Estimation of floodwater depth in Quang Tri province using Sentinel-1 data

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Abstract

Floodwater depth is an essential parameter to assess the flood damages and release the prompt decisions to mitigate severe consequences. In the context of climate change, water-related disaster becomes more frequent and severe; therefore, rapid estimation of floodwater depth plays a vital role in disaster response and damage mitigation. In recent years, the approach of integrating Sentinel-1 data that is independent of weather conditions and GEE, a cloud-based platform attracts many researchers in flood extent and floodwater depth assessment. In this paper, the authors apply a Google Earth Engine implementation of the Floodwater Depth Estimation Tool (FwDET-GEE) algorithm on the Sentinel-1 images to detect the flood extent extraction and DEM accuracy improvement for floodwater depth estimation. The authors also use GEE to conduct further analysis about flood damages based on the estimated floodwater level dataset and the cloud-based datasets of population, cropland, and urban area. The results reveal that 0.5m floodwater depth has covered an area of 19,000 ha, and 3m floodwater depth covered an area of 800 ha in the Hai Lang district. Furthermore, the 2020 flood event has respectively impacted 9,100 ha of cropland and 360 ha of the urban area.

1. Introduction

Flood is a phenomenon causing massive catastrophic impacts on humans and nature. In recent years, extreme floods have been more frequent and severe on the Central Coast of Vietnam. Quang Tri province has diverse water resources with a dense river network, composed of 3 main river basins with a total catchment area of more than 4,000 km^2 and more than 600,000 residents (Quang Tri Province, n.d.). Therefore, rapid floodwater depth assessment is crucial for mitigating flood risk on people and infrastructures.

Recently, satellite-based Remote Sensing Technology has been shown as a valuable dataset for flood risk and depth assessment (Abrishamchi et al., 2012; Anusha and Bharathi, 2020; Do et al., 2019; Quang et al., 2021; Vuong Tai Chi et al., 2020). Among available satellite data, Sentinel-1 Synthetic Aperture Radar (SAR) data has become a more attractive data resource for flood mapping and damage assessment (Huang and Jin, 2020). This is because Sentinel-1 SAR provides Level-1 Ground Range Detected products independent of weather conditions, especially clouds. For this reason, Sentinel-1 data can even be used to analyze under cloudy conditions during flood events, which is a huge difference compared to the Optical Satellite data. Moreover, Google Earth Engine (GEE), a cloud-based image processing platform, appears as a high-performance tool to access numerous satellite images and process a large scale of geospatial data (Gorelick et al., 2017). This approach helps reduce significant time intervals for data processing compared to desktop-based tools, which require a considerable duration for data downloading and processing (Tiwari et al., 2020).

The FwDET-GEE tool, developed by Peter et al.(2020), appears to be an effective and reliable tool for floodwater depth estimation implemented on the GEE platform. It uses flood extent layer and DEM data

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as its main inputs. Peter et al.(2020) evaluated the results from FwDET-GEE with iRIC-FaSTMETCH hydrodynamics model. They achieved an RMSE up to 0.7m and sufficient good to apply for floodwater depth estimation.

This paper aims to integrate FwDET-GEE with Sentinel-1 data for floodwater depth estimation on the GEE platform. Further assessment about exposed people, affected cropland, and urban areas are also conducted to obtain an overview of flood damages in Quang Tri province.

2. Case study and data collection

2.1. Case study

Quang Tri province is located on the North Central coast of Vietnam with a total area of 3,469 km^2 and 75km of coastline (Quang Tri Statistics Office, 2015). The province has diverse and complex terrain, comprising wide sand dunes, a deep delta area along the coast, and an increasingly high elevation towards the West. The high mountainous area is about 100km away from the sea. Quang Tri province has a dense river network with 17 primary rivers and 13 secondary ones, supplying water for more than 4000km^2 river basin (NewsTech and SWS Consulting Engineering S.r.l (Italy), 2019). These topography characteristics make the province vulnerable to storms with very high landslide risk in the West and heavy floods in the East.

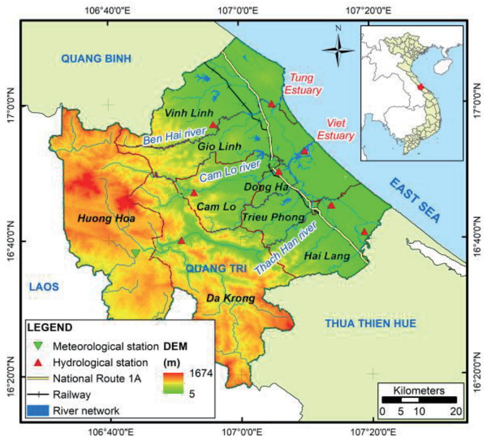


Figure 1. Administrative map of Quang Tri province

Quang Tri province is a very attractive tourist destination with many famous historical and revolutionary sites. Moreover, the province is a part of the economic center of the region and the East-West Economic Corridor (EWEC), offering multiple opportunities for economic development and international economic integration (Vietnam Chamber of Commerce and Industry (VCCI), 2017). However, these economic potentials are annually being threatened by tropical storms. For instance, Quang Tri has directly suffered at least 15 tropical storms in the last three decades and three severe storms in 2020. Especially, the Molave tropical storm, hitting Quang Tri province from 26 October 2020, has caused extreme floods and landslides and forced thousands of people to excavate their homes.

