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The Quick Assessment of Agricultural Flood Damage in Ha Tinh Province Using Sentinel-1 SAR Data

D. L, Nguyen.,[1]* T. Y, Chou.,[2] T. V, Hoang.,[2] M. H, Chen.,[2] and Y. M, Fang.[2]

[1]*Ph.D. Program for Civil Engineering, Water Resources Engineering, and Infrastructure Planning, College of Construction and Development, Feng Chia University, Taichung 40724, Taiwan*

[2]*Geographic Information Systems Research Center, Feng Chia University, Taichung 40724, Taiwan*

Abstract: This study aims to quickly assess the effects of flood on agriculture that occurred in October 2020 in Ha Tinh province, Vietnam. The spatial extent of the flood was mapped using two Sentinel-1 SAR images which were acquired before and during the event. These images were pre-processed to reduce the effects of thermal noise, speckle, and geometric distortion. Image ratioing, one of the change detection methods, was applied to detect the appearance of floodwater. Thirty-two flood points were utilized to determine the threshold to separate floodwater and other land covers. The results revealed that there was 33912.3 ha of the total inundated area all over the district, accounting for 5.7% of the total natural area. Agriculture was severely damaged with 26099.6 ha of total submerged area, including 23559.4 ha of paddy rice, 2428.5 of annual crops, and 111.7 ha of perennial crops.

Keywords: Agriculture, flood,image ratioing, Sentinel-1 SAR, threshold.

1. Introduction

Flood is considered as one of serious natural disasters in the world. It causes direct or indirect damages on infrastructure, agriculture, environment, economy, health and human life. In agriculture sector, flood is a main reason in the decline of crop health and crop productivity, even crop failure. According to Food and Agriculture Organization of the United Nations (FAO) report, the damage of crop and livestock production caused by floods was 21 billion USD from 2008 to 2018 in least developed countries and lower middle income countries [1]. And these adverse effects might be more severe by the increase of floods in the climate change context.

Agricultural damage assessment is a crucial task after each flood event. It helps local authorities release agricultural production recovery policies. Furthermore, crop loss assessment after flood events is also essential for crop production determination, agricultural product pricing, and agricultural insurance payment[2]. Flood assessment report involves information of the inundated area, flood depth and flood duration. Collecting these data by traditional methods is time and money-consuming over the vast agricultural lands. With the support of remote sensing and GIS, these spatial data can be collected fast and analyzed accurately.

With the fast development of space technologies, satellite data has been broadly utilized for flood damage evaluation in recent years. There were many studies that utilized this kind of data for flood mapping [3, 4]and flood damage evaluation [2, 5]by scientists and researchers all worldwide. Satellite images used for flood mapping include optical data and SAR data. It is easy to extract water bodies from optical images. Nevertheless, this kind of data is only useable when acquired in the daytime and cloudless sky conditions. While floods often occur in severe weather with heavy rains and cloudy sky.The application of optical remote sensing data in flood mapping is therefore still restricted.As an active remote sensing system, SAR remote sensing data operate both day and night time. Furthermore, its long wave length allows penetrating through clouds and smoke. Hence, it is effectively utilized in flood mapping.

Aperture synthetic radar (SAR) system Sentinel-1 includes two C-band satellites, Sentinel-1A and Sentinel-1B. It operates day-night time and acquires high-quality images regardless of adverse weather conditions. Sentinel-1 has been operated for seven years, from 2014 till now. Sentinel-1 data is free of charge. Hence it has been widely exploited by researchers for their study fields, such as land use/land cover mapping [6, 7], deforestation monitoring [8, 9], earth's surface activities [10, 11], and flood mapping [12, 13].

Due to the effects of tropical depressions and storms in the East Sea, Ha Tinh province got a huge of amount rainfall in October 2020, with 2388mm (Figure 2). This resulted in a heavy flood and seriously affected agricultural production in Ha Tinh province. The purpose of this study was to: (1) develop a flood map using Sentinel-1 SAR data and (2) assess agricultural flood damage for Ha Tinh Province in October 2020.

