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Detection of Flood Affected Areas Using Radar and Optical Images in the January 2020 Flood in Chabahar City

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Original Article

Abstract

INTRODUCTION: One of the technologies that can have significant results in the field of crisis management is remote sensing, which has the ability to quickly and accurately assess floods and is considered an important and safe tool for reducing risk and responding to this hazard.

METHODS: In this study, radar data was used to quickly estimate the areas affected by the flood in the Chabahar city in January 2020, and the Normalized Difference Water Index (NDWI) was used to verify the validity.

FINDINGS: According to the research findings, the use of Sentinel-1 radar satellite data in critical situations such as flooding has a high potential for rapid and accurate monitoring of affected areas. Comparison of the results extracted from radar images with the NDWI based on Sentinel-2 optical images also showed that although there are differences between the two methods, a significant overlap was recorded between their results, indicating the relative validity of radar data for estimating flooded areas.

CONCLUSION: Overall, it seems that the benefits of using radar images to estimate areas affected by floods are undeniable and that by optimizing the algorithms and methods used, desirable results can be achieved in line with the desired goal.

Keywords: Flood; Chabahar; Radar images; Spectral index; Remote sensing; Crisis management.

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Introduction

Natural disasters have always had destructive effects on human life, causing not only material damage but also the loss of many lives and serious physical injuries. Among the natural disasters widely occurring around the world, floods are among the most devastating. Although floods are a natural phenomenon, their frequency and intensity have increased significantly in recent years. Today, destructive floods occur continuously and within shorter intervals across various regions globally. Experts largely attribute this increase to climate change, arguing that global warming and consequent climatic shifts have extensively disrupted environmental balance and intensified harmful phenomena, ranging from droughts to catastrophic floods. The impact of climate change on extreme environmental events such as floods has been a subject of extensive discussion in Iran over recent years. Studies indicate that the likelihood of deadly floods in southwestern and western Iran will increase between 2006 and 2050. According to the World Health Organization, over two billion people worldwide were directly or indirectly affected by floods between 1988 and 2017. (1)

In light of such forecasts and statistics, it is necessary to adopt measures to reduce damage and mitigate the adverse effects of such disasters. Equally important is planning and preparing for rapid and effective response to these events. The adoption of recent technologies that integrate

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diverse datasets supports the development of response strategies before and after disasters. (2)

Operational response plans for events like floods require tools that provide crisis managers with sufficient information to take appropriate measures for minimizing casualties and restoring affected communities to normalcy. In the future, analyzing such data should be conducted by experts at the Red Crescent Society's Operations Control and Coordination Center.

Due to Iran's position in a warm and arid climate zone, the impacts of climate change manifest as prolonged droughts as well as extensive floods. In recent years, devastating floods in Golestan, Lorestan, Sistan and Baluchistan, Khuzestan, and Hormozgan provinces have caused significant economic and social damage. Loss of lives, destruction of crops, damage to homes and infrastructure are among the major consequences. Time is a critical factor in disaster management, as much of the response must be completed shortly after the event. Recent floods have affected large geographical areas, often spanning multiple provinces. For example, the January 2022 flood affected vast parts of southern and southeastern Iran. When the operational area is extensive and rescue resources are limited, this can severely disrupt relief efforts.

One of the earliest steps in disaster management is damage assessment, which informs resource allocation and planning. When the affected area is large, the speed of assessment decreases significantly and damaged infrastructure restricts access to some locations. Under such conditions, tools that enable fast and accurate damage evaluation are essential. Monitoring flood-affected areas and assessing flood damage are key steps in crisis management; however, the lack of hydrological and meteorological data, along with the complexity of hydrological models, often pose challenges. Consequently, airborne and satellite data remain the most practical choice for continuous monitoring of extensive flood zones. (3)

Remote sensing technology is one such tool that can provide valuable information on wide areas impacted by disasters to crisis managers and emergency operation centers. Although there are notable limitations in using this technology for disaster management, its undeniable advantages can substantially meet the needs for responding to floods.

