



## GOOGLE EARTH ENGINE FOR FLOOD MAPPING USING SENTINEL-1 GRD SAR IMAGES AND IMPACT ASSESSMENT ON SOCIO-ECONOMIC FACTORS: A CASE STUDY IN DA NANG

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### Abstract

*This study exploits the high computing performance of the Google Earth Engine (GEE) cloud computing platform to process Sentinel 1 images to rapidly establish a flood map in the coastal city of Da Nang through the historic flood in October 2022. The flood map is eventually exported to a shapefile and overlaid with socio-economic data in a GIS environment to assess the impact of flooding on socio-economic activities. The results indicate that the entire city has 10.505 ha flooded, concentrated in the Northwest and Southeast of Hoa Vang district, Lien Chieu district, and the results of geo-spatial statistical analysis also show that 189.161 km of flooded roads, 184 flooded residential areas, 12 flooded commercial service-school-hospital areas, and 9,786.81 ha of flooded agricultural land. The consequences were considerable damage to property, houses, crops and serious impacts on the lives and livelihoods of Da Nang residents.*

**Keywords:** Flooding; Coastal urban; GEE; Sentinel 1; Da Nang.

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### 1. Introduction

Floods are one of the most popular natural disasters and a major threat in the whole world. Recently, flood disasters have increased in frequency and intensity. The consequences of floods are complex, affecting many aspects of life, economy and society such as destroying houses, bridges, roads, trees, agriculture, causing landslides and threatening human lives,

especially in urban areas - where the population is concentrated (Mai et al., 2020, Zope et al., 2016). The specific characteristics of urban flooding are that it often occurs in a short time, the urban landscape structure is complex, the proportion of impervious surfaces is large, the use of remote sensing images to detect floods in the city center is also more difficult due to the ability to reflect and

backscatter from water areas that are also affected by the dispersion of (Biadgilgn buildings Demissie 2023).

Da Nang used to be a model for coastal urban development in many provinces and cities in Vietnam. However, recently, Da Nang has been continuously flooded and inundated in many residential areas. In October 2022, Da Nang experienced a huge flood, with nearly 70,000 houses in the city being flooded, thousands of cars and motorbikes damaged, and total material damage due to the flood was around 1,500 billion VND. One year later, Da Nang suffered another prolonged heavy rain and hundreds of flooded areas occurred throughout the city; the situation has highlighted the shortcomings of this coastal urban area (<https://baotainguyenmoitruong.vn>).

The increasing frequency of urban flooding seriously threatens the sustainable urban development and safety of citizens, leading to severe damage and loss (Wang et al., 2021, Wei et al., 2022). Therefore, timely flood monitoring (mapping, rapid impact assessment) is of great significance for urban flood management.

During the flood time, data and information collection is exceedingly difficult, and many places cannot even be accessed directly. Therefore, remote sensing has become a useful tool and has attracted the attention of many scientists. Sentinel 1 images are a source of SAR Radar data provided free of charge with the ability to collect images in all extreme weather conditions and regardless of day or night, suitable for flood monitoring, which can overcome the disadvantages of optical images in tropical and cloudy

climates like in Vietnam.

The GEE cloud computing platform was launched by Google in 2010. GEE uses Google's computing infrastructure and a huge remote sensing image database (Amani et al., 2020), solving the problem of big data processing when using personal computers. Thus, exploiting GEE applications is becoming an emerging trend in flood mapping, typically the study of the UNSPIDER Organization in 2015 proposed a specific method and instructions for producing flood maps using Sentinel-1A image pairs before and during flooding (UNSPIDER, 2015) and was applied by many authors later. Some typical studies are: Biadgilgn Demissie (2023) discovered the spatial, temporal distribution model and flood evolution in the tropical urban area of Dar es Salaam. Somya Jain et al., (2022) used VH and VV polarization of SAR radar data for Odisha state in India through Google Earth Engine, the results analyzed the area and extent of floods, in addition to many other authors such as Tiwari et al., 2020; Inman & Lyons, 2020; Moharrami, 2020; Singha et al., 2020; Vanama et al., 2020; DeVries et al., 2020; Mehmood et al., 2021; Pandey et al., 2022.