2.2. Data collection

Sentinel-1 data provides Level-1 Ground Range Detected (GRD) products, consisting of the SAR data, with the advantage of operating at wavelengths without being affected by cloud cover or lack of illumination (European Space Agency, n.d.). Sentinel-1 data provides multiple polarizations, including VH (Vertical transmit – Horizontal receive) and VV (Vertical transmit – Vertical receive) polarizations, which provide more information on inundated areas than that in single-polarized radar. In this study, two Sentinel-1 GRD scenes with a resolution of 10m are used, focusing on the flood event on 28 October 2020 caused by the tropical storm Molave (Table 1).

Table 1. List of Sentinel-1 images used in the study

Product	Date	Polarization
S1_GRD/S1B_IW_GRDH_1SDV_20201028T224307_20201028T224332_024019_02DA78_5453	28-Oct-20	VH + VV
S1_GRD/S1B_IW_GRDH_1SDV_20201028T224332_20201028T224357_024019_02DA78_486D	28-Oct-20	VH + VV

Digital elevation model (DEM) represents elevation data to represent the Earth's topographic surface. In this study, the 30m-resolution SRTM (Shuttle Radar Topography Mission) is used as an important part of the floodwater depth estimation process (https://developers.google.com/earth-engine/datasets/catalog/USGS_SRTMGL1_003).

In addition, the assessment of flood damages are estimated based on the 100m-resolution dataset of population statistics, and 500m-resolution dataset of cropland and urban area in Quang Tri province in 2020 from WorldPop (https://www.worldpop.org/) and Moderate Resolution Imaging Spectroradiometer (MODIS) image, respectively.

3. Methodology

The procedure for floodwater depth estimation follows three main steps: i) flood extent extraction; ii) DEM accuracy improvement; iii) floodwater depth estimation (Figure 2).

For flood extent extraction, the authors based on the ratio between pixel values of the during-flood-event image and the before one to produce the temporal water layer. The generated temporary water layer includes floodwater and the water resulting from radar error on mountainous areas. In GEE, this error is assigned to low values, corresponding to the values of water. In this context, the areas having a slope of greater than 5% are removed based on the DEM layer from the HydroSHEDS data, also available in GEE. This procedure helps to remove the non-correct pixels and retrieve only the floodwater layer. Within the process of floodwater extraction, the removal of permanent water is not conducted since the permanent water is included in both before and during-flood-event images.

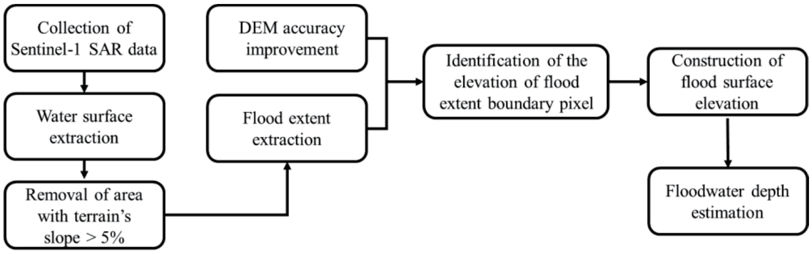


Figure 2. Flowchart of the methodology for floodwater depth estimation

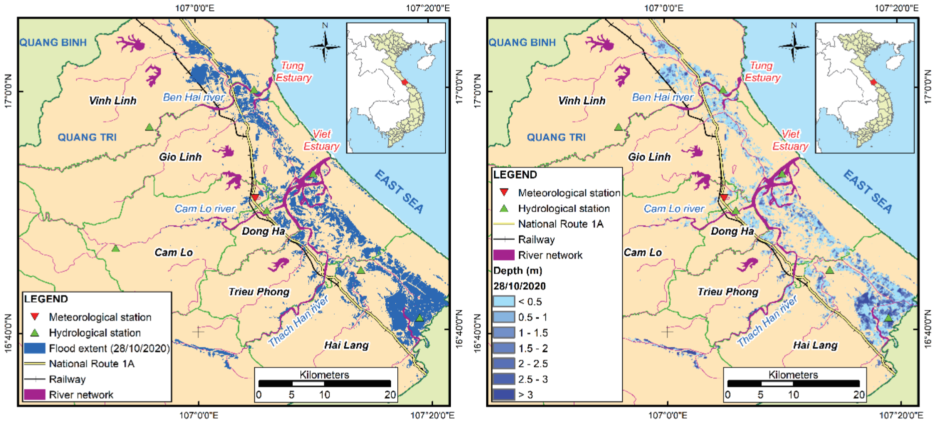
Two filtering processes are used to improve the accuracy of DEM data. The first process is applied for the entire DEM layer using a low-pass filter with a 3×3 square kernel and the modified z-score. Each pixel with an outlier value is detected and replaced by the median of the surrounding eight pixels. The second process is similar but applied for DEM pixels nearest the floodwater surface boundary pixels.