Regarding floods, prevailing weather conditions often limit the use of optical remote sensing images, as cloud cover after a flood usually prevents their use. Radar satellite imagery, however, is a useful tool for estimating flood-affected areas. Its key advantages are independence from weather conditions and the ability to capture images at any time of day or night, enabling maximum utilization.

In this regard, Soleimani Sarvar and et al. (2021) proposed using a random forest algorithm to monitor flood damage in southern Kerman province during April 2020. (5)

Cunjian & et al (2001) applied a threshold-based segmentation technique to extract flood boundaries from radar satellite images. (4)

In another study, Zhang & et al (2020) introduced a thresholding model combined with fuzzy logic applied to elevation data to map floods in Pakistan. This approach is suitable for extensive geographic areas with diverse land cover and terrain similar to Pakistan's. (6)

Tavus & et al. (2020) examining the 2018 flood in Turkey's Urdo province, combined Sentinel-1 radar images with Sentinel-2 optical images, exploiting the strengths of both to produce better results. (7) Benzougagh & et al. (2022) also recommended radar data for rapid flood area estimation in Morocco. (8)

This study aims to develop a flood map of the study area to enable rapid identification of flood-impacted zones for use in rescue and relief operations, employing radar data as a monitoring tool within emergency operation centers.

Methods

Various approaches have been developed to identify flood-affected areas using radar data, using different algorithms or combining different methods to create hybrid models. To speed up processing and produce flood maps suitable for rescue and relief operations, this study suggests using fast algorithms that maintain adequate accuracy for damage assessment.

Precise flood mapping often relies on pixel backscatter intensity and involves methods such as thresholding and supervised classification algorithms, including random forest, k-nearest neighbors, and maximum likelihood classifiers. (5)

In recent years, severe floods—particularly in the southern regions of the country—have caused extensive damage to infrastructure,

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residential areas, and agricultural production. In Sistan and Baluchistan province, especially in Chabahar County, flooding has become a major environmental hazard that annually affects the local economy and communities to varying degrees.

This study investigates the potential of radar imagery for estimating flood-affected areas in Chabahar County, Sistan and Baluchistan province, which experienced flooding and waterlogging on December 29, 2021. Synthetic Aperture Radar (SAR) data were used to estimate the affected zones and the results were validated using the Normalized Difference Water Index (NDWI).

Sentinel-1, the first satellite in the Sentinel series, was launched by the European Space Agency on April 3, 2014. It provides images with a spatial resolution of 10 by 10 meters. This sun-synchronous satellite consists of two polar-orbiting sensors, Sentinel-1A and Sentinel-1B, capable of capturing data both day and night. Operating in the C-band, the satellite uses SAR technology. (3)

SAR is a radar imaging method developed for earth observation without requiring large antennas. It is implemented on aircraft or space platforms by synthesizing multiple antenna positions to create an effective aperture. (9)

These features allow Sentinel-1 sensors to capture images regardless of weather conditions. The two satellites are positioned 180 degrees apart and image the entire planet every six days. Sentinel-1 offers various processing levels, including SLC and GRD, and operates in four imaging modes, delivering resolutions up to 5 meters and coverage widths of 400 kilometers. Its polar orbit and dual-polarization capabilities enable rapid data transfer to ground stations. The satellite's virtual aperture radar provides high-resolution images, which are highly useful for regional identification and crisis planning. (10)

In this research, radar images before and after the flood in Chabahar County were preprocessed and corrected as needed. Flood-affected areas were extracted using the unsupervised K-means classification method and compared accordingly. To validate the results, the flood extent derived from radar data was compared with the flood area obtained using the NDWI which reduces the influence of non-water features such as soil and vegetation by leveraging the higher reflectance of water in the green wavelength compared to near-infrared. McFeeters (1996) proposed a zero threshold where positive values indicate water presence, and negative values represent non-water features like soil and vegetation. (11)

Radar imagery processing in this study utilized SNAP-8 software, while Sentinel-2 images were processed using the Google Earth Engine (GEE) platform which developed by Google, is a powerful computational environment that provides processed global datasets—including precipitation, temperature, evapotranspiration, population, land use, and elevation—readily accessible for public use. (12)

