at the flood peak by the Otsu threshold method does not exclude permanent water area with an overall accuracy of 82,5%. The flood extent are estimated at 1324 hectares, approximately 4% higher than the official data of local authorities. Secondly, the study overlayed the official land map and the flood map to determine the location and area of the affected area by the flood. Calculation results show that storm Son Tinh has affected approximately 33% (1261 ha) of agricultural land (not accounting forestry) in 5 communes. The difference is about 1.2 % (15 ha) compared with statistical results from state management agencies. The results show the valuable potential of using free Synthetic Aperture Radar (SAR) from S1A images to quickly monitor and assess flood-affected agricultural land over a small and large area using the Google Earth Engine.

Keywords: Agricultural land, Bui River Basin, Flood, Google Earth Engine, Sentinel 1A.

1. INTRODUCTION

Every year, major floods cause severe damage to people, agriculture, disruption of infrastructure, and socio-economic activities worldwide [1, 2]. In climate change, the frequency and intensity of floods have increased over the last few decades [3], and downstream rivers are more likely to experience extreme flooding [4]. A flooding map will address several urgent needs, such as identifying affected areas, estimating flood damage, and identifying flood movement to calibrate flood models [5]. In addition, a flood map helps policymakers propose appropriate planning options for the living space of local people to reduce flood risks for residential and agricultural areas. Therefore, flood monitoring and assessment of flood effects on crops and livestock have received increasing attention from researchers [6–8].

There are many approaches to determining flooding maps and determining the flood-affected area. Hydrological and hydraulic models are the traditional approach to determining flooding depth and extent [9, 10]. However, the model requires a huge amount of data on topography, meteo-hydrology, and land use [11]. These data are often insufficient in many areas on the world, except in developed countries [12]. Another approach used to determine flood extent and the flood-affected area is through field surveys [13]. However, this method requires a lot of time and effort. Many studies have recently used the Google Earth Engine (GEE) in developing flood and land use maps. For example, DeVriesa et al. [8] built an algorithm on GEE that can quickly determine the extent of flooding in different regions from the US, Greece, and the east coast of Madagascar. In another research, Tiwari and his team used GEE for identifying areas at risk of flooding through algorithms available on GEE, sometimes not necessarily using referenced data from reality, except required for verification [14]. The above studies have shown the advantages of the cloud computing tool, GEE, in observing and monitoring the flood situation: speed of processing, no satellite image download requirements.

Vietnam has an extensive coastline and diverse topography and locates in a tropical region [15]. Every year, Vietnam faces several natural disasters. According to National Assembly, Vietnam has 21 types of natural disasters [16], of which floods are the most common and impact people and agriculture. The agriculture, forestry, and fishing sectors play an essential role of the country's economy, two- fifth of the country labor force services for these sectors [15]. Vietnam's agricultural land is divided into five main categories: land for rice cultivation, land for perennial crops, land for aquaculture, land for forestry, and land for salt production [17]. However, the problem of flood monitoring and flood-affected agricultural land assessment is still a concern for this country because of technology limitations and human resources. In Vietnam, the application of GEE in flood management is still limited. An initial application belongs to Phan and his team's work [18]. The research proposed a methodology for quick estimation of rice areas affected by flooding using Sentinel 1A (S1A) to determine flood extent and rice map of 10 provinces in the Red River Delta. However, the research did not consider other agricultural areas like crops and aquacultural areas.

The Bui River Basin is a sub-catchment of the Red River Basin, considered a floodplain area to reduce flood damage to the Hanoi capital. However, due to the impact of climate change, the rainfall in this area has increased both frequency and intensity. As a result, Bui River Basin witnessed several big floods, such as the 2008, and 2018 floods, while the moderate floods happened regularly over two decades. In addition, land use change causes floods being more exacerbated. Toan et al. [19] also studied and built a flood map for the Bui River area from Sentinel - 1 using Remote sensing and GIS. However, the results were not checked because of the lack of validation datasets. Until now, the investigation of flood impacts on agricultural land in Vietnam in general, the Bui River Basin in particular, is mainly based on the statistics from the local authority, which requires much effort. Therefore, to quickly assess the agricultural land areas affected by floods in the lower Bui River area, using Sentinel 1 image combined with GEE and Gcadas tools is essential and meaningful. The study results are intended to provide a new approach to flood mapping in the Bui River basin area and a way to determine the area of agricultural land affected by floods.