In Vietnam, there have been many studies on flooding using remote sensing and GEE such as Vu Huu Long et al., (2018), Vo Quoc Tuan et al., (2018), Luu Thi Dieu Chinh et al., (2022), Chi Tran Thuy & Linh Phung Thi (2022), Nguyen Thanh Ngan & Nguyen Hieu Trung (2021), etc. In general, the studies focused on two directions: The first one is algorithm development - technical improvement - methods and the second

one is flood mapping in non-urban areas, mapping and monitoring floods in complex urban environments is still a big challenge (Pelich et al., Cites2022) and there have not been many studies in Vietnam.

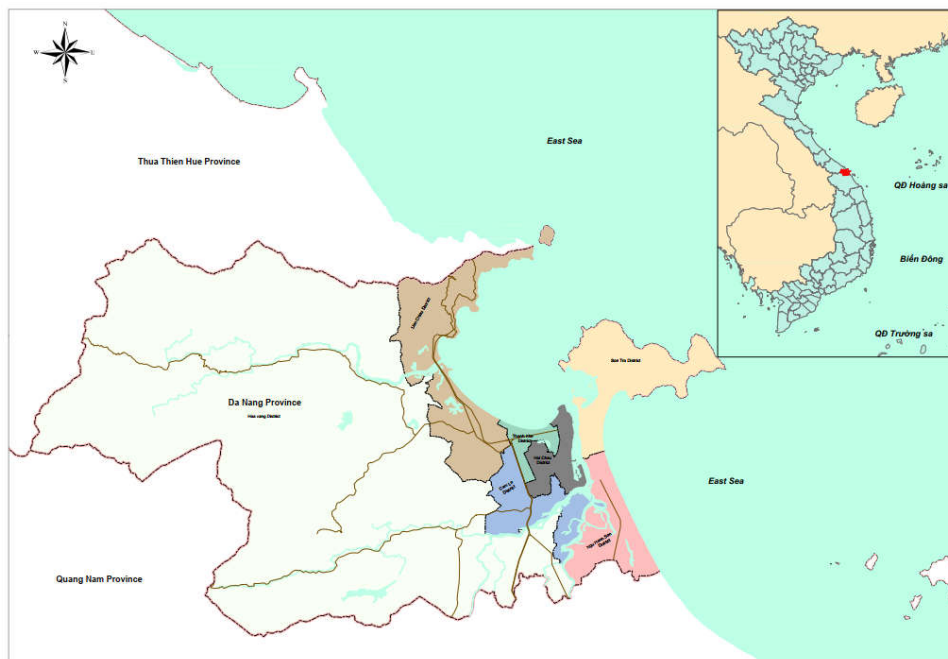
This study used the GEE platform to process Sentinel 1 images, for the coastal urban flood mapping - Da Nang, thereby assessing the impact of flooding on life, economy and society, including: Population, services - schools - hospitals, traffic, agriculture through the historic flood in October 2022.

## 2. Study area

Da Nang is a centrally run city, shaped as an important coastal urban node in the South Central region. The whole province has 7 districts on the land, in addition to Hoang Sa island district. In this study, we limit the scope to 7 districts on the land with an area of 97,988 ha, a total population of 5.8 million people

(<https://danang.gov.vn>).

The land of Da Nang city stretches from 15°15' to 16°40' North latitude and from 107°17' to 108°20' East longitude. Da Nang has a particularly favorable geographical location for economic development. Da Nang is located on National Highway 1A and the North-South railway. Da Nang connects to the Central Highlands via National Highway 14B and is the gateway to the sea of the Central Highlands and Laos, Cambodia, Thailand, Myanmar to Northeast Asian countries and territories via the East - West economic corridor. In addition, Da Nang also has important traffic routes such as the China - ASEAN international railway, seaports and international airports. Da Nang is only about 2,000 km from the developed economic centers of Southeast Asian countries and the Pacific region, which is very convenient for economic and cultural exchanges (<https://danang.gov.vn>).



