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APPLICATIONS OF SATELLITE DATA FOR RAPID INUNDATION ASSESSMENT - A CASE STUDY IN THUA THIEN HUE PROVINCE

Hoang Nam Binh[1*], Le Van Nghi[2], Hoang Vu Huy[3]

[1]University of Transport and Communications, No 3 Cau Giay Street, Hanoi, Vietnam

[2]The National Key Laboratory of River and Coastal Engineering, Vietnam Academy for Water Resources, 171 Tay Son Street, Dong Da district, Hanoi, Vietnam

[3]Student, K62 Business Administration, University of Transport and Communications, No 3 Cau Giay Street, Hanoi, Vietnam

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[*] *Corresponding author:*
Email: binhhn@utc.edu.vn

Abstract. Floods are one of the most significant devastating natural hazards around the globe. Recent development in remote sensing technology supports faster and low-cost analysis of flood hazards. This study used the Sentinel-1 SAR data for flood mapping and damage assessment. We selected the October 2022 flood event in Thua Thien Hue province, Vietnam. The Change Detection and Thresholding (CDAT) method was adopted to detect the inundation areas. The results showed that The flood event affected to several districts with Quang Dien being the worst hit, followed by Phu Loc and Huong Tra. Phu Vang had the smallest flooded area. The total inundated area was up to 33,384.08ha. The derived flood map was overlaid onto the current land cover map to conduct an initial evaluation of the potential flood damage corresponding to each land use category. The damage to the land cover was estimated that most of the affected areas were in the cropland and accounted for 77.07% of the total inundated area. The results can assist decision-makers in monitoring and assessing flood damage in Central Vietnam.

Keywords: Sentinel-1, Inundation assessment, Flood maps, Thua Thien Hue.

1. INTRODUCTION

Floods have a significant impact on Vietnam, a country located in a tropical monsoon region with many rivers and a long coastline. The country is prone to natural disasters such as typhoons, storms, and heavy rainfall, which often result in floods and landslides. The impacts of floods in Vietnam include loss of life, damage to property and infrastructure, disruption to transportation and communication, and long-term effects on the environment and public health. In recent years, the impact of floods in Vietnam has been exacerbated by climate change, with more extreme weather events and sea level rise increasing flood risk [1]. The Vietnamese government has implemented various measures to mitigate flood impacts, including early warning systems, the construction of flood protection infrastructure, and community-based approaches [2].

Remote sensing technology has revolutionized the field of natural hazard and flood management, providing valuable information for understanding and predicting these events. Remote sensing involves the use of satellite and airborne sensors to collect data about the Earth's surface, atmosphere, and oceans. This technology can be used to detect and monitor changes in the environment, such as changes in vegetation, water levels, and land use, which can be indicative of natural hazards such as floods. The application of remote sensing in natural hazard and flood management has several advantages, including the ability to provide rapid and accurate information about the location and extent of flooding, enabling timely responses and reducing the impact on affected communities. Remote sensing can also support the development of early warning systems, aid in the assessment of flood damage and assist in the planning and management of flood-prone areas [3].

Synthetic Aperture Radar (SAR) imagery has proven to be a valuable tool in the assessment of inundation events. SAR is an active remote sensing technology that can penetrate cloud cover and provide images day or night, making it an ideal tool for monitoring flood conditions. The high spatial resolution of SAR imagery allows for detailed mapping of inundated areas and identification of specific features such as levees, waterways, and urban areas. SAR can also detect changes in surface water levels, providing valuable information for predicting and responding to floods [4]. The combination of its ability to penetrate cloud cover and its high spatial resolution make SAR an essential tool for flood risk management and disaster response. In recent years, advances in SAR technology and increased availability of SAR data have enabled more accurate and timely inundation assessments.

The Sentinel-1 SAR satellite has proved to be a valuable tool in the detection and mapping of inundation events. The high spatial resolution of Sentinel-1 SAR images enables detailed mapping of flood extents, providing valuable information for flood risk management and disaster response efforts. This satellite has been used to detect and map inundation events in various regions around the world, including those affected by monsoon rains and typhoons [5]. The use of Sentinel-1 SAR in flood detection and mapping provides disaster response organizations with the timely and accurate information they need to respond effectively to affected communities [6].