2. RESEARCH METHOD

2.1. Study area

Bui River Basin is a sub-basin of the Red River Basin, which locates 30 km far from western Hanoi, Vietnam's capital. The Bui River, which is 91km long, originates from Lam Son commune (Luong Son, Hoa Binh), flows through Chuong My, Hanoi, and pours into the Day River in Phuc Lam commune, My Duc district. The area of the Bui River basin is around 1365 km^2. The Tich and Bui Rivers are the two main rivers in the basin. The Tich River is a tributary of the Bui River, originating from the Ba Vi mountain range. The Bui River receives its water from the Tich River at the junction of the Tan Truong bridge. Figure 1 diagrams the river system in the Bui River Basin. The research interest area is Xuan Mai urban floodplain area (red line in Figure 1). There are five communities in the pilot area, including Thuy Xuan Tien, Tan Tien, Nam Phuong Tien, Hoang Van Thu communes, and Xuan Mai town [20]. The pilot area has an area of 74 km^2, accounting for one-twentieth of the Bui River Basin.

According to a study by Phan et al. [18], Chuong My district, Hanoi city, is an area with a high frequency of flooding (> 5 times). This area is prone to flooding in the future, and rice will be damaged severely during storms, prolonged heavy rain, or even the whole summer-autumn crop (from May to October), like the 2018 Son Tinh storm.

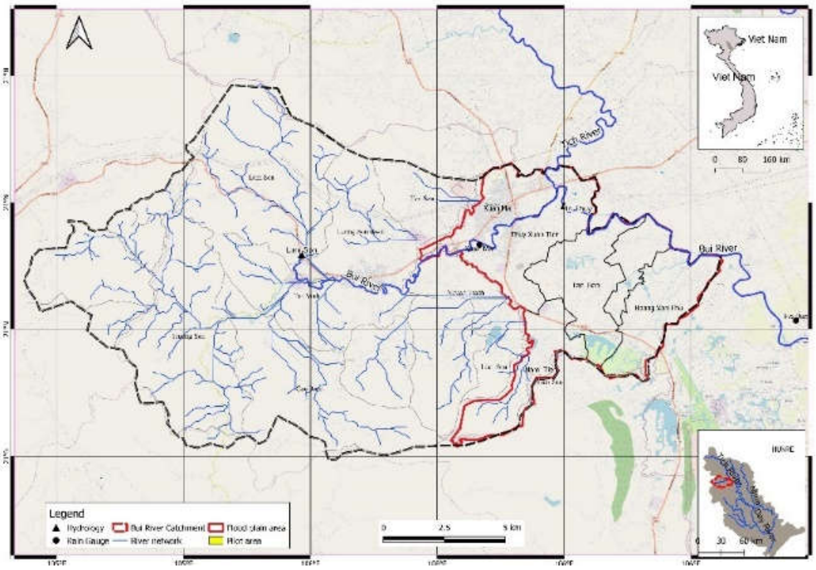

Figure 1: The river system of Bui River Basin and pilot area

Source: [21]

2.2. Image data

Sentinel -1 is the name of a cluster of earth observation satellites belonging to the European Space Agency's (ESA) Copernicus Program. Sentinel -1 satellite consists of 2 satellites 1A and 1B, that receive the image of Synthetic Aperture Radar (SAR) C-band (5.4 GHz) and are provided free of charge worldwide [22]. These two satellites operate in parallel in the same orbit, with a frequency of 6 days/scenes. In addition, sentinel -1 has a 10 m resolution, which enhances the detail level of research.