After the DEM improvement, the boundary pixel elevations of flood extent are extracted based on corresponding pixels of the DEM layer. These values are assigned to the nearest pixels to the flood extent boundary by the focal statistic method with the condition of choosing the smallest neighborhood value. This process is conducted until assigned to all pixels within the floodwater surface. For floodwater depth estimation, the elevation of floodwater surface is subtracted from corresponding pixel elevations of DEM. After using a low-pass filter to calculate the average value for each pixel based on its 3×3 neighborhood, the final floodwater depth layer is retrieved. The estimated floodwater depth is validated using the 2D hydrodynamic model – MIKE 21.

4. Results and discussion

4.1. Flood extent and floodwater depth of the flood event on 28 October 2020

Figure 3 shows the results of flood extent extraction with a total area of more than 19,000 ha of Quang Tri province during the flood event on 28 October 2020. From Figure 3a, floodwater was mainly in the low-elevation region along the coast and mountainous area. Hai Lang district has the largest inundated area with nearly 8,000 ha and accounts for 50% of the whole inundated area. The Quang Tri floodwater depth results in Figure 3b reveal mainly less than 0.5m and covered around 10,500 ha. A 3m floodwater depth covered more than 400ha of the Hai Lang district.



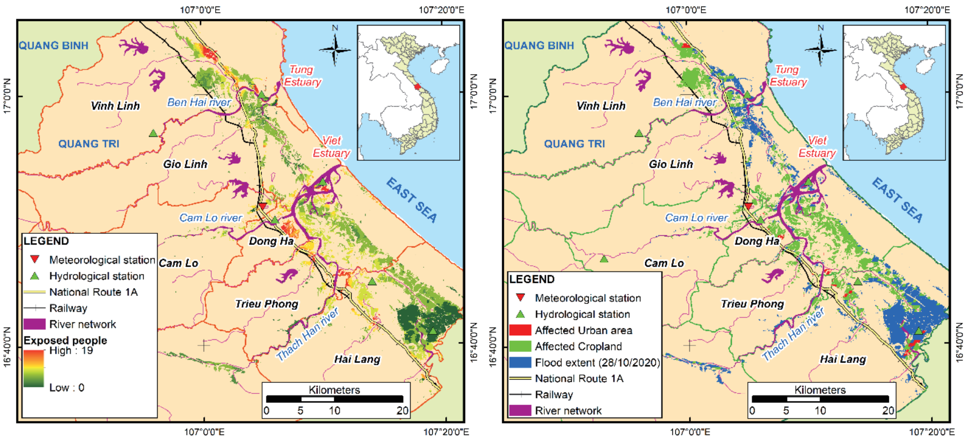
a) Flood extent map *b) Inundation map*

Figure 3. Flood extent and floodwater depth of the flood event on 28 October 2020 in Quang Tri province

4.2. Flood damage assessment of flood event on 28 October 2020

Based on the flood extent boundary, the layers of the population, cropland, and urban area are extracted on GEE to assess the flood damages during the target flood event. The estimation reveals that about 54,000 people in Quang Tri province were exposed to floods, in which Vinh Linh and Dong Ha were two districts with the highest affected population density (Figure 4a). In addition, the region with the deepest floodwater level in Hai Lang district had the lowest population density exposed to the flood event on 28 October 2020.

The results in Figure 4b highlight that cropland area was impacted by less-than-0.5m floodwater level with more than 5,000 ha. In addition, the most affected cropland area focused on Trieu Phong, Hai Lang, and Vinh Linh districts with a total area of 3,450 ha, 2,000 ha and 1,881 ha, respectively. On the other hand, the affected urban area was mainly in Hai Lang district with around 200 ha, in which about 7.3 ha was inundated by 2m floodwater depth..



a) Exposed people *b) Affected Cropland and Urban area*

Figure 4. Damage assessment due to the flood event on 28 October 2020 in Quang Tri province

5. Conclusion

In this study, the authors introduce the FwDET-GEE algorithm for rapidly estimating floodwater depth on GEE with integration with Sentinel-1 data. This approach helps reduce a significant time interval and requires minimal computer capability. After achieving the floodwater depth result, the authors integrate with the population, cropland, and urban area dataset recorded in 2020 to give the detailed assessment of flood damages to Quang Tri province in the flood event of 28 October 2020. The results reveal that the dominant floodwater depth was less than 0.5m covered about 10,500 ha; in addition, greater-than-3m floodwater depth covered the area of 800 ha and mainly appeared in the Hai Lang district. Furthermore, the flood event on 28 October 2020 impacted about 54,000 people, 9,100 ha and 360 ha of cropland and urban area, respectively. In the future, since natural flood disaster becomes more frequent and severe, integrating Sentinel-1 data and GEE will help achieve reliable assessment rapidly, hence obtaining better disaster response and management.

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