Additionally, ArcGIS-10 software was used for post-processing and working with vector layers. (See Figure 1)

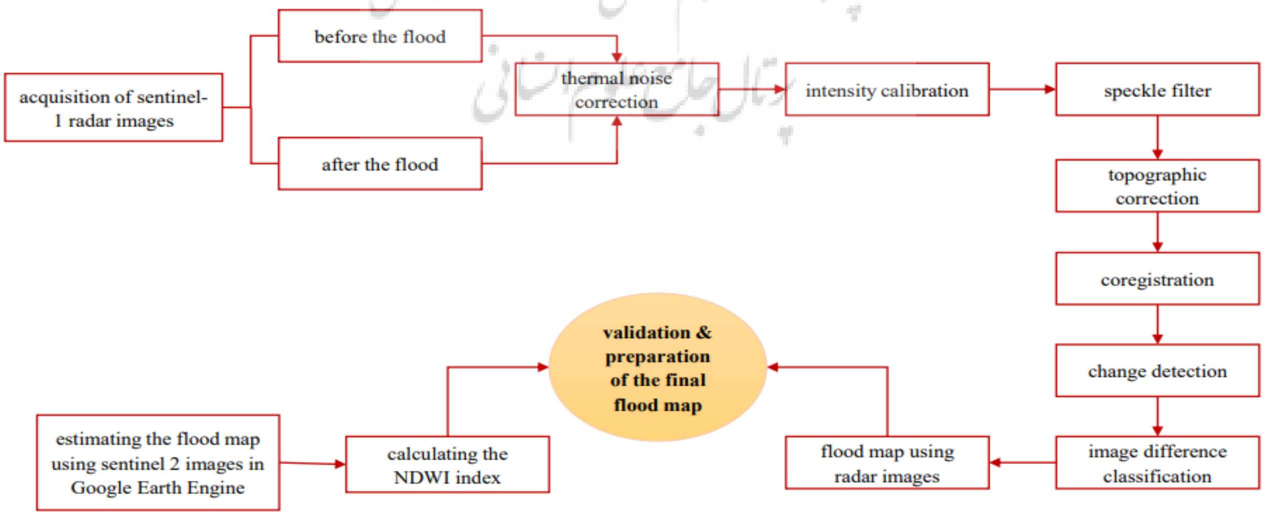

Figure 1. Conceptual model for estimating flood-affected areas using radar images

Findings

Chabahar County is situated in the southernmost part of Iran, close to the equator. Due to its coastal location along the Gulf of Oman, it experiences a hot and humid climate. It is bordered to the north by Iranshahr and Nikshahr counties, to the south by the Gulf of Oman, to the east by Pakistan, and to the west by the provinces of Kerman and Hormozgan. The city of Chabahar, which serves as the county's center, spans approximately 843 hectares and lies at an elevation of 7 meters above sea level, located at 60 degrees 37 minutes east longitude and 25 degrees 17 minutes north latitude. (Figure 2)

According to data from the Disaster Management Information System (DMIS) of the IRCS, the flood on January 29, 2022 severely affected parts of southern and southeastern Iran, including Chabahar County. During this event, three residents of Chabahar lost their lives, and over 1,700 households across the city and 29 neighboring villages suffered varying degrees of damage. Approximately 4,100 people were left temporarily or permanently without shelter (13).

The southern region of Sistan and Baluchistan province, including Chabahar County, had previously experienced another destructive flood in 2019.