2. Study area

Ha Tinh is located in the North of North Central Coast of Vietnam. Its geographic location ranges from 17°54'N to 18°37′N latitude and 105°07″E to 106°30′E longitude. It borders with NgheAn province in the North, QuangBinh province in the South, the Lao People's Democratic Republic in the West, and the East Sea in the East (Figure 1). The total natural area is 5,994.4 km2, with a population of 1,296,622 people [14].

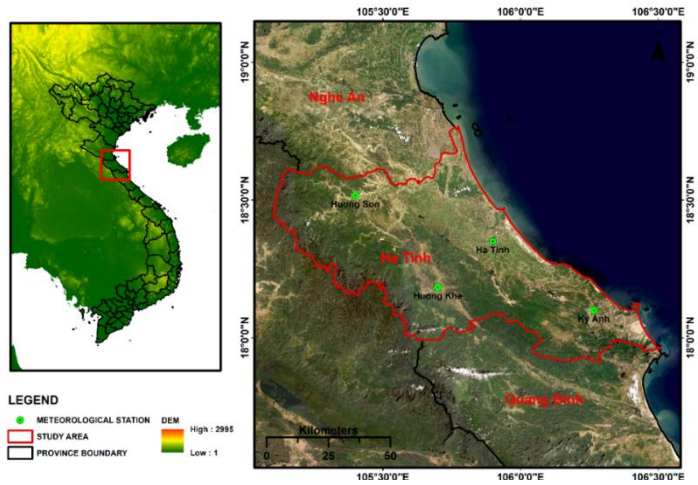

Figure 1. Study area

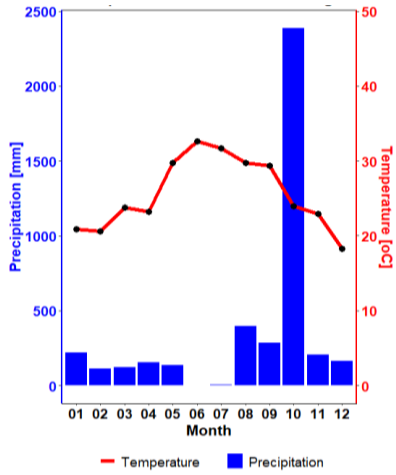

Figure 2. Meteorological data in 2020

The topography of Ha Tinh slopes from the West to the East with the average, including three natural geographic zones: high mountainous, hilly, and coastal plains. The average annual temperature is 24.5°C while maximum temperatures can pass over 40°C in summer. In the mountain region, the temperature can be decreased to 7°C in winter. The annual total precipitation is about 2500 mm - 2650 mm, mainly occurring from August to November. During these months, floods happen frequently.

3. Data and Methodology

3.1. Data

Satellite imagery data: The Sentinel-1 SAR data was freely downloaded NASA's Alaska Satellite Facility (https://asf.alaska.edu/data-sets/sar-data-sets/sentinel-1/). The Sentinel-1data is provided by different product types (RAW, SLC, GRD, OC), acquisition modes (SM, IW, EW, WV), and two polarizations (VV and VH). This study used the GRD product and IW mode of Sentinel-1A, which was acquired on 18th October 2020, as a satellite imagery resource for flood mapping. Previous study results showed that VV polarization is slightly better than VH polarization for flood mapping purposes[15, 16]. Therefore, this study used two Sentinel-1A images with VV polarization to develop the flood map. The characteristics of satellite imagery data was shown in Table 1.