The study aimed to demonstrate how Sentinel-1 SAR data can be used to quickly and accurately map the extent of flooding and provide valuable information for decision making and response efforts with a case study of a flood event in October 2022 in Thua Thien Hue province, Vietnam (Figure 1).

Thua Thien Hue province has a very diverse river system, most of which are small watershed from less than 100km^2 to nearly 3,000km^2 [7]. The terrain is mainly hills and high mountains (Figure 2). The plain has only a small area in the downstream [8]. The distribution of the river network is uniform, but most of them are short and steep and regulated by the Tam Giang - Cau Hai lagoon system [7].

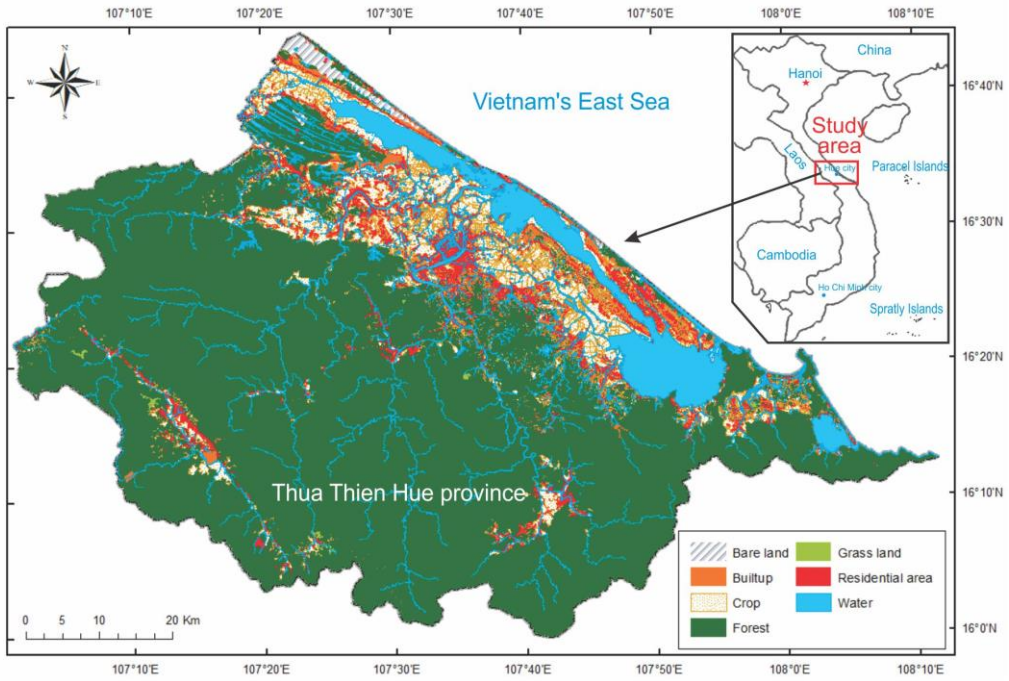

Figure 1. Location and land use land cover of Thua Thien Hue province.
(provided by the Ministry of Natural Resources and Environment of Vietnam - MONRE)