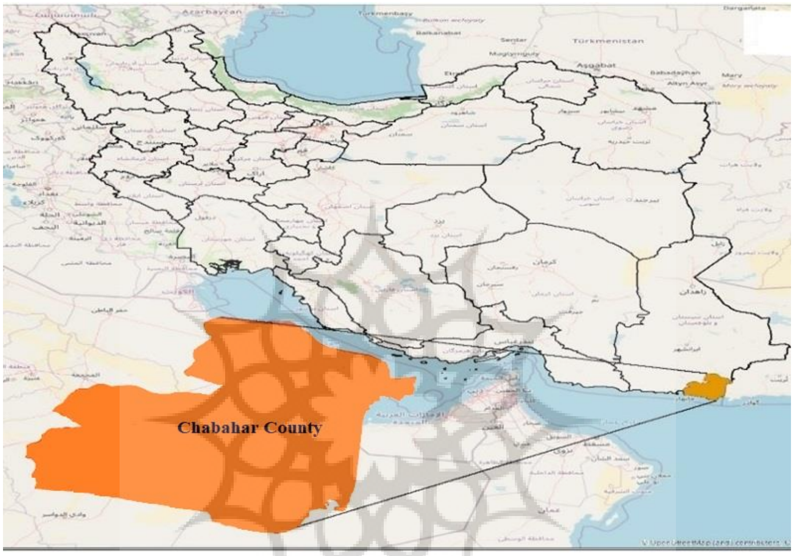

Figure 2. Location of Chabahar County (source: Authors)

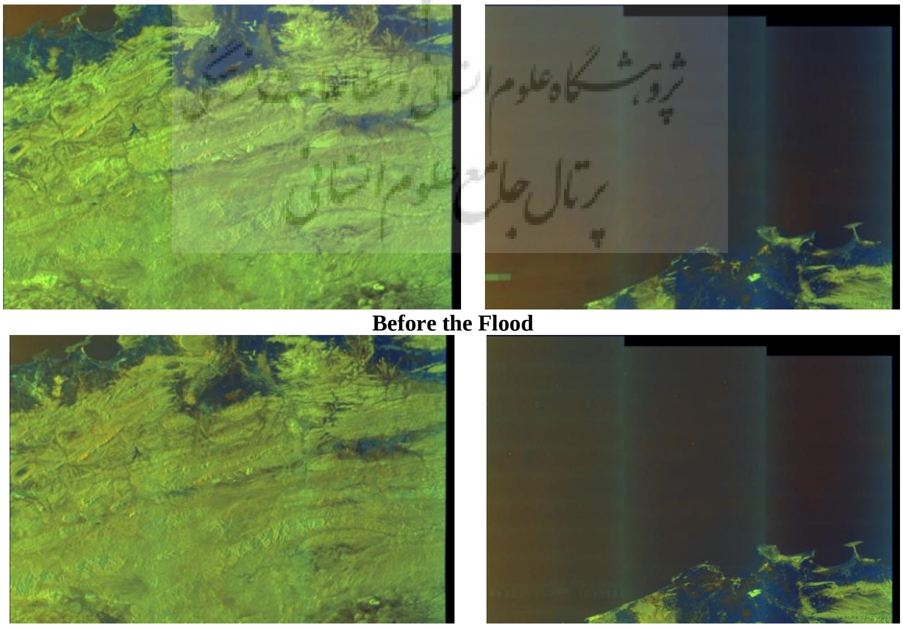

Figure 3. Sentinel 1 images of the study area before and after the flood

Table 1. Specifications of the acquired images for flood impact estimation in this study

Image Name	Satellite name	Pass type	Image type	Imaging method	Polarization	Date	Number of images
Before the Flood	S1-A	Asandinge	GRD	IW	VV	2021-12-21	2
After the Flood	S1-A	Asandinge	GRD	IW	VV	2022-01-02	2

Radar Image Acquisition

Following the flood event in Chabahar County on January 29, 2022, Sentinel-1 radar images dated January 2, 2022 were obtained. For comparison purposes, pre-flood images from December 21, 2021 were also collected. Each acquisition consisted of two images covering different parts of Chabahar County. These images were downloaded from the website of Copernicus.(Figure 3) (Table 1)

Preprocessing

Before any analysis, it is necessary to perform preprocessing on the acquired images to remove errors. The corrections applied to the images are as follows:

A)Thermal correction: Sentinel-1 image intensity is affected by additive thermal noise, particularly in the cross-polarization channel. (14) Thermal correction must be applied during preprocessing to eliminate this noise. Although thermal noise is rarely visible, it can reduce image quality, especially over calm water, rivers, and areas with low backscatter. Removing thermal noise is therefore essential for accurate flood mapping. (15)