Table 1. Characteristics of satellite imagery data

ID	Product Type	Acquisition mode	Polarization	Pixel Spacing	Pass Direction	Acquisition Date	Flood Condition
1	GRD	IW	VV	10m	Ascending	08 June 2020	Pre-flood
2	GRD	IW	VV	10m	Ascending	18 October 2020	During-flood

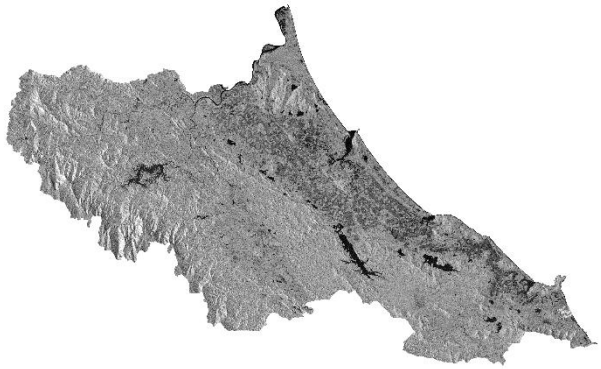

Figure 3. Pre-flood Sentinel-1 image

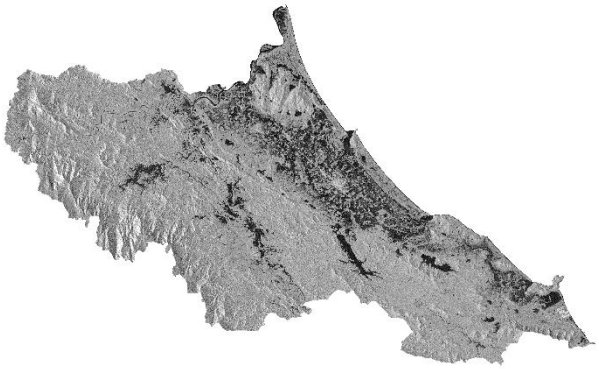

Figure 4. During-flood Sentinel-1 image

Flood points: Thirty-two flooded points collected from various sources were used to determine the threshold to separate floodwater from other land cover types.

Land use map: The land use map of the year 2019 was used to assess the agricultural flood damage accurately. This thematic map is generated from a large-scale cadastral map source and updated yearly by Microstation software. In order to prepare for overlay analysis, it was standardized and converted from .dgn (Microstation) format into .shp (ArcGIS).