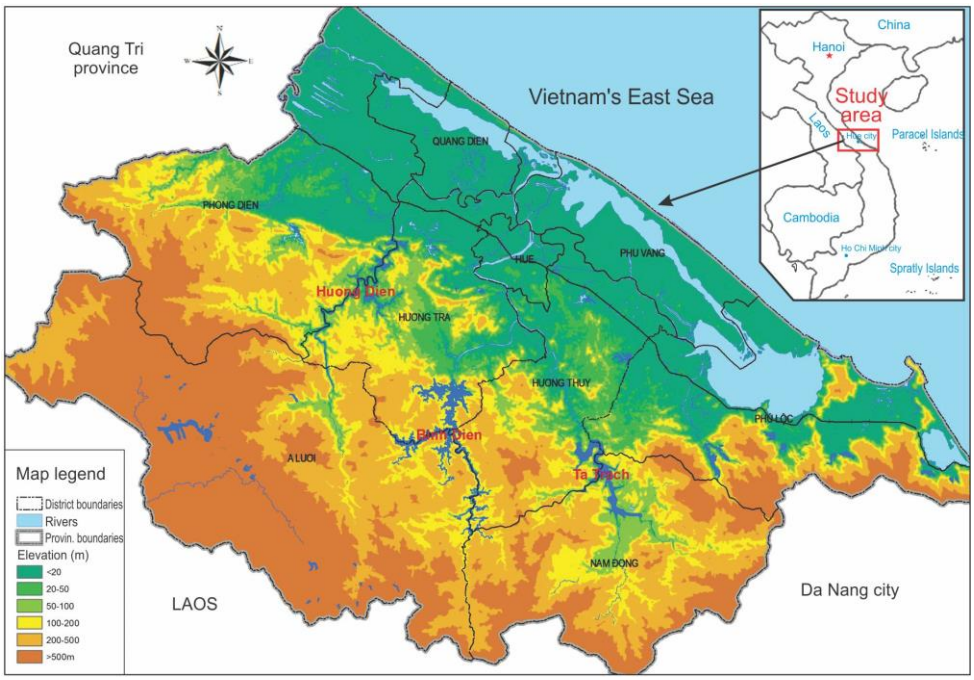

Figure 2. Elevation map of Thua Thien Hue province.
(provided by the Ministry of Natural Resources and Environment of Vietnam - MONRE)

The study area is often affected by storms and heavy rain. The number of storms directly impacting Thua Thien Hue province tends to decrease compared to the 1970s and 1980s, but the storm scale tends to increase and usually occurs in September and October with the probability 34% and 27% respectively [9]. The water level recorded at the Kim Long hydrological station on the downstream of the study area shows that there are about 4 - 5 floods occurring annually [8]. On October 14 - 15th, 2022, storm Son Ca - the fifth storm to hit the Vietnamese coast, experienced severe flooding due to heavy rain. Many areas in central Vietnam have been submerged, including Thua Thien Hue province (Figure 3).

Figure 3. A view from above looking across Hue Imperial Citadel, October 15, 2022 [10].

The results of the research will provide insight into the potential of Sentinel-1 SAR in supporting disaster response organizations in their efforts to respond effectively to flood events in Thua Thien Hue province and similar regions around the world. The findings of this research will also inform future efforts to improve flood risk management and disaster response through the effective use of SAR technology.

2. METHODOLOGY

The study was designed in two main components. The first one is mapping flooded extent from Sentinel 1 SAR images by Change Detection and Thresholding (CDAT) method. The second one is flood damage assessment for each district and each land cover types. All these steps were illustrated in Figure 4.

In the first component, the inundated area was produced by applying the CDAT method [11] on Sentinel-1 data based on the Google Earth Engine platform (GEE). CDAT is a valuable method employed in analyzing Sentinel-1 satellite imagery for flood area delineation. One notable advantage of CDAT lies in its objectivity, offering an automated and quantitative approach to identify changes in pixel values between different time points. This objectivity reduces subjectivity and enhances the precision of flood extent assessments. The

method is particularly well-suited for multitemporal analysis of large datasets generated by Sentinel-1, enabling the capture of dynamic changes over time [6].