Sentinel -1 is responsible for providing continuous all-weather satellite images, day and night. The Sentinel -1 satellite provides highly reliable imagery, improves view time and geographic coverage, and disseminates data rapidly to support applications for land and marine monitoring, emergency response, climate change, and security [22].

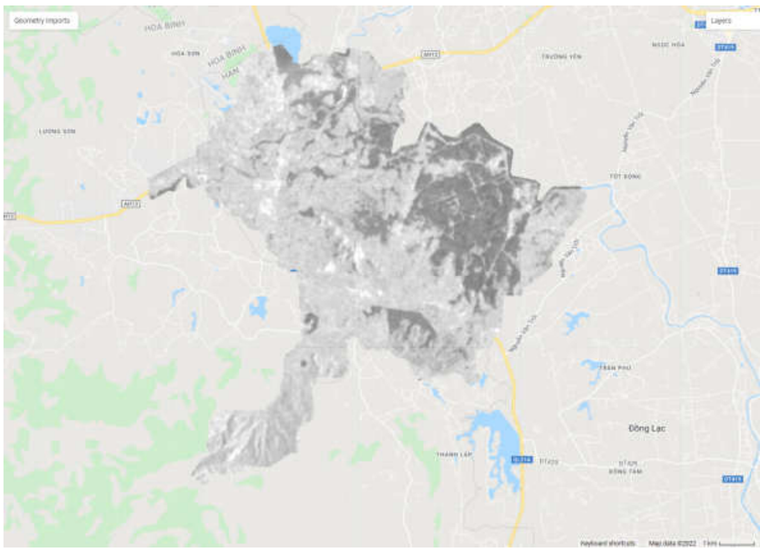

Figure 2. Sentinel 1 on July 22nd, 2018 extracted from Google Earth Engine

Table 1. The image information used for the study

Time	Scene number	RoN (Number of orbits)	Band	Polarization	Orbital Type
22/07/2018	S1A_IW_GRDH_1SDV_20180722T225046_ 20180722T225111_022913_027C51_6953	91	C	VV	Decensding

The research used Sentinel-1 with the reverse orbit (descending) to determine flood extent on the study area. The flood occurred from July 19th to August 11th, 2018 (Figure 2). The study obtained a satellite image that coincided with the time of the maximum water level on July 22nd, which allows researchers to determine the potential maximum flood extent. In this study, backscatter values in VV polarization were used for automatic extraction of flood-affected areas. Phan et al. [18] showed that VV polarization has potential in flood mapping because the co-polarized VV band has a stronger backscatter intensity than the cross-polarized VH band.

2.3. Tools used

2.3.1. GEE Tool

The research used the GEE to program the processing and analysis of satellite images. In which the program was created on GEE's code editor website (Earth Engine Code Editor) through the Application Programming Interface (API), with a set of JavaScript programming libraries [23]. The research used ee.ImageCollection. function () to declare and work with Sentinel-1 images ('COPERNICUS/S1_GRD') at the flood's peak in 2018. These programs will send processing commands to Front-End servers, from where the actual commands are executed. The exam will be redistributed as more complex query codes to servers (Compute Masters) [23].

In this study, a computer program to process and analyze satellite image data sets was used created in the GEE. The program includes Sentinel-1 radar remote sensing image processing components. Otsu method was used to classify surface and non-water layers of Sentinel-1 images via Google Earth Engine, which bases on segmentation thresholds. Otsu automatic thresholding is an iterative method to find the optimal threshold by testing all possible values. It maximizes the variance between the two segments' types and minimizes the internal variance [24].

Images after classification were converted to vector format for processing to create flood maps on the GIS applications like Arc/Gis, Mapinfo, and gCadas.

2.3.2. Gcadas tool

The study used the gCadas tool to overlay the land map and the flood extent to estimate the flood-affected agricultural land. The difference between gCadas software and other software is that this tool can create a land map quickly and complies with the Ministry of Natural Resources and Environment regulations when building the current status map during the inventory period land. The land map has two levels specifying land use purposes [25]. Level 33 shows the main purpose class, while level 36 shows for multi-purpose class, which has at least two landuse purposes [26]. In the five communes of Xuan Mai urban area, the multi-purpose layer often implies residential and perennial land, residential and aquacultural land. When converting land zoning maps or current land use maps on ArcGIS, QGIS applications, level 36 will be omitted, which leads to a part of agricultural land being ignored. This new point in the study can be used to explain the cause of area bias when maps created by software do not match the statistics.

