RESEARCH PAPER

Flood Mapping and Change Detection of Delhi 2023 Floods

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Abstract

Floods are a natural occurrence in water bodies, essential for maintaining balance in nature. However, the increasing frequency of floods has raised concerns due to climate change, shifts in rainfall patterns, soil erosion leading to siltation, and the impacts of unplanned development in river areas. In July 2023, heavy rainfall caused severe flooding in Delhi NCR, resulting in the Yamuna River reaching a 45-year high water level. Accurate flood inundation maps, generated using remote sensing techniques, are crucial for mitigating the impact of flood disasters. The utilization of publicly available Sentinel-1A SAR data, well-known for its all-weather imaging capabilities, holds promise for mapping flood inundation. This study leveraged temporal dual-polarization Sentinel-1 SAR for inundation mapping and change detection. This research employs open-source datasets for inundation mapping and damage assessment, and the methodology can be easily adapted to different study areas, depending on data availability. The findings revealed a clear progression in flood extent, with initial flooding observed on 12th July, peak flooding on 16th July, and recession by 24th July. The assessment indicated flooding occurring in three stages, covering 170.326 sq. km, 365.929 sq. km, and 92.514 sq. km on 12th, 16th, and 24th July, respectively. Such research is valuable for policymakers and local authorities, enabling efficient resource allocation and damage assessment in flood-affected areas. The methodology adopted for this study is cost-effective, time-efficient, and easily replicable.

Introduction

Floods are complex natural disasters that cause significant loss of life and property globally while also helping to restore balance in rivers and other water bodies(Janizadeh et al., 2024). The increasing frequency of floods in recent years is a major cause for concern and can be attributed to various factors such as climate change, shifts in rainfall patterns, heightened soil erosion, which leads to excessive siltation, and the significant impact and loss of life resulting from haphazard development and unregulated settlements in river catchment zones(Di Baldassarre et al., 2010; Jha et al., 2012).

This study proposes an approach to promptly assess flood extent and detect changes using SAR earth observation data(Vanama, Musthafa, et al., 2021; Vanama, Rao, et al., 2021). Assessing the impact of damage and losses is crucial for flood management but can be challenging due to the complexity of dealing with extensive data, various types of damage, and different spatial and temporal scales. Evaluating damage involves making assumptions about factors such as spatial and temporal boundaries, financial considerations like depreciated values or alternative costs, categorizing at-risk assets, determining the value of uncovered assets, and formulating strategies to assess vulnerability(Shen et al., 2015; Tavus et al., 2022).

(Landuyt et al., 2018) provides an in-depth assessment of various SAR-based flood mapping algorithms, including global and enhanced thresholding, active contour modeling, and change detection. These methods were tested on medium-resolution SAR images of different flood events and lakes across the U.K. and Ireland. The findings indicated that the most suitable method depends on the area of interest and its specific characteristics. The tiled thresholding approach was found to be robust and well-suited for automated, near-real-time flood detection and monitoring, while active contour models offered higher accuracy but required longer computation times. This comprehensive evaluation of different algorithms provides valuable insights into selecting appropriate methodologies for specific flood mapping scenarios.

Study Area

The city of Delhi, located in the northern part of India and also known as the National Capital Territory (NCT) of Delhi, covers an area of approximately 1,484 square kilometers. Among its total area, around 470 square kilometers are designated as urban. With a length of 51.90 kilometers and a width of 48.48 kilometers, Delhi is one of the world's seven largest cities and has been experiencing a steady increase in population. The city's population rose from 14 million residents in the 2001 census to 16 million in the 2011 census, solidifying its status as one of the most densely populated regions in India. The extent of the Study Area is 29.037830°N to the north, 28.142567°N to the south, 76.918008°E to the west, and 77.763766°E.

In July 2023, extensive rainfall led to severe flooding in Delhi NCR, resulting in the Yamuna River reaching its highest water level of 208.46 meters in 45 years after 207.49 meters in 1978. Floods present significant risks to urban areas like Delhi, and remote sensing technologies, such as Synthetic Aperture Radar (SAR) data from satellites like Sentinel-1, offer valuable tools for monitoring and assessing flood events(Delhi Floods, 2023).

Methodology

The preprocessing of Sentinel-1 SAR data involves essential steps within the "Synthetic Aperture RADAR" toolbox in ArcGIS Pro software provided by Esri. This includes radiometric calibration, multi-looking, speckle filtering, and geometric calibration applied to GRDH products. Operators like "Download Orbit File", "Apply Orbit Correction", "Apply Radiometric Calibration", "Despeckle" with "Refined Lee" filter, and "Apply Geometric Terrain Correction" resulting in terrain-corrected images with a pixel size of 10 m × 10 m are used for scientific analysis and "Convert SAR Units" with conversion type "Linear to dB".

After preprocessing the images, we used the flood binary masking technique to categorize them as either flood or non-flood, as per (Liang & Liu, 2020). The "Raster Calculator" feature under the "Image Analyst Toolbox" in ArcGIS Pro was utilized to create a classification equation based on the pixel values from the "Sigma0_VV_db" band. Histogram statistics for flood events on various dates were produced, using different values for each, ensuring an accurate distinction between flooded and non-flooded areas in the images.