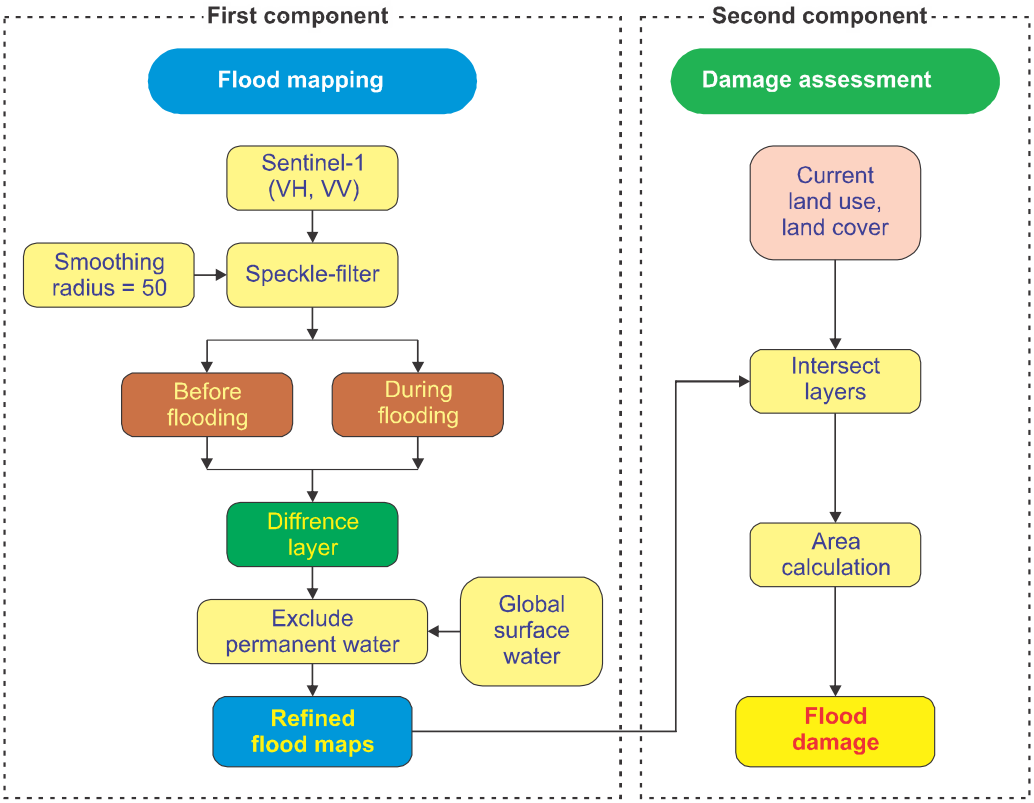

Figure 4. The workflow of flood mapping and damage assessment.

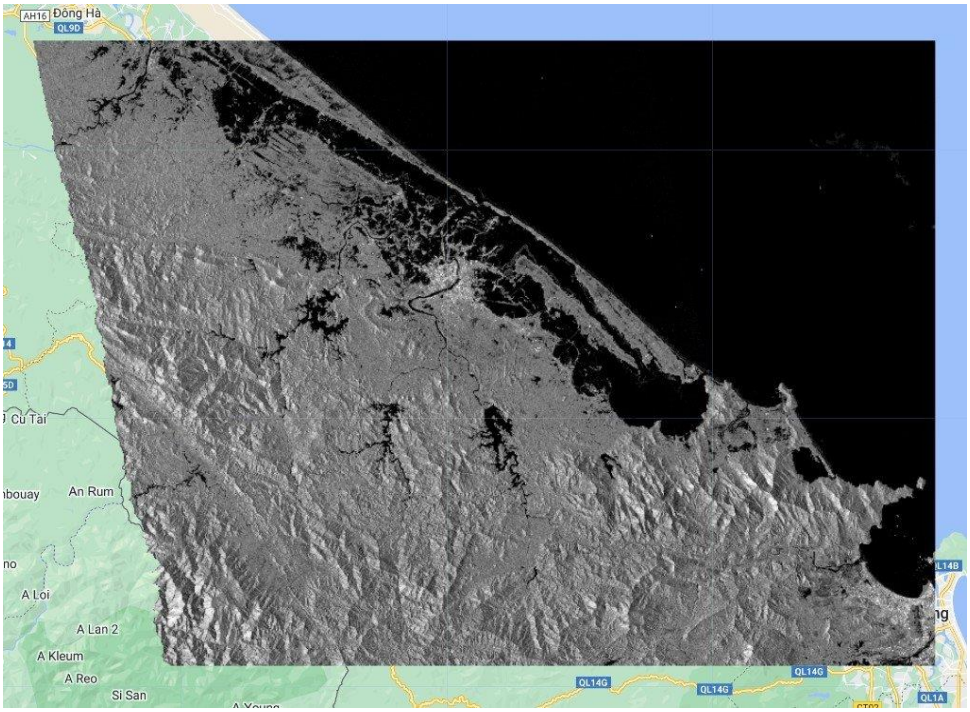

Figure 5. Flood event image from satellite.