2.3. Validation datasets

The application of information technology in surveying helps to shorten the collection time and reduce the cost of the collection. In addition, this approach improves the accuracy of the results compared to traditional methods, surveys, and surveys on paper [27].

Field survey sites were collected using the ODK Collect mobile data collection application running on the Android operating system. A free, open-source application capable of determining GPS location and accompanying images without an internet connection when investigating. This tool ensures that the data is collected objectively and can check the relevance of the survey results. The samples taken were evenly distributed within the study area. In 2021 and 2022, the research team surveyed and collected data on the flooding situation of 5 communes in the Bui river basin. The study surveyed 174 locations, including 105 flooded points and 69 non-flooded points, to accurately assess the image classification method of Flood extent. Tran et al. [21] described and developed the detailed approach to creating validation datasets. Apart from on-ground validation datasets, the research used the official report about the flood situation in 2018 to increase the reality of the research [28].

2.4. Accuracy Assessment

The flood map classification result was evaluated in 2 ways: (1) the classification results are compared with the control data, and (2) the flooded area is compared between the calculation and the statistics. The study also used the Overall assessment and Cohen's Kappa coefficient to evaluate the similarity (or fit) between the results of the classification of flooded and non-flooded areas [29]. In addition, the user accuracy, production accuracy, and difference indexes are used to evaluate the result's accuracy.

According to Loi et al [30], the accuracy of the interpretation results is evaluated through the overall accuracy of the error matrix. The higher the overall accuracy, the more accurate the classification results. However, there is currently no standard framework for the accuracy of classification results by the remote sensing method. The reason is that the standard framework of this method often depends on the object and target of the map to be classified. The study used an overall accuracy of 70% as the standard to evaluate the classification results.

2.5. Study Diagram

The entire process of image processing to create a map to assess agricultural land affected by floods is determined as follows:

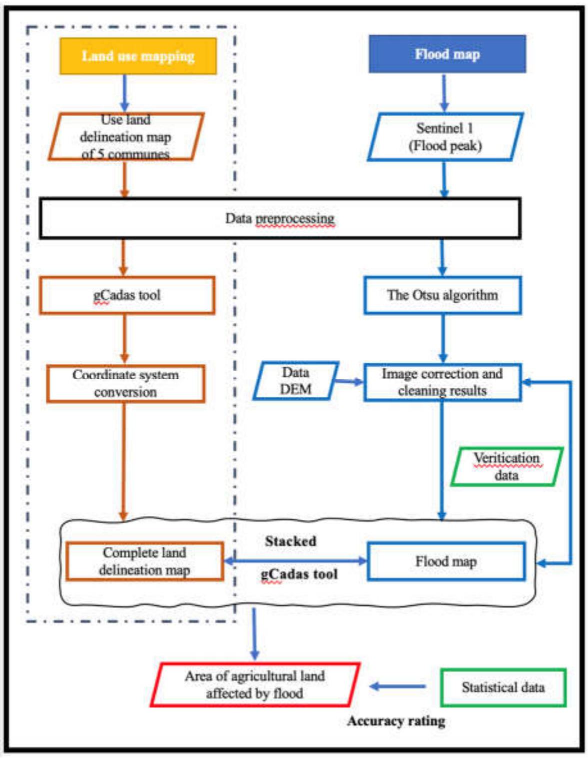

Figure 3. Overall diagram of the research process

3. RESEARCH RESULTS

3.1. The results of classification of flooded area map from Sentinel 1A image in 2018

The permanent water surface will change slightly over the years due to human impact on rivers, lakes, and aquacultural areas. Therefore, to get an accurate flood map, the team had to create a permanent water map for 2018. The permanent water surface was then excluded from getting the map caused by the flooding. However, this is the limitation of the study when using the Otsu algorithm to create a flood map for the Bui river basin in 2018 without removing the water surface permanently. The resulting fractional threshold determination is -14.9 dB.