B) Radiometric calibration: The goal of radiometric calibration (sigma calibration) is to convert raw pixel values into ground backscatter values. While uncalibrated images may be suitable for qualitative use, calibration is necessary for quantitative analysis. The calibration table included in the data allows for easy conversion from intensity values to sigma naught values. (16)

C) Speckle noise filtering: Radar images often suffer from speckle noise, which appears as granular interference resembling salt-and-pepper texture. Speckle filtering smooths these noisy areas without sacrificing image detail. This filter works based on sigma standard deviation statistics calculated within specific filter windows. Each pixel is replaced with a value derived from its neighbors to reduce noise while preserving image sharpness. (17)

D) Topographic correction: Terrain variations combined with the satellite sensor's viewing angle cause distortions such as foreshortening and shadowing in radar images. These distortions must be corrected to accurately locate each pixel geographically. (14) This is done by matching radar data with the region's digital elevation model, correcting height, and aligning the image with its proper geographic position.

E) Coregistration: It is a key step in processing Synthetic Aperture Radar Interferometry (InSAR) data (18) and involves aligning two or more images of the same area taken at different times, from different angles, or by different sensors. (Figure 3)

Difference Image Creation and Classification

To detect changes, the difference between post-flood and pre-flood images is calculated using software (Figure 4). Then, using this difference image, a two-class K-means clustering algorithm classifies the radar data into changed and unchanged areas.

After processing Sentinel-1 radar images to identify flood-affected areas in the January flood in Chabahar County, areas with slopes exceeding 5% were filtered out using elevation data to improve the accuracy of the results. From a geomorphological perspective, it is important to note that floods are more likely to occur in flat plains where the slope is close to zero. (1) Ultimately, approximately 175,523 hectares of Chabahar County were identified as flood-affected. (Figure 5)

Overlaying the settlement layer of Chabahar County with the extracted flood zones shows that 69 villages were located within the estimated flood-affected areas. (Figure 6)

As seen in Figure 4, the largest extent of flooding occurred in the southeastern coastal plain of the county, an area with a very gentle slope. The distribution of flood-affected areas is largely influenced by the topography and general slope of the county. Floodwaters were naturally channeled from the northern highlands towards the south, especially the southeast, following natural drainage paths.

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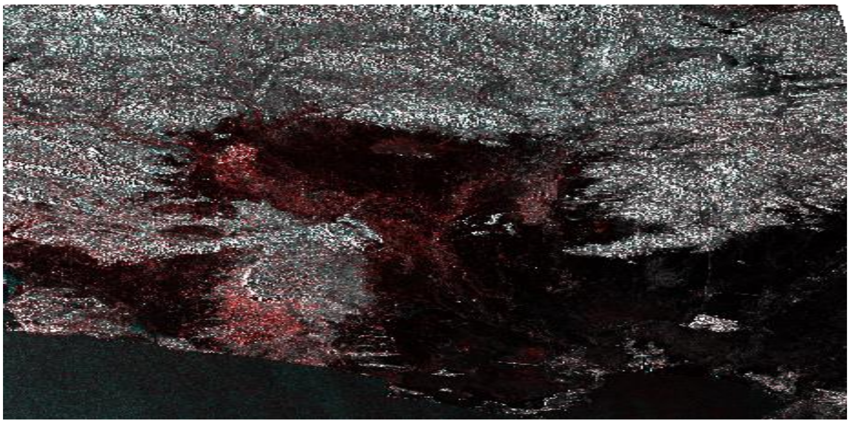

Figure 4. Change detection map before and after the flood (red areas indicate flood-affected zones) (Source: Authors)