*Figure 1: Location of the study area*

Da Nang is affected by tides and storms. Storms in Da Nang often appear in January, October and December; storms normally are level 9 - 10, causing heavy, prolonged rain and the risk of flooding. The rivers flowing through Da Nang all have the characteristics of the central coastal region: short and steep, large fluctuations in water level and water flow, and poor alluvium. In the rainy season, river water rises quickly, causing floods in the downstream areas, whereas the flood period is short, lasting only a few days (<https://danang.gov.vn>).

### 3. Data and methods

#### 3.1. Data

Sentinel-1 is a radar mission that continuously captures images in all weather conditions, regardless of day or night, in the C band. Sentinel-1 satellites

have high reliability, improved repeat times, wide geographic coverage and rapid data dissemination, to support applications operating in priority areas such as maritime surveillance, land surveillance and emergency services (<https://www.esa.int>).

In this study, main input data is Sentinel 1 GRD images, the geometric resolution of 20 m, acquired from 2022-10-01 to 2022-10-10 (before flooding) and from 2022-10-14 to 2022-10-16 (after flooding) to extract information and generate an urban flood map of Da Nang.

In addition, population and socio-economic data are employed to assess the impact of flooding on people's lives. These data are all in vector format (points, lines, polygons) and are exploited from open sources, detailed information is mentioned in Table 1.

**Table 1. Socio-economic data**

	Socio-economic factors	Sources	Geometries
1	Transport systems	<a href="https://download.geofabrik.de/asia/vietnam.html">https://download.geofabrik.de/asia/vietnam.html</a>	Lines
2	Residences	<a href="https://download.geofabrik.de/asia/vietnam.html">https://download.geofabrik.de/asia/vietnam.html</a>	Points
3	Service-school-hospital	<a href="https://download.geofabrik.de/asia/vietnam.html">https://download.geofabrik.de/asia/vietnam.html</a>	Points
4	Agricultures	<a href="https://dynamicworld.app/explore">https://dynamicworld.app/explore</a>	Polygons

#### 3.2. Methods

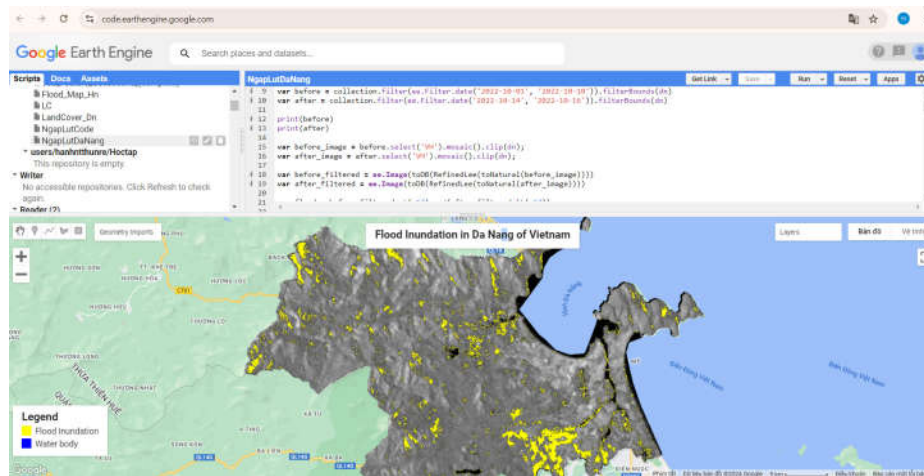
##### 3.2.1. Google Earth Engine platform

Google Earth Engine is a cloud computing platform for analyzing remote sensing images, environmental and meteorological parameters from regional to global scales, allowing users to run geospatial analyses on Google's platform. There are several ways to interact with the platform, the Code Editor is a web-based IDE (Interactive Development Environment) for writing and running scripts, the Explorer is a web application

for exploring the data catalog and running simple analyses, and the documentation library provides Python and JavaScript (Mutanga & Kumar, 2019). GEE has a built-in repository of tens of petabytes of freely available remote sensing data from NASA, the United States Geological Survey (USGS), the European Space Agency (ESA), and others. GEE's cloud computing infrastructure is optimized for spatial data processing, including time series analysis of remotely sensed data (Moore & Hansen 2011).