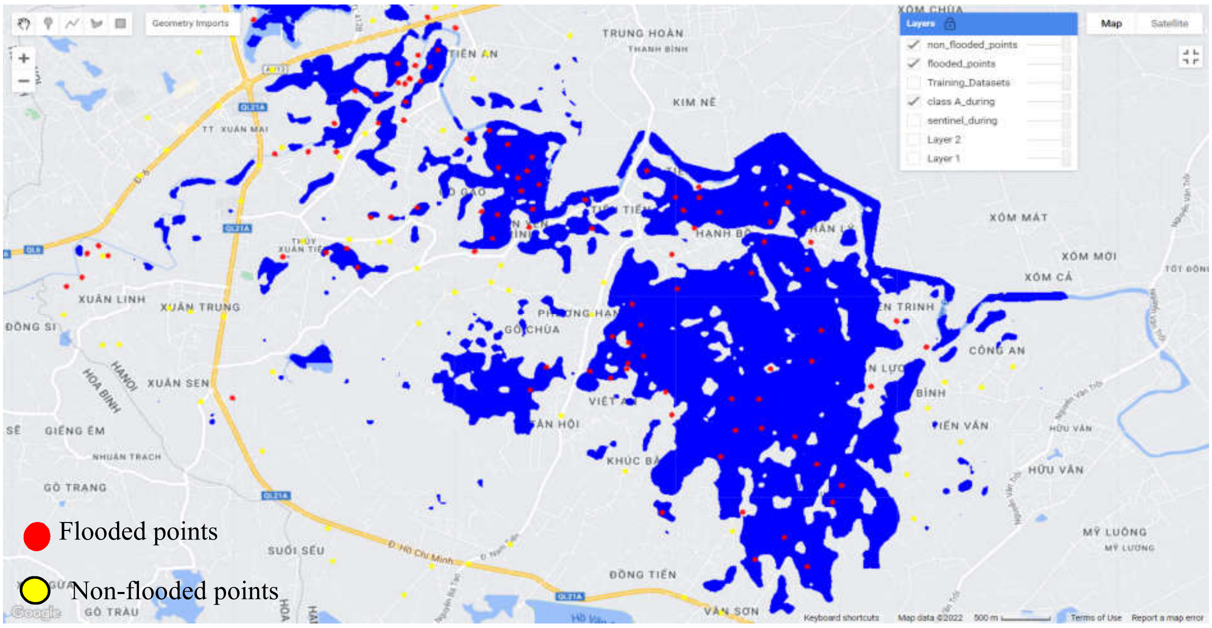

Figure 4. Flood extent map and the location of validation datasets

Table 2. The statisticial results of accuracy assessment for image classification method

Coefficient		User Accuracy (%)		Producer Accuracy (%)		Flooded area		
OA	Kappa	Flooded	Non-flooded	Flooded	Non-flooded	Calculation (ha)	Statistics (ha)	Error %
0,82	0,65	70	100	100	69	1324	1276	3.8

The results in Table 2 show that the flood extent has relatively high, with OA of 82.5 % and Kappa coefficient of 0.65. There is no significant deviation when comparing the value of the flooded area from the calculation and statistical values provided by Chuong My District People's Committee [28]. The calculated area is 48 hectares higher (about 3.8 %), partly because the study does not exclude the water surface area outside the river or the water surface area for irrigation.

The spatial distribution of flooded areas in the Xuan Mai urban area was determined and shown on the map in 2018 (Figure 4). In general, the flood-affected areas are distributed along the main river on the right bank of the Bui River, especially in the communes of Tan Tien, Nam Phuong Tien, and Hoang Van Thu. The area having the largest flooded area is Hoang Van Thu commune, with a total flooded area of 452 ha, accounting for 34% of the area of the whole Xuan Mai urban area, followed by Nam

Phuong Tien commune, with a flooded area of 360 ha accounted for 27%. The area with the least flooded area is Xuan Mai town, with a flooded area of 108 ha, concentrated mainly in Bui Xa village. The detailed statistical results of the flooded area are shown in the table below.