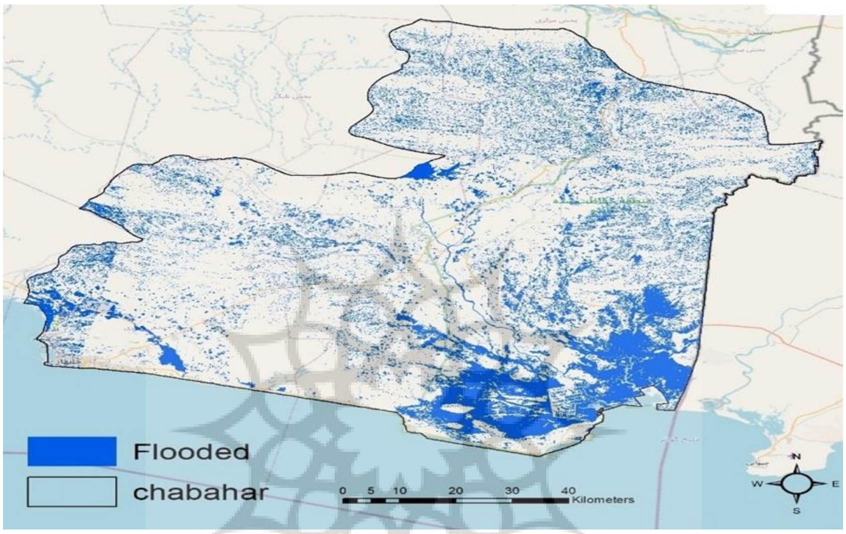

Figure 5. Flood-affected area in Chabahar County derived from Sentinel-1 radar images (Source: Authors)

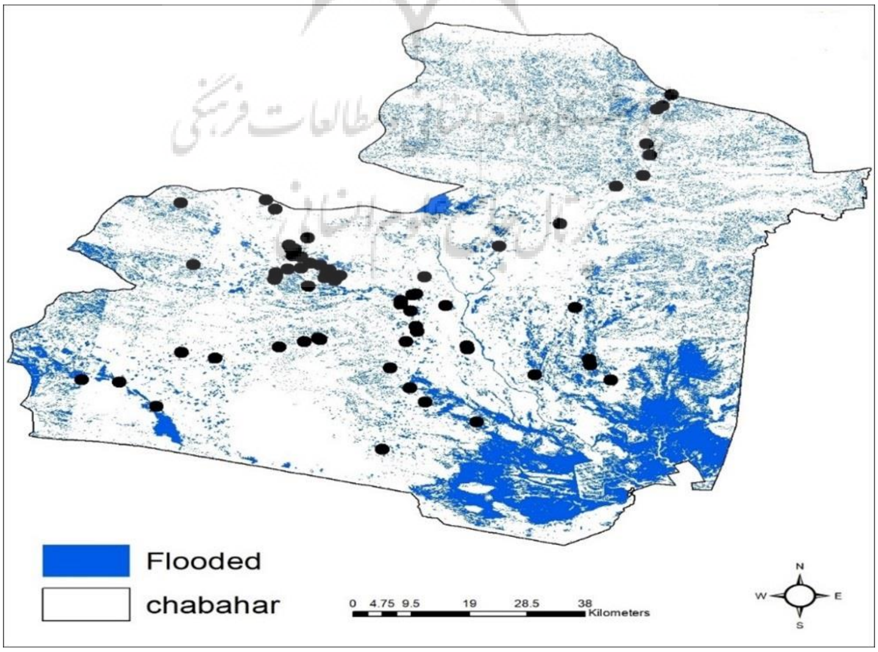

Figure 6. Distribution of villages within the flood-affected area in Chabahar County (Source: Authors)