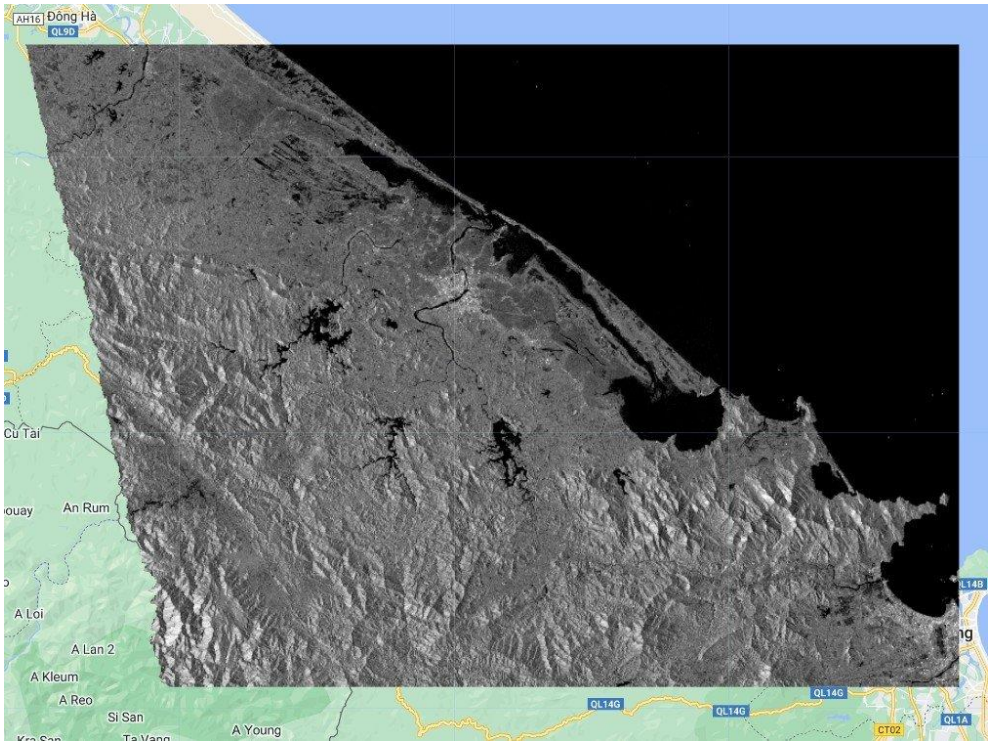

Figure 6. Satellite image on a sunny day.

```
29  //                                SET TIME FRAME
30
31  //   Set start and end dates of a period BEFORE the flood. Make sure it is long enough for
32  //   Sentinel-1 to acquire an image (repitition rate = 6 days). Adjust these parameters, if
33  //   your ImageCollections (see Console) do not contain any elements.*/
34
35  var before_start= '2022-04-01';
36  var before_end='2022-04-08';
37
38  // Now set the same parameters for AFTER the flood.
39  var after_start='2022-10-13';
40  var after_end='2022-10-16';
41  //*************************************************************************************************
42  //                            SET SAR PARAMETERS (can be left default)*/
43
```

Figure 7. Code on the Google Earth Engine platform.

- First, a pair of Sentinel-1 SAR images contained during the flood event (15th Oct, 2022) (Figure 5) and pre-flood (sunny day) (Figure 6) in Thua Thien Hue province was obtained.

- Second, performed pre-processing of the SAR images, including calibration, filtering, and speckle reduction. Then, applied CDAT method to analyze the difference between the two periods (Figure 7).

The change detection generated a difference layer (D), which was conducted by comparing the absolute backscatter values of before - and during - flood event images. The inundated area was determined by classifying the difference layer using a threshold. The threshold is defined as less than the mean pixel value minus the standard deviation of the entire image multiplied by the coefficient k_f.

$$P_D < \left(\left\{ L_{mean} \left[D \right] \right\} - k_f \left\{ L_{stdev} \left[D \right] \right\} \right) \quad (1)$$

where P_D is the inundated pixel, L_{mean} and L_{stdev} are mean and standard deviation of difference layer. The optimum value of k_f is 1.5 [11][12].