Table 3. Statistics of flooded areas by commune-level administrative units in 2018

No	Commune	Statistical flooded area (ha)	Flooded area according to map calculation (ha)	Rate of difference (%)
1	Xuan Mai	189.71	107.68	8.1
2	Thuy Xuan Tien	236.44	155.25	11.7
3	Tan Tien	381.84	247.93	18.7
4	Nam Phuong Tien	295.44	360.17	27.2
5	Hoang Van Thu	172.78	451.64	34.1
	Total	**1276.1**	**1324.0**	**100**

3.2. Assessment of flood-affected agricultural land in the Bui River Basin

Tropical storm Son Tinh made landfall on July 19, 2018, with heavy rain causing severe flooding between July 19 and July 25, 2018. Therefore, the flood map was created during the peak flood time of 22/7/2018. The flood-affected agricultural land area was determined by overlapping the flood map and the land delineation map. After overlaying the flood map and the land map, the research manually removed the permanent water surface layer, such as river land and irrigation land. Therefore, the exact flooded area is narrowed. The areas and locations of flooded agricultural land are shown in Figure 5 and Table 4 as follows:

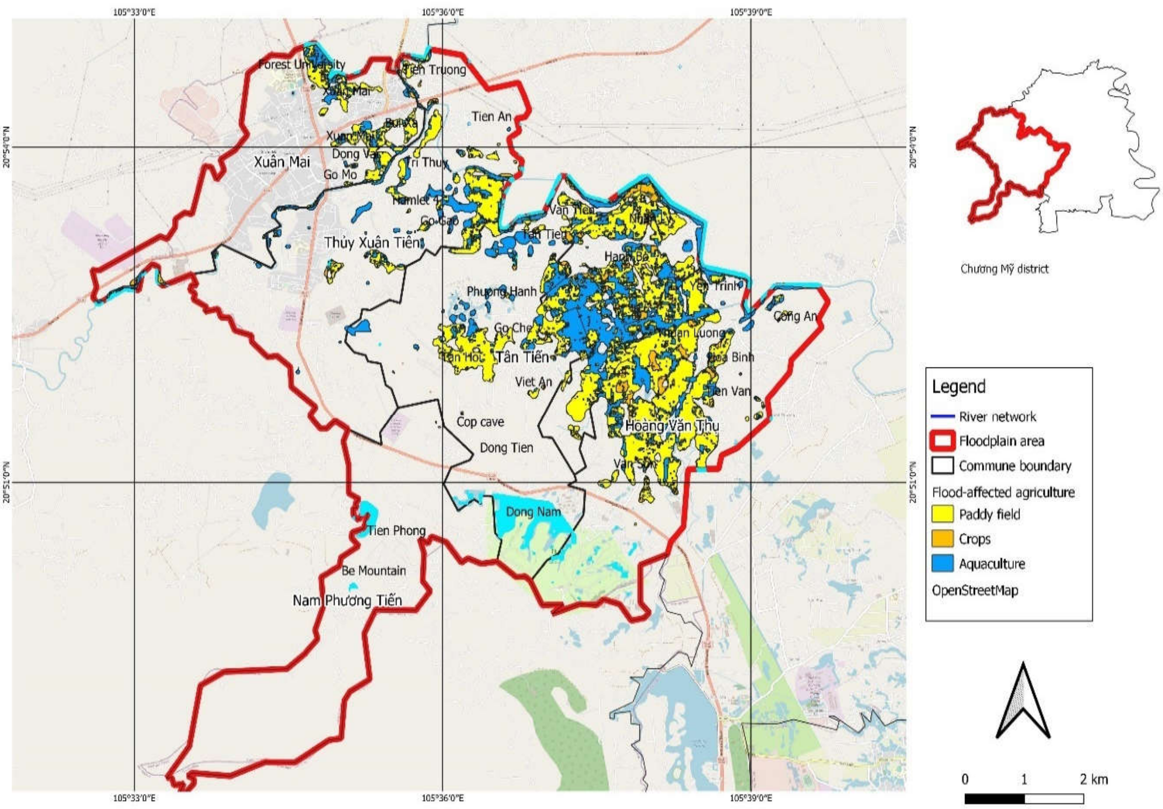

Figure 5. Map of agricultural land affected by floods on the Bui River 2018

The flood in 2018 submerged 1,261.0 hectares of agricultural land. The results of data analysis show that rice land is the most affected (810 ha), accounting for nearly 64% of the flood-affected area, aquaculture land is flooded 334ha, accounting for 26%, and cropland mage 117ha, accounting for 9%.

Table 4. Area of flood-affected agricultural land in 2018

Land type	Commune	Statistics (ha)	Calculation (ha)	False (3-2) (ha)	Accuracy between figures (%)
	1	2	3	4	5
Rice land	Xuan Mai	96.88	67.36	-29.52	-30.5
	Thuy Xuan Tien	63.76	86.54	22.78	35.7
	Tan Tien	205.28	116.92	-88.36	-43.0
	Nam Phuong Tien	169.2	227.48	58.28	34.4
	Hoang Van Thu	81.22	311.81	230.59	283.9
	Total	**616.34**	**810.11**	**193.77**	**31.4**
Crop land	President Xuan Mai	33.01	5.6	-27.41	-83.0
	Thuy Xuan Tien	51.32	10.79	-40.53	-79.0
	Tan Tien	59.37	38.07	-21.3	-35.9
	Nam Phuong Tien	25.62	24.5	-1.12	-4.4
	Hoang Van Thu	30.56	38.1	7.54	24.7
	Total	**199.88**	**117.06**	**-82.82**	**-41.4**
Aquaculture land	President Xuan Mai	59.82	26.93	-32.89	-55.0
	Thuy Xuan Tien	121.36	50.09	-71.27	-58.7
	Tan Tien	117.19	58.3	-58.89	-50.3
	Nam Phuong Tien	100.62	80.42	-20.2	-20.1
	Hoang Van Thu	61	118.22	57.22	93.8
	Total	**459.99**	**333.96**	**-126.03**	**-27.4**
Total		**1276.21**	**1261.13**	**15.08**	**1.2**