GEE was born from the idea of combining scientific knowledge with Google's huge data sources and the state of the art technology. This combination brings great efficiency such as processing speed and the ability to customize application development. The calculation and processing speed on GEE is unprecedentedly rapid (Mutanga & Kumar, 2019).

GEE allows the construction of calculation programs based on an application programming interface (API) using the extremely popular programming languages of JavaScript and Python (Mutanga & Kumar 2019; Moore & Hansen 2011). Thereby, the research team built a program to extract flood information from Sentinel-1 images data (Figure 2).



**Figure 2: Illustration of data analysis on GEE**

### 3.2.2. Satellite image processing

Sentinel-1 images are new generation satellite data of the European Space Agency. These satellites were developed to provide global remote sensing surveillance data under Europe's Copernicus Program (DeVries et al., 2020) and are currently provided for GEE's cloud computing system without charge, the product is put into use after preprocessing according to the standard process of the Sentinel preprocessing tool.

#### *Calculate backscatter difference*

Compute the backscatter difference using a simple formula:  $\Delta\sigma = \sigma_{\text{before}} - \sigma_{\text{after}}$  where  $\sigma_{\text{before}}$  and  $\sigma_{\text{after}}$  represent the backscatter values of each pixel before and after flooding.

*Principle:* Flooded areas will have lower backscatter values compared to non-flooded conditions because the smooth water surface creates a mirror-like reflection, reducing the radar return, while other dry surfaces should show minimal change.

#### *Apply thresholding*

To identify flooded areas, apply a threshold to the  $\Delta\sigma$  image. Pixels with a negative  $\Delta\sigma$  (or lower than a predefined threshold) can be classified as flooded regions. The threshold can be fixed or adaptively set based on statistical analysis of the image to ensure it's suited to the specific area and environmental conditions.

To produce a flood map of Da Nang city in the historic flood of October

2022, this study used the JavaScript programming language directly on the GEE platform (<https://developers.google.com/earth-engine>), including declaring commands to put imageries into the platform, image processing and analysis, displaying and extracting results.

### 3.2.3. Spatial statistical analysis

The result of analyzing and processing Sentinel-1 data on the GEE platform is flood inundation pixels for Da Nang city. The pixels converted to shapefiles to edit into a Da Nang urban flood map in 2022, and overlaid with traffic, residential, service-school-hospital and agriculture layers through geo-spatial statistical analysis tools in the GIS environment to assess the impact of flooding on people’s lives and activities. The specific implementation steps are described in the diagram as Figure 3.

### 3.2.4. Validation

In this study, to assess the accuracy of the flood map and the impact on socio-economic factors, we rely on reference data from reports by environmental and disaster management agencies, as well as information from local authorities and residents about flood damage published on official news sites: <https://danang.gov.vn/>; <https://baodanang.vn/>; [https://baotainguyenmoitruong.vn.](https://baotainguyenmoitruong.vn/) This information allows for qualitative comparisons of the sites and levels of flooding that occurred in the Da Nang, as well as the timing of the events.