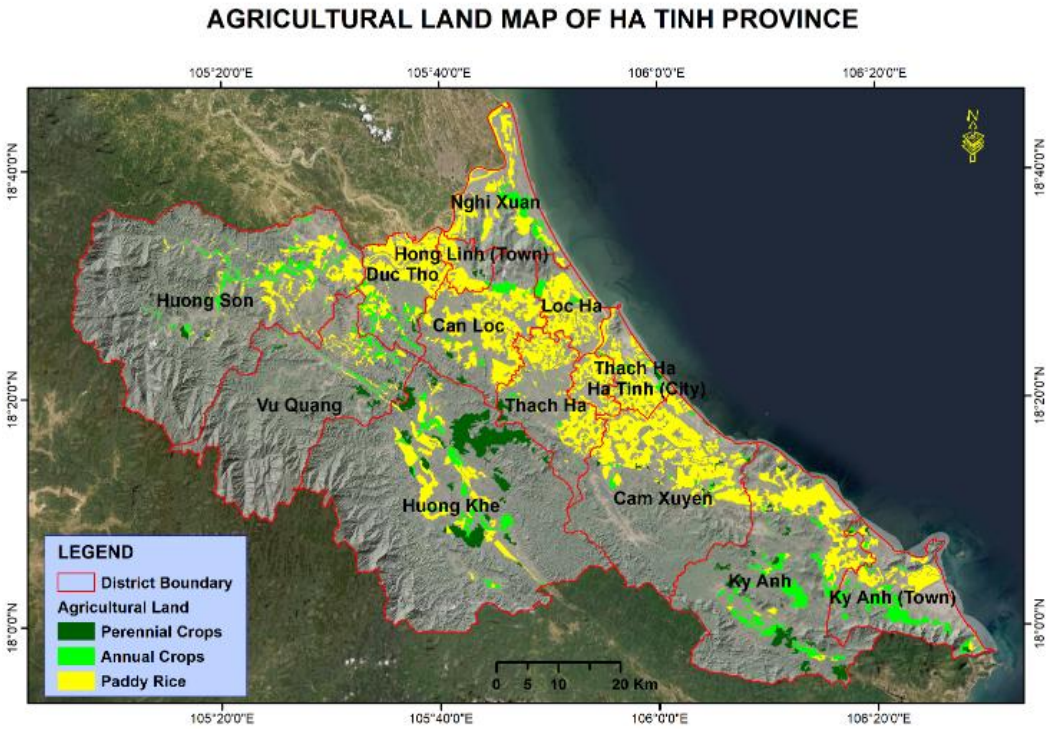

Figure 5. Agricultural land map

3.2. Methodology

Pre-processing Sentinel-1A data:Before using for flood mapping, the two Sentinel-1A images were preprocessed by SNAP 8.0 software. Firstly, they were applied precise orbits of satellites to update accurate satellite position and velocity information. Secondly, noise effects were reduced by thermal noise removaloperator. Next step, the DN numbers in two images were converted to sigma nought (σ^o) values. The quality of images was continued to improve by reducing speckle using speckle filter tool (Lee 5x5). Finally, digital elevation was used to correct geometric distortions which caused by topography. Range Doppler Terrain-Correction operator implemented this step. Finally, the backscatter coefficient (σ^o) was transformed into decibels (dB).

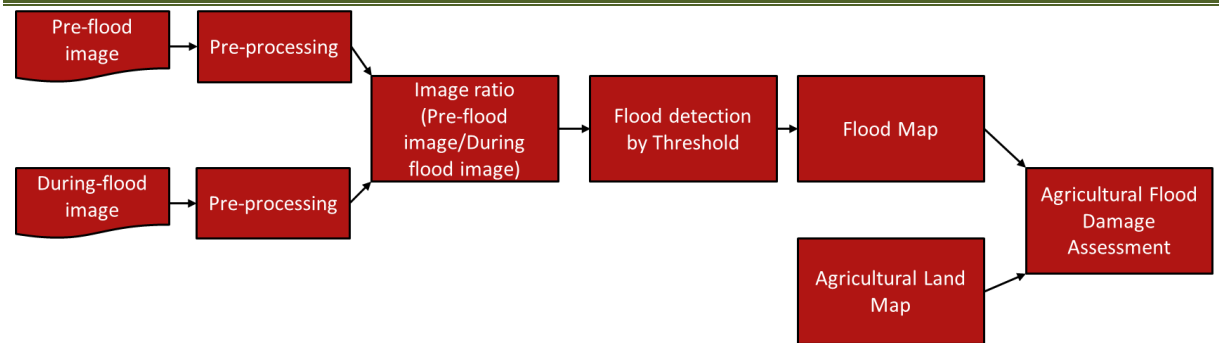

Figure6. Flowchart of the study

Flood mapping method:In previous studies,change detection was effectively used to delineate floodwater [17-19].In this method, a new image is generated by image differencing or image ratioing. For SAR data, image ratioing is more appropriate because it reduces the effects of speckle noise [20, 21]. In order to differentiate floodwater and other land covers, a reasonable threshold is needed to be determined. In this study, it was calculated by overlaying 32 flooded points over ratioing image and the value of each point was determined by Extract Value to Points tool in ArcGIS software. The result showed that the values range from 1.30 to 2.15. Hence, the threshold 1.3 was chosen. The flood map in raster type was converted into vector for further analysis.

Agricultural damage assessment: Finally, the agricultural damage by flood was figured out using overlay analysis of the two maps, flood map and agricultural map. The results include flood inundated map and flooded agricultural land map of Ha Tinh province, the statistical results of the inundated area of districts and inundated area of agricultural land of districts for Ha Tinh province.