The vegetable land group has a slight difference in the affected area (83 ha) among the three main agricultural land groups. For rice land, the difference is the largest (194 ha). In general, affected agricultural areas from S1A data tend to be small compared with statistical reports. The main reason for this issue is that the flooded area obtained from satellite images is often smaller than in reality due to image resolution; a satellite can not detect flooding under the canopy, building, or even cloud area [13]. However, some calculated areas are much larger than the statistical results, such as the rice land area in Hoang Van Thu commune, which is 231 ha different from the statistical data. The main reason is that during flood time, most people abandon their fields for rainy seasons. Therefore, the statistics will not calculate these areas but abandoned rice areas were still counted as affected areas when overlay classes. On the other hand, the rice and crop areas among communes is intertwined. For example, people in Tan Tien commune move to cultivate rice and crops in Hoang Van Thu commune, and people in Xuan Mai town go to Thuy Xuan Tien commune for aquaculture. Hence, according to statistics, the area of aquaculture land in Xuan Mai town is only 27 ha, but the statistical damage area is two times higher. Unfortunately, the investigation is complicated due to bad weather conditions, which can cause errors in statistical data.

3.3. Land use planning orientation for flood-affected areas

During the 2016-2018 period, Chuong My District People's Committee implemented the new rural construction general plan and the agricultural production planning for 30 communes across the District. Hoang Van Thu commune has the most heavily flooded area among the five studied communes in the Bui River basin. Hoang Van Thu commune's new rural construction general planning was approved in December 2018, four months after the storm Son Tinh passed. Hoang Van Thu commune has changed its crop structure to adapt to extreme weather. Specifically, the commune has converted about 78 hectares of rice land to aquaculture land in areas that are frequently flooded when there is heavy rain in villages such as Yen Trinh village, 17.23 hectares, Thuan Luong, 10.74 hectares, the highest is 17.23 hectares. Van Son village, with 28.18 ha converted from rice cultivation to aquaculture land. In addition, about 8.97ha of rice land in low-lying areas has been converted to perennial crops [31].