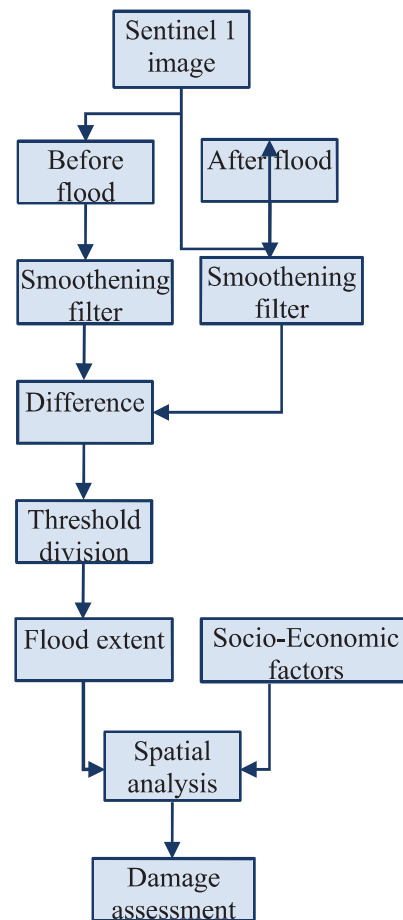


Figure 3: The flowchart and analysis

## 4. Results and discussion

The results are the Da Nang urban flood inundation map and map series assessing the impact of flooding on the socio-economic activities, and statistics on the damage caused by the flood in October 2022.

### 4.1. Urban flood map in Da Nang

According to the result of the flood map, the whole city has 10.505 ha flooded, concentrated in the Northwest and Southeast of Hoa Vang district, Lien Chieu district, Ngu Hanh Son and Son Tra district, specifically: Cam Le 103.14 ha, Hoa Vang 9183.82 ha, Lien Chieu 624.02 ha, Ngu Hanh Son 177.87 ha, Son Tra 399.88 ha, Hai Chau 16.41 ha.

The statistical chart of flooding rate in each district/total flooded area indicates that Hoa Vang district accounts for the largest rate of 71 %,

followed by Lien Chieu district 12 %, Son Tra 7 %, and finally Ngu Hanh Son 5 %, Hai Chau 3 %, Thanh Khe 2 %, Cam Le 1 %.