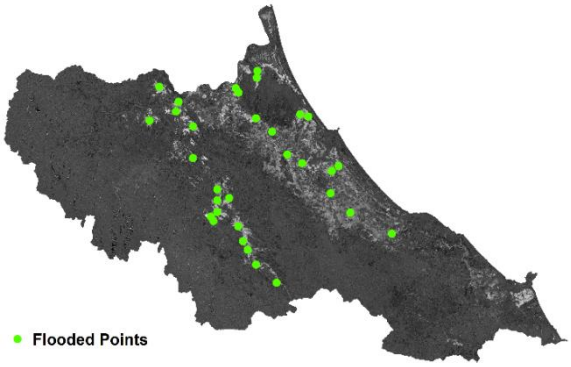

Figure 7. Ratio image and location of flooded points

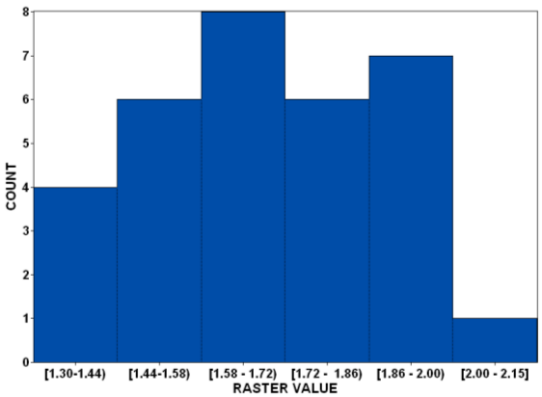

Figure 8. Histogram of flooded points' value on ratio image

4. Study results

4.1. Flood inundated situation in Ha Tinh province on 18 December 2020

The flood map of Ha Tinh province on 18 December 2020 is shown in Figure 9. The overlay analysis was implemented based on the flood map and administrative boundary map to calculate the flood area for the province and its districts. The calculation results were presented in Table 2.