4. CONCLUSION

The study used high-resolution remote sensing image data integrated with the GEE tool to detect changes in flood status over time in the Chuong My district. Research has shown that flood-prone areas are usually distributed along the Bui River. The flood detection results are very positive, which can be quickly calculated for the 2018 flood when using the same algorithm and only changing the time of the image stage with high accuracy of 82.5%. The flooded area difference between calculated and official data is less than 3%. The results show that nearly 33% of the agricultural production area of the district is affected by floods, of which the most affected rice land accounts for 64%, followed by aquacultural land 26%), and the minor effects were on other crops (9%). The study's results improve the understanding of the impact of flooding in low-lying areas. In the coming time, GEE technology will be an effective tool to help state managers have correct and long-term planning orientations in the future.

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ỨNG DỤNG CÔNG NGHỆ ĐIỆN TOÁN ĐÁM MÂY GOOGLE EARTH ENGINE TRONG GIÁM SÁT LŨ VÀ XÁC ĐỊNH DIỆN TÍCH ĐẤT NÔNG NGHIỆP BỊ ẢNH HƯỞNG DO LŨ TRÊN LƯU VỰC SÔNG BÙI, THÀNH PHỐ HÀ NỘI

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TÓM TẮT

Bão nhiệt đới đi kèm với mưa lớn thường xuất hiện và gây lũ lụt nghiêm trọng từ tháng 5 đến tháng 11 hàng năm trên lưu vực sông Bùi gây ảnh hưởng nghiêm trọng đến tình hình sản xuất nông nghiệp tại địa phương. Do đó, việc đánh giá nhanh diện tích đất nông nghiệp bị thiệt hại do ngập úng là rất quan trọng đối với người dân và cán bộ quản lý nhà nước tại địa phương. Trong nghiên cứu này, chúng tôi đề xuất một phương pháp mới để ước tính nhanh diện tích đất nông nghiệp bị ảnh hưởng do lũ lụt bằng ảnh Radar Sentinel 1A (S1A). Thứ nhất, bản đồ lụt được ước tính từ ảnh S1A bằng Google Earth Engine tại thời điểm đỉnh lũ bằng phương pháp xác định ngưỡng Otsu không loại trừ khu vực nước vĩnh viễn với độ chính xác tổng thể đạt 82,5%. Diện tích vết ngập ước tính là 1324 ha, cao hơn 4% so với diện tích thống kê. Thứ hai, nghiên cứu sử dụng bản đồ khoanh đất đã được công bố, sau đó sử dụng công cụ Gcadas để chồng xếp bản đồ lụt và bản đồ khoanh đất để xác định vị trí cũng như diện tích vùng bị ảnh hưởng thiệt hại do lũ. Kết quả tính toán cho thấy, cơn bão Sơn Tinh đã làm thiệt hại xấp xỉ 33% (1261 ha) diện tích đất sản xuất nông nghiệp (không xét đến diện tích lâm nghiệp) trên địa bàn 5 xã, chênh lệch khoảng 1,2% (15 ha) so với kết quả thống kê từ các cơ quan quản lý nhà nước. Kết quả thử nghiệm cho thấy tiềm năng rất hữu ích của việc sử dụng ảnh Radar khẩu độ tổng hợp (SAR) miễn phí từ ảnh S1A để theo dõi và đánh giá nhanh các diện tích đất nông nghiệp bị ảnh hưởng bởi lũ trên 1 vùng diện tích nhỏ và rộng lớn.

Từ khóa: Bản đồ ngập lụt, Đất nông nghiệp, Google Earth Engine, Lưu vực sông Bùi, Sentinel 1A.

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