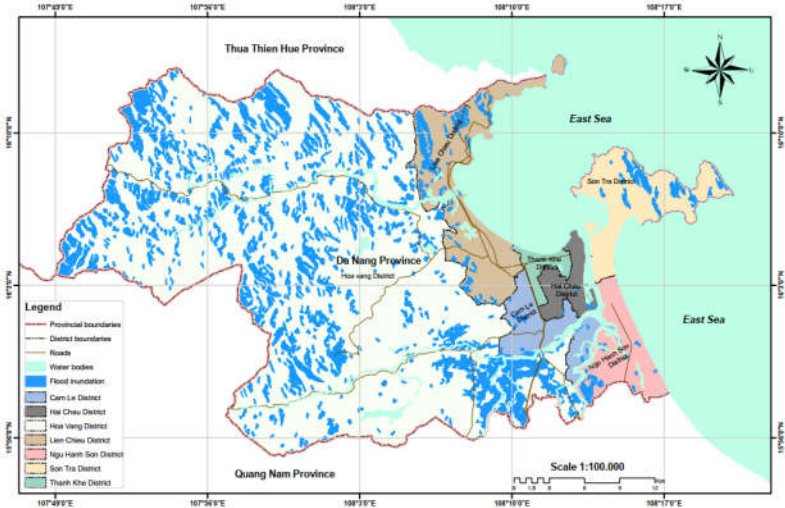


Figure 4: Urban flood map in Da Nang, Oct 2022

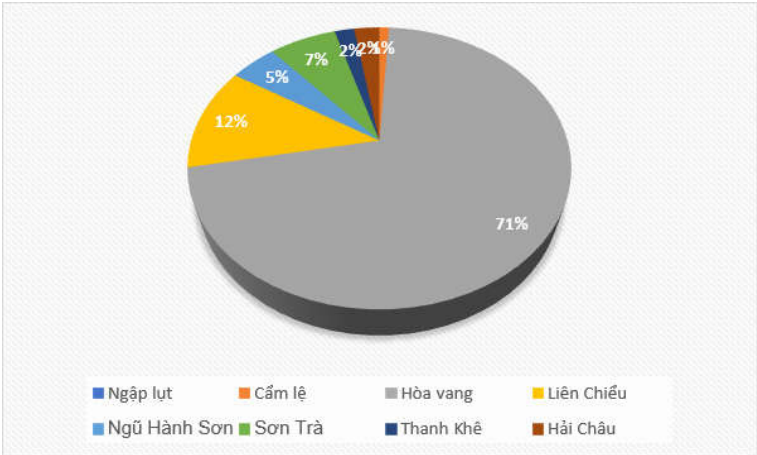


Figure 5: Percentage chart of flooded area in districts

The research results are completely consistent with the practical situation: In the evening of October 14, 2022 and early morning of October 15, 2022, in Da Nang, there was heavy rain, combined with high tides, leading to localized flooding from 0.6 to 1.5 m deep, in some places over 2 m, many households had to evacuate to safe places. A total of 124 points at risk, 10 heavily flooded points in the city including the area

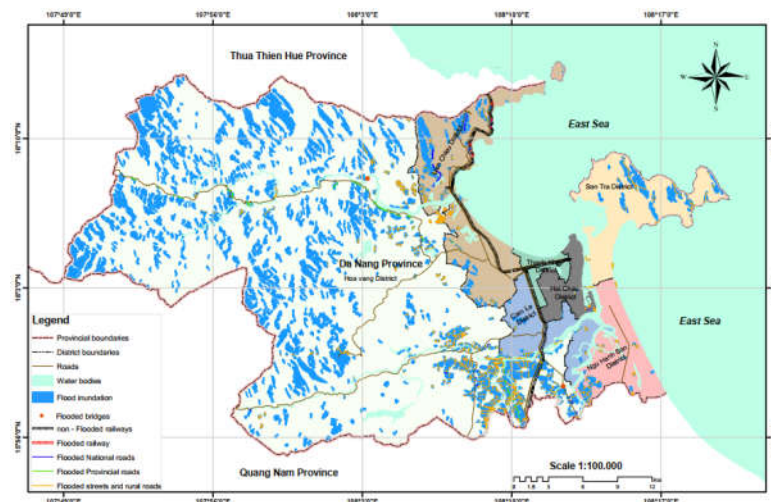
around Thac Gian - Vinh Trung lake, Da Nang hospital surrounding, Hai Ho street, alley 640 Trung Nu Vuong, Nguyen Nhan street (Phong Bac canal), Nui Thanh, Le Tan Trung, low-lying alleys on both sides of Me Suot street, Hoa Khanh Industrial Park gate, along Yen The and Bac Son streets, residential areas along the downstream of Khe Can sewer (Thanh Khe Tay ward, Thanh Khe district) (<https://baodanang.vn>).

## 4.2. Impact of flooding on population, socio-economic situations

### 4.2.1. Influences of flooding on the transport system

The study results showed that 7.626 km of National Highways were flooded, with sections passing through Hoa Vang district (1.240 km), Lien Chieu district (5.712 km), Hai Chau district (0.674 km); 2.297 km of railways were flooded, with segment passing through Hoa Vang district (0.086 km), Lien Chieu district (2.211 km); 11.114 km of provincial

roads were flooded, with sections passing through Hoa Vang district (10.955 km), Lien Chieu district (0.072 km), Cam Le district (0.087 km); 168.121 km of streets and rural roads were flooded in most districts, of which 123.759 km were in Hoa Vang district, 15.210 km were in Lien Chieu district, 10.970 km were in Son Tra district, 10.160 km were in Ngu Hanh Son district, 4.379 km were in Cam Le district, and 3.643 km were in Hai Chau district. Da Nang has 13 bridges, of which 2 were flooded.