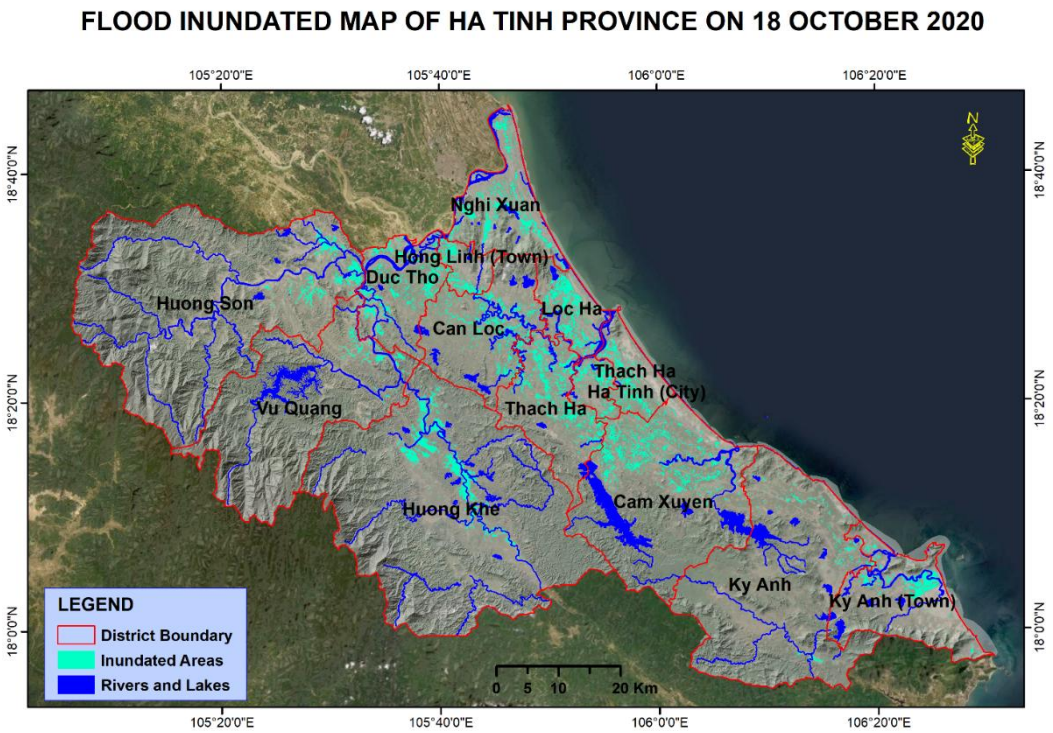

Figure9. Flood inundated map

The total inundated area was 33912.3 ha, accounting for 5.7% of total natural area of the province. The flooded area of Thach Ha district was the largest, with 5349.0 ha which was followed by the corresponding areas of HuongKhe, Cam Xuyen, and DucTho. In fact, these areas were 4576.4 ha, 4491.2 ha, and 3091.9 ha, respectively.Conversely, KyAnh and Vu Quang had the most minor inundated areas, with 946.4 ha and 911.4 ha.The flooded area of remaining districts ranged from one thousand hectares to over two thousand hectares.Considering the percentage, Ha Tinh city, Loc Ha district and Hong Linh town were the highest, with over 20%.KyAnh, Vu Quang, Huong Son, and HuongKhe had the lowest percentage, with under 5%.

Table 2. Flooded area of districts

ID	District	District Area (ha)	Inundated Area (ha)	Percentage (%)
1	Ha Tinh city	5655	1198.6	21.2
2	Hong Linh town	5897.3	1180.6	20.0
3	KyAnh town	28553.9	1961.0	6.9
4	Nghi Xuan	22251.1	2840.2	12.8
5	DucTho	20349.9	3091.9	15.2
6	Huong Son	109679.5	2087.1	1.9
7	Vu Quang	63766.3	911.4	1.4
8	HuongKhe	126293.9	4576.4	3.6
9	Can Loc	30212.7	2795.9	9.3
10	Thach Ha	35356.7	5349.0	15.1
11	Loc Ha	11697.3	2482.5	21.2
12	Cam Xuyen	63703.6	4491.2	7.1
13	KyAnh	76027.9	946.4	1.2
Total		599445.1	33912.3	5.7

4.2. Agricultural flood damage

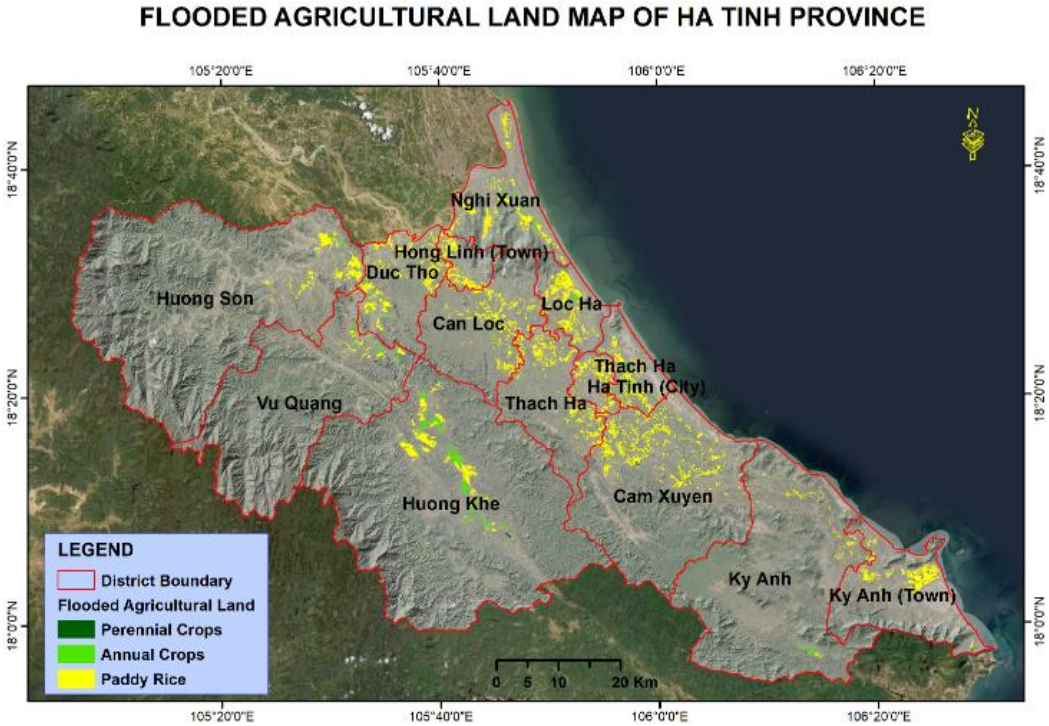

Figure 10. Flooded agricultural land map

The flooded agricultural land map was generated by overlaying of flood map and agricultural land map. The statistical number of agricultural flood damage was pointed out also based on overlay analysis of flood map and agricultural land map.