The final inundated area was refined by excluding areas having more than 5% of slope value and pixels having lower than 4 neighbors.

In the second component, the high-precision land cover map, which was provided by the Ministry of Natural Resources and Environment of Vietnam (MONRE), was intersected with the flood map to analyze the flood area for each land cover type. Then, each type of land cover was calculated how much area was inundated by the flood event.

3. RESULTS AND DISCUSSION

The results of flooded extent detection were show in Figure 8. The total flooded area in the region is 33,384.08ha. The district with the largest flooded area is Quang Dien with 5,470.05ha, followed by Phu Loc with 4,674.76ha, and Huong Tra with 4,495.54ha. The district with the smallest flooded area is Phu Vang with only 3.55ha.

The Figure 9 represents the flooded areas (in hectares) for a particular land cover type. The crop land was inundated the most with 25,728.37ha. The land cover types in the region, in descending order of area covered, are forest (1,967.36ha), built-up (1,528.28ha), resident (340.84ha), bare (584.04ha), and grass (56.42ha).

The results suggested that flooding event in October 2022 was a significant issue in the Thua Thien Hue province, with a total inundated area of 33,384.08ha. The district-level analysis indicated that Quang Dien, Phu Loc, and Huong Tra were the most affected districts, while Phu Vang is the least affected. The finding that crop land was the most inundated land cover type in the region (77.07%) was particularly concerning as it could lead to significant agricultural losses. The data on other land cover types, such as forest and built-up areas, can also be used to inform flood management and planning efforts in the province. Overall, these results underscore the need for effective flood mitigation and management strategies in the region.