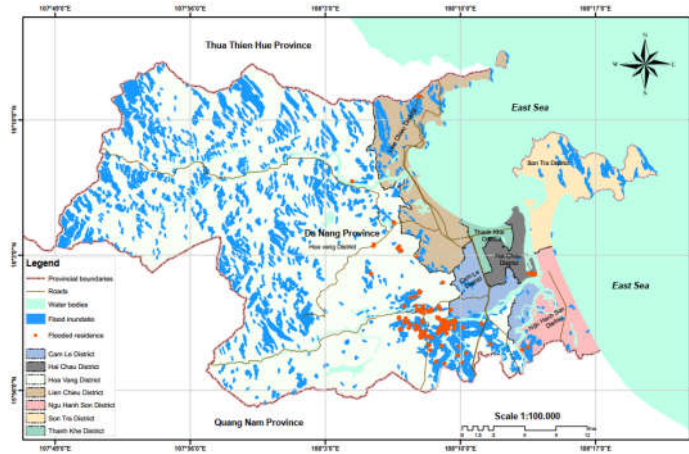
**Figure 6: Map assessing the impact of flooding on the transportation system**

Many flooded roads caused traffic jams, and many vehicles stalled. Particularly on the roads leading to Son Tra peninsula, some cars stalled and some areas suffered landslides. Soil, rocks, and mud on Son Tra peninsula flooded onto Le Van Luong street over a large area, obstructing traffic, affecting residents and tourists. Many roads in the city were eroded, damaged, and ruined; Severe landslide locations include Hoang Sa road, the road leading to Son Tra mountain; Nam Ky Khoi Nghia road, inter-commune and inter-village roads in

Hoa Vang district, etc. Estimated damage to the transport sector is about 190.5 billion VND (<https://baodanang.vn>).

### 4.2.2. Impact of flooding on residential areas

The results show that there are 184 residential areas flooded, mainly in the Southeast of Hoa Vang district as shown as red points on the map, of which Hoa Vang district has 169 points, Lien Chieu district 4 points, Ngu Hanh Son district 2 points, Cam Le district 1 point, Hai Chau district 8 points. Causing damage to many people's properties.

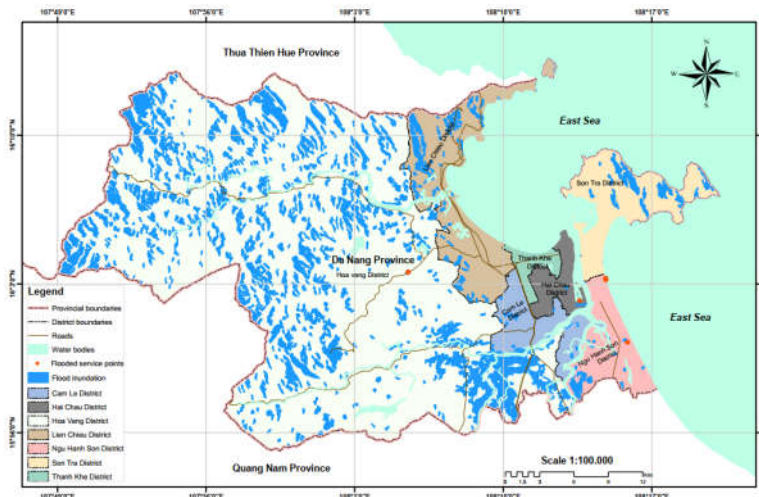


**Figure 7: Map assessing the impact of flooding on the residential areas**

Heavy rain at the time of high tide (high tide peaked at 1.4 m at 11 pm on October 14) caused widespread flooding in 52/56 wards and communes in 8 districts. Areas were deeply flooded, isolated and had strong currents include Hoa Khanh Nam ward, Hoa Hiep Bac ward, Hoa Hiep Nam wards in Lien Chieu district; Hoa Phong commune, Hoa Nhon commune, Hoa Bac commune, Hoa Lien commune in Hoa Vang district; Thanh Khe Tay ward, Thanh Khe district; Hoa Tho Dong ward, Hoa Phat ward in Cam Le district, Hoa Thuan Tay ward in Hai Chau district. Thousands of houses were

deeply flooded, some up to 2 m deep, with a total of nearly 70,000 houses flooded, the most in Lien Chieu district with 27,328 houses, Hoa Vang district with 16,040 houses, Hai Chau district with 12,012 houses, Cam Le district with 5,398 houses, Ngu Hanh Son district with 131 houses, and Thanh Khe district with 12,009 houses. More than 14,000 people had to evacuate to safety. Heavy rains and floods have caused severe damage to houses, property and infrastructure throughout the city, greatly affecting people's lives, socio-economic activities and production (<https://baodanang.vn>).