The result showed that the total area of flooded agricultural land was 26099.6 ha and mainly belonged to paddy rice land with 23559.4 ha, accounting for 90.3%.It is understandable because paddy rice is a major crop, planted with the biggest area and generally distributed in low lying area. The flooded area of annual cropsland was about one-ninth of paddy rice, with 2428.5 ha, accounting for 9.3%. Because of planted in high land, flooded perennial crops land was fewer, with only 111.7 ha, accounting for 0.4%.

In term of paddy rice, the flooded area in Cam Xuyen and Thach Ha was the largest, with 3672.1 ha and 3381.7 ha, respectively. KyAnh and Vu Quangwere the two districts having the smallest flooded area. However, their flooded area still be big, with 614.8 and 410.9 ha, in that order. It seems to be that the flooded area has a strong relationship with planted area. According to Ha Tinh Statistical Yearbook 2020, Cam Xuyen (18591 ha) and Thach Ha (15793) were two of the districts that had the biggest planted area of paddy rice, KyAnh (1638 ha) and Vu Quang (1607 ha) were two districts that had the biggest planted area of paddy rice.

Flooded annual cropland is mainly concentrated in HuongKhe district, with 1246.7 ha, accounting for over 50%. The districts DucTho, KyAnh, Nghi Xuan, and Vu Quang had an inundated area from 146.7 ha to 263.9 ha. The rest districts had a small or negligible quantity of flooded areas. For perennial cropland, the most flooded areas occurred in HuongKhe district, with 76.4 ha, accounting for 68.4%. It was over two times higher than that of the total amount flooded area of Cam Xuyen district (19.1 ha) and KyAnh district (15.2 ha). The perennial cropland in the ten remaining districts was not submerged or negligibly flooded.

5. Conclusions

This study developed the flood extent map and flood effects on agriculture in Ha Tinh province, Vietnam by two SAR images. The results showed that under extreme rainfall amount in October 2021, Ha Tinh was suffered a serious flood with 33912.3 ha of total inundated area. Floods occurred in all districts, with inundated areas ranging from 911.4 ha to 5349.0 ha. Agriculture was also heavily influenced. Paddy rice was submerged on large scale with 23559.4 ha which was followed by annual crop and perennial crops, with 2428.5 ha and 111.7 ha of the inundated area, respectively.

The study has proved the effectiveness of Sentinel-1 SAR data in fast flood mapping which has been difficult to implement by optical data due to adverse weather. Furthermore, Sentinel-1 data is freely downloaded

from ESA's website or can be easily processed by Google Earth Engine, a powerful cloud-based platform. This advantage allows scientists and researchers to utilize this data in studies that need to process huge amounts of data.

Table 3. Flooded area of crops by districts

ID	District	Paddy Rice (ha)	Annual Crops (ha)	Perennial Crops (ha)
1	Ha Tinh City	1093.4	0	0
2	Hong Linh Town	1159.4	1.0	0
3	KyAnh Town	1538.6	63.7	0.7
4	Nghi Xuan	1880.9	242.1	0
5	DucTho	2290.6	146.7	0
6	Huong Son	1351.1	98.9	0
7	Vu Quang	410.9	263.9	0.2
8	HuongKhe	2018.9	1246.7	76.4
9	Can Loc	2109.8	4.3	0
10	Thach Ha	3381.7	75.8	0.2
11	Loc Ha	2036.9	80.8	0
12	Cam Xuyen	3672.1	55.0	19.1
13	KyAnh	614.8	149.6	15.2
Total	26099.6	23559.4	2428.5	111.7

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