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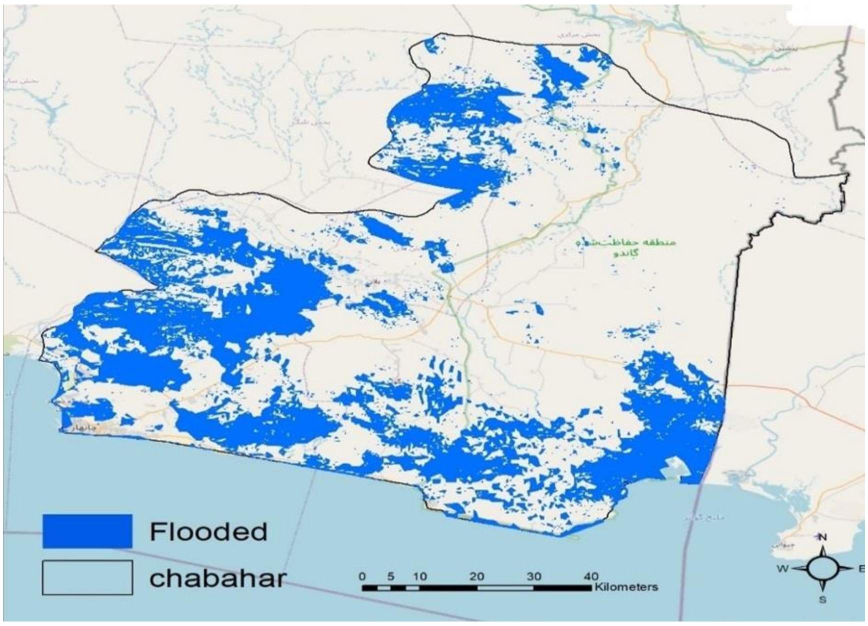

Figure 7. Flood-affected area in Chabahar County extracted from Sentinel-2 optical images (Source: Authors)

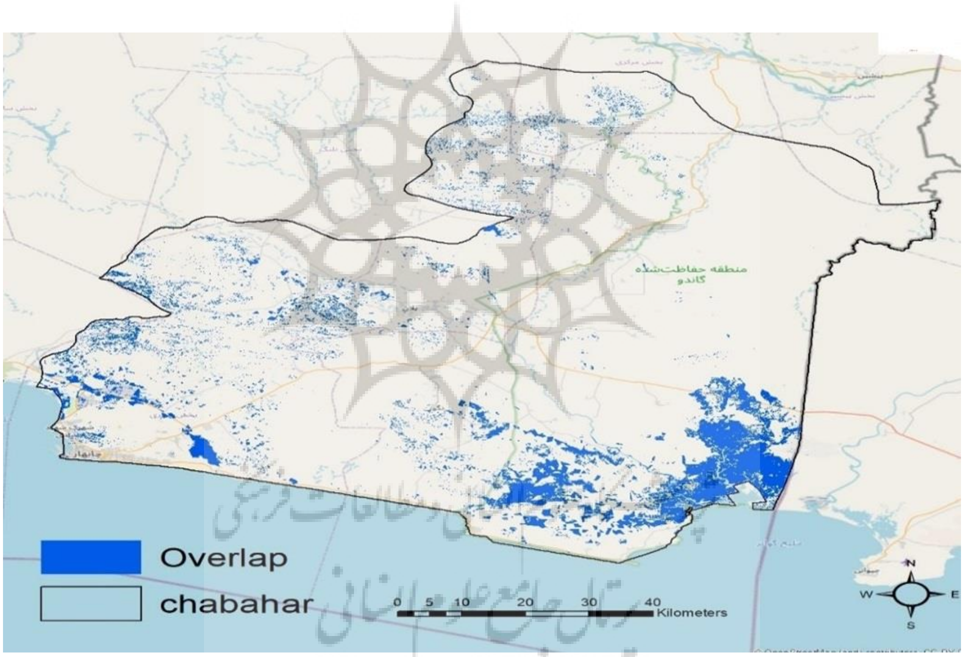

Figure 8. Overlap of radar and optical image flood maps (Source: Authors)

According to Figure 5, the eastern and southeastern regions of the county, which receive the greatest runoff, are border areas with few large human settlements. Most villages are located in the central plains and along main transportation routes. It appears that beyond the 69 villages directly impacted by flooding, a larger number of villages may have been indirectly affected due to damage to infrastructure and roads, resulting in isolation by floodwaters. Field observations indicate that the soil texture limits infiltration of floodwater, causing indirect flood effects to persist for a long time and affecting additional villages outside the immediate flood zones. Consequently, rescue and relief efforts may be needed for an extended period following the flood.