Date	Threshold Value	Equation
4th July 2023	-11.5	$Sigma0_{VV_{db}} < -11.5$
12th July 2023	-9.87	$Sigma0_{VV_{db}} < -9.87$
16th July 2023	-10.58	$Sigma0_{VV_{db}} < -10.58$
24th July 2023	-9.26	$Sigma0_{VV_{db}} < -9.26$

Table 1: Threshold Values for different flood dates

To assess the impact of flooding on backscatter values, the Normalized Change Index (NCI) was computed for each flood date (12th, 16th, and 24th of July). The NCI serves as a quantitative measure to evaluate the changes in backscatter values between the flood and pre-flood conditions. By utilizing the equation specified, the NCI was calculated using the "Raster Calculator" feature under "Image Analyst Toolbox" in ArcGIS Pro based on the difference and sum of Sigma0_VV values for the flood and pre-flood images, providing insights into the variations in backscatter intensity resulting from the flooding event.

$$\text{NCI} = \left\{\frac{(Sigma0_{VV}Flood - Sigma0_{VV}PreFlood)}{(Sigma0_{VV}Flood + Sigma0_{VV}PreFlood)}\right\} + 1$$

Equation 1: Normalised change index

A value greater than 1 in the NCI indicates an increase in backscatter values following the flood, suggesting a potential change in surface properties or conditions due to inundation. Conversely, a value less than 1 signifies a decrease in backscatter intensity, and 1 signifies that there has been no change in the Pixel Values.

Results and Discussion

Flood Extent:

Delhi NCR region experienced significant flooding in July 2023, systematically monitored using Sentinel-1 SAR datasets. The flood extent was quantified on three specific dates: 12th July, 16th July, and 24th July 2023. The observed flood extents on these dates were 170.326 km^2, 365.929 km^2, and 92.5154 km^2, respectively. The findings revealed a clear progression in flood extent, with initial flooding observed on 12th July, peak flooding on 16th July, and recession by 24th July. The assessment indicated flooding occurring in three stages, covering 170.326 sq. km, 365.929 sq. km, and 92.514 sq. km on 12th, 16th, and 24th July, respectively. The flood event in Delhi NCR during July 2023, as quantified by the Sentinel-1 SAR datasets, revealed a significant temporal variation in flood extent. The initial, peak, and recession phases of flooding presented unique challenges and implications for flood management and mitigation. This analysis underscores the critical role of timely and accurate flood monitoring in enhancing the resilience of communities to such natural disasters.

This analysis of flood extent provides critical insights into the flood management practices required for the Delhi NCR region. The data underscores the importance of integrating remote sensing technologies, such as Sentinel-1 SAR datasets, into flood monitoring and response frameworks. By leveraging such technologies, authorities can enhance their capacity to predict, respond to, and recover from flood events, thereby reducing the adverse effects on human life and infrastructure(Thakur et al., 2020).

Inundation Dates	Flooded Area (Sq. Kms)
12th July 2023	170.326
16th July 2023	365.929
24th July 2023	92.5154

Table 2: Flooded Area on Different dates

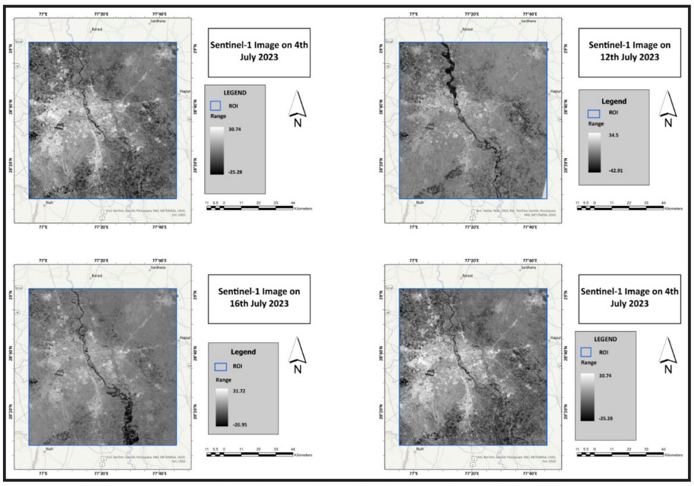

Figure 1: Sentinel-1 Images on different dates

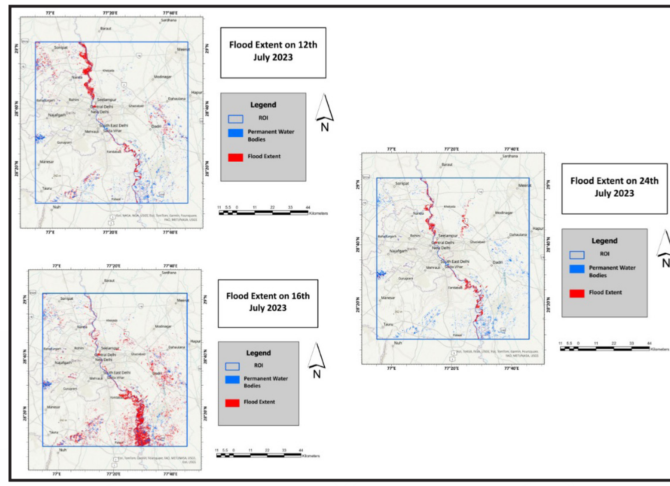

Figure 2: Flood Extent on different dates

Normalized Change Index:

The Normalized Change Index (NCI) is calculated by normalizing the absolute difference between the flood and pre-flood σ° values according to a specific equation. NCI values range from 0 to 2, with a value of 1 indicating no change in the images. Positive changes in NCI values signify flood areas. The 4th July 2023 image is utilized as the pre-flood reference for generating all temporal NCI indices using the specified equation. The histogram observed in the NCI image was derived from the pre-flood and peak flood images (4th July and 16th July 2023, respectively). The histogram distribution is attributed to the presence of permanent water bodies and flood areas in the images. The flood normalized change index image's histogram ranges from 0 to 1.97. The statistical analysis reveals a mean of 1.04959, a median of 1.06058, and a standard deviation of 0.27443. This suggests that most values are concentrated around the mean and median, with a moderate level of variability indicated by the standard deviation.

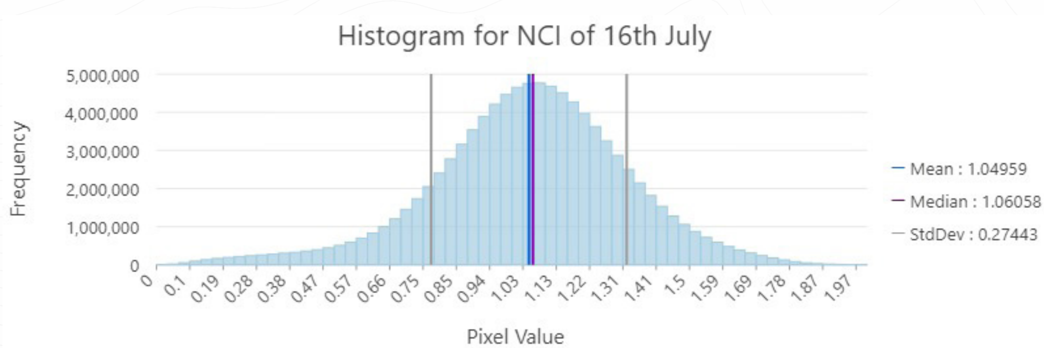

Figure 3: NCI Histogram for 16th July

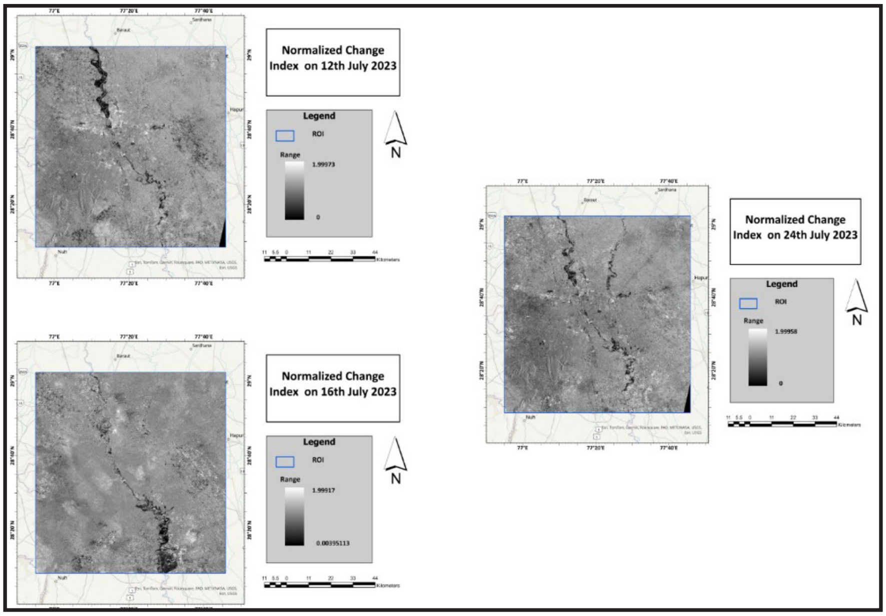

Figure 4: NCI on different dates

Conclusion

The launch of the Sentinel-1 SAR satellite has expanded the potential benefits of freely available SAR data for different applications, particularly due to the access to extensive time-series SAR data. Mapping large areas affected by natural disasters like floods is crucial for targeted relief efforts. This research investigates the effectiveness of C-band SAR data in accurately mapping flood inundation using straightforward methods. It showcases the capabilities of flood mapping with datasets collected on multiple dates and emphasizes the use of the Binary classification method and Change detection through Spatial Indices.

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