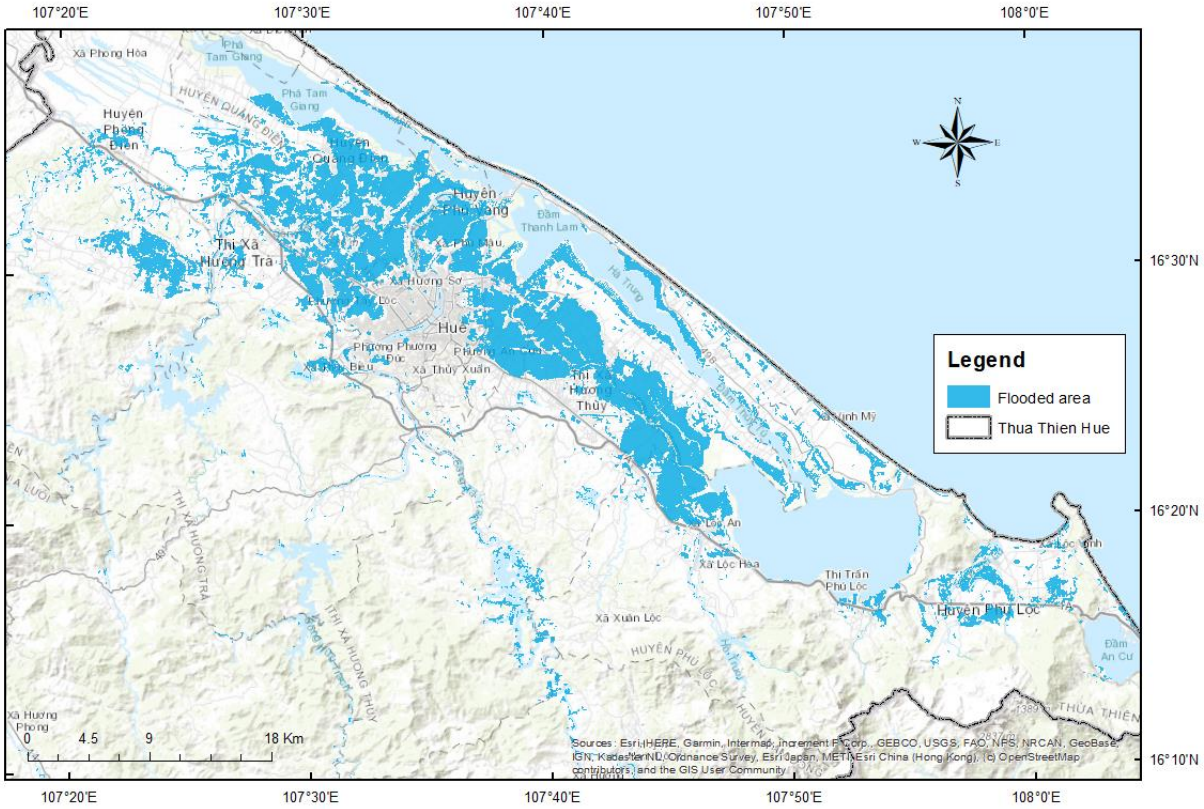

Figure 8. The flooded extent in Thua Thien Hue in the 15th October, 2022.

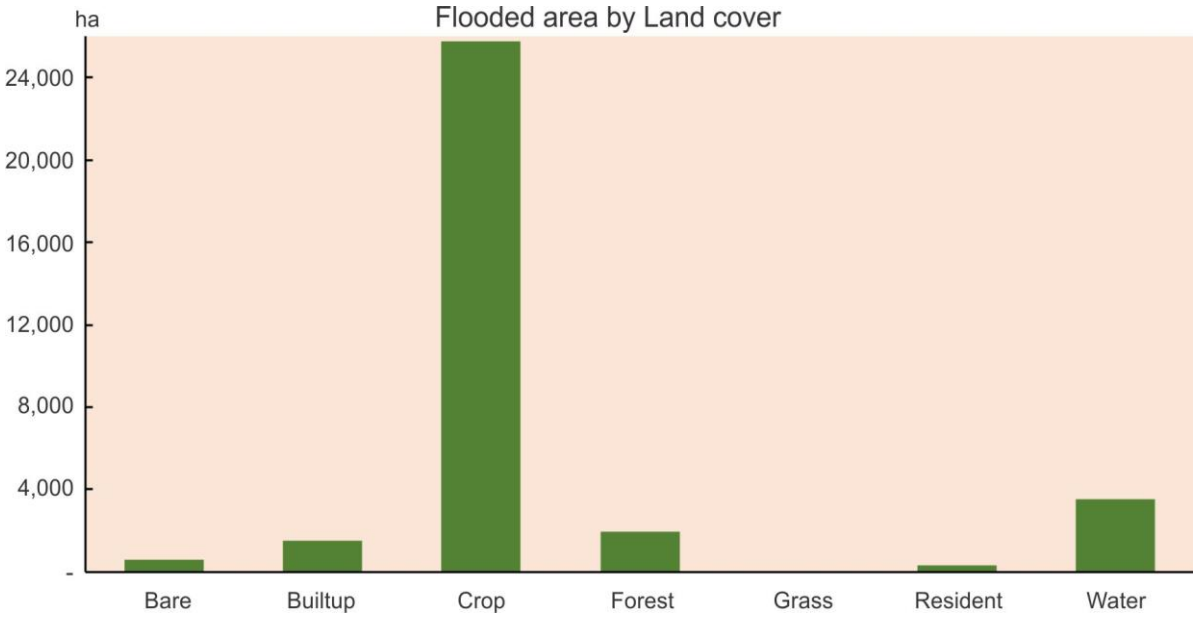

Figure 9. Flooded area (ha) for each land cover type of Thua Thien Hue province.

4. CONCLUSIONS

In conclusion, the study has succeeded in applying Sentinel 1 SAR data to quickly generate an inundation map and assess its damage for Thua Thien Hue province in flood event

on 15th October 2022. The adoption of the CDAT method facilitated the identification of inundated areas, revealing a total inundated area of 33,384.08 ha. The flood event affected to several districts with Quang Dien being the worst hit, followed by Phu Loc and Huong Tra. Phu Vang had the smallest flooded area. The study further demonstrated the practical application of overlaying the derived flood map onto the existing land cover map for an initial evaluation of potential flood damage across different land use categories. Notably, the assessment revealed that croplands were disproportionately affected, constituting 77.07% of the total inundated area. These findings provide valuable insights for decision-makers, offering a basis for monitoring and assessing flood damage in Central Vietnam, and underscore the efficiency of utilizing remote sensing technology for swift and cost-effective flood hazard analyses.

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