To validate the flood areas identified from radar images, optical images from Sentinel-2 were processed using the NDWI on the GEE platform. (Figure 7) The results show that this method estimates the flood-affected area at about 249,446

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hectares. The overlap between radar and optical image estimates is approximately 69,328 hectares, indicating only about 40% agreement between the two methods. (Figure 8)

Discussion and Conclusion

Estimating floods using radar and optical imagery is a modern and effective approach for flood management and forecasting. This study utilized radar and optical data, along with the NDWI, to analyze and model the January 2022 flood in Chabahar County. The results show that combining Sentinel-1 radar data with Sentinel-2 optical data and the NDWI enables fast and accurate identification of flood-affected areas. Radar images have unique advantages, such as the ability to capture data regardless of weather conditions or lighting, making them a reliable tool for assessing damage during critical events like floods. Although optical data depend on weather conditions, they serve as valuable complementary information when conditions permit.

Differences in flood extent estimates from NDWI and radar data may arise due to regional physical characteristics, spatial resolution limitations, and algorithmic constraints. These findings highlight the importance of integrating multiple data sources to improve accuracy. Given the rising frequency of floods in southeastern Iran, it is essential to develop early warning systems and decision-making tools based on remote sensing technologies.

Previous studies have confirmed the usefulness of radar and optical imagery in flood forecasting and disaster management. Our research also confirms this, showing that these data sources are powerful tools for identifying flood-prone areas and supporting disaster response planning. For example, one study found that radar and optical imagery can reliably identify flood-prone areas, while another showed that combining these data sources increases the accuracy of estimates.

Furthermore, our analysis showed that combining radar and optical data with other satellite datasets can further improve the accuracy and reliability of flood mapping. Overall, this study confirms that radar and optical imagery are key resources for flood monitoring and forecasting. However, improvements in algorithms and data quality are necessary to achieve better results.

Given the focus on rapid flood area estimation and flood mapping to support relief operations—and considering the limitations of optical imagery during cloudy flood events—this study recommends using radar images for damage assessment. Although the results from NDWI and radar-based change detection showed some discrepancies, this may reflect the inherent limitations of the NDWI in identifying flood areas.

The main goal of this research was to evaluate how well radar imagery can quickly identify flood-affected zones for use in rescue and crisis management. The case study of the January 2022 flood in Chabahar demonstrated that Sentinel-1 radar images are highly effective for fast flood damage analysis due to their weather- and light-independent imaging capabilities.

Radar image analysis indicated that about 20% of Chabahar County was flooded, while the NDWI method estimated roughly 29%. The partial overlap between these results suggests that integrating both methods increases detection accuracy and provides a more complete understanding of the disaster. Considering each method's limitations, their combination offers a practical approach for real-world emergencies.

Our findings also show that Sentinel-1 radar data are valuable for rapid and accurate flood monitoring, thanks to their ability to capture images in any weather or lighting condition. Comparison between radar-derived flood maps and NDWI results from Sentinel-2 optical images showed significant overlap, confirming the reliability of radar data for flood extent estimation.

The NDWI is widely used to detect water in optical images by comparing reflectance in green and near-infrared bands. However, its accuracy decreases in cloudy conditions, poor image quality, or when surface moisture is high. In contrast, radar data can penetrate clouds and operate day or night, making it effective for detecting flooded areas under challenging conditions. From an operational viewpoint, remote sensing technologies—especially cloud-based platforms like GEE—have great potential for deployment in emergency response centers. These platforms provide fast access to up-to-date satellite data and significantly reduce reaction times during disasters.

Compliance with Ethical Guidelines

There were no ethical considerations in this research.

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Author's Contributions

This article is based on Ebrahim Jahangir's idea at Rescue and Relief Organization, who was responsible for conducting the research, collecting, and analyzing the data; also, the second author Faezeh Faryadras and Ebrahim Jahangir were responsible for the methodology. The third author, Hossein Derakhshan was responsible for the design and supervision. However, Faezeh Faryadras was responsible for correspondence and editing the final manuscript submitted to the journal.

Conflict of Interests

The authors declare no conflict of interest.

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