#### 4.2.3. Impact of flooding on commercial service - school - hospital areas

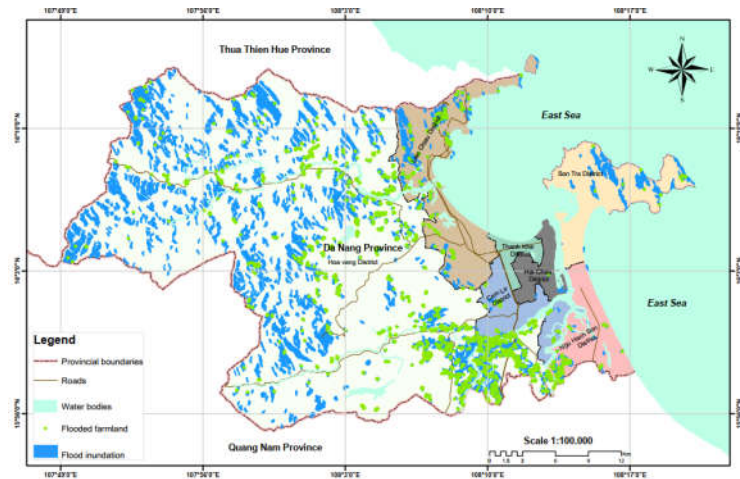


**Figure 8: Map assessing the impact of flooding on commercial service - schools - hospital points**

According to the research results, there are 12 flooded service - schools - hospital points, of which 1 point is in Hoa Vang district, 10 points are in Ngu Hanh Son district, 1 point is in Hai Chau district, causing damage to the library system, computers, classrooms; markets, shopping centers, schools had to close for several days, medical examination and treatment faced many difficulties.

#### 4.2.4. Impact of floods on agriculture

Observing the map of impacts of floods on agriculture, we see that 9,786.81 ha of cultivated land are affected, the flooded areas are mostly concentrated in Hoa Vang district and Lien Chieu districts; Specifically, Cam Le district accounts for 64.97 ha, Hoa Vang district 8,631.71 ha, Lien Chieu district 561.88 ha, Ngu Hanh Son district 137.44 ha, Son Tra district 390.77 ha. The consequences have damaged and lost many vegetables and crops.



**Figure 9: Map assessing the impact of flooding on agriculture**

## 5. Conclusion

The results showed the spatial distribution of urban flooding in Da Nang during the historic flood in October 2022. Due to heavy rain combined with high tides, the entire city had flooded areas, the most severe being Hoa Vang district and Lien Chieu district. The analysis and processing of Sentinel 1 images on the GEE cloud computing platform makes flood monitoring mapping convenient, simple and rapid, easy to automate and share data with stakeholders for timely disaster response. This method is scalable and can be applied to other coastal urban areas in Vietnam.

Combining geospatial statistical analysis, a series of map was established to assess the impact of urban flooding on the transportation system (189.161 km of flooded roads), residential areas (184 flooded residential areas), commercial service - schools - hospital areas (12 flooded areas), and agricultural land area (9,786.81 ha of flooded agricultural land). The consequences were extensive damage to property, housing, food supply, and serious impacts on the lives and livelihoods of Da Nang residents.

This study investigated flooding at the urban area scale and did not delve into complex urban environments. Therefore,

we recommend further research to develop advanced methods for detecting downtown flooding and address the reduction in backscattered reflections from water areas due to the dispersive effects of buildings and other urban features. Furthermore, developing methods that can integrate Sentinel-1 with other remote sensing data could be a solution to increase the frequency of observations. A comprehensive next research direction, combining Sentinel-1 imagery, measured flood data, and community participatory approaches for integrated disaster planning and management.

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