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Review Article

Flood Susceptibility Assessment using Remote Sensing and GIS: A Case Study of the 2025 Punjab Floods

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A B S T R A C T

Natural disasters have become more common and destructive due to climate change, particularly in South Asia. Recent severe flooding has resulted in widespread relocation and financial loss in India. The 2025 floods in Punjab, which impacted every district, revealed significant weaknesses in health, education, infrastructure, and agriculture. Flood susceptibility modelling has become crucial for risk reduction because floods cannot be completely avoided. Effective tools for mapping flood-prone areas and assisting with data-driven disaster management are provided by remote sensing (RS) and GIS technology. This study emphasises how crucial flood susceptibility assessments based on RS and GIS are for directing planning, mitigation, and long-term resilience initiatives.

Keywords: Flood, Remote sensing, GIS technology, Agriculture

Introduction

Climate change has led to an increase in natural hazards such as floods, earthquakes, landslides, cyclones, and droughts. Compared to previous natural disasters, numerous South Asian nations, such as Bangladesh, India, and Pakistan, have faced extreme flooding in recent years, which has devastated more people.[1]

Floods are thought to be the most frequent and catastrophic hazard in the current global environment, contributing significantly to societal risk, economic losses, and human fatalities, as primarily revealed by people.[2] Floods are often caused by unanticipated rainfall, melting ice and snow, river embankment breaching, inadequate structural measures, and insufficient reservoir capacity. Human escalation variables include population expansion, land use change, deforestation, ecosystem degradation, and encroachment into floodplains.[3] Riverine flooding has increased significantly in recent decades due to variables such as climatic variability, sea-level rise, and heavy rainfall. In recent years, a huge number of riverine floods have been produced by the breakdown of dams, barrages, and embankments, which rendered calamitous capability to disturb human life and property owing to the unpredictability and intensity.[4] Riverine floods in the Indus Basin are caused by factors such as flat topography, hydrology, climate, and demographic and socioeconomic characteristics in the catchment area around the river.[5] Riverine flooding causes significant loss of life and disrupts economic development in all sectors. Floods cause extensive harm to all socioeconomic sectors worldwide. Flooding claims around 20,000 lives and affects 1.4 million people annually.[6]

Flood management consists of three stages: estimating flood extent, estimating damage to all socio-economic sectors, and recovering and rehabilitating the affected areas. Flood recovery and rehabilitation are still in progress. Several structural and non-structural measures can reduce flood damages.[7]

Punjab, where flood-resistant infrastructure is not a post-disaster response but a fundamental component of urban and rural design.[1] The terrible floods in September 2025, which affected all 23 districts and displaced approximately 4 lakh people, are more than just a humanitarian problem; they are a stern warning. The damage to health infrastructure alone exceeds ₹780 crore, necessitating a rethink in the state's disaster preparedness and long-term development strategies. The floods had an immediate and devastating impact. Aside from the devastating loss of life and displacement, the agricultural industry, the backbone of Punjab's economy, has sustained tremendous harm. Over 1.76 lakh hectares of agriculture are submerged, endangering food security and livelihoods.[8] The loss of more than 2.52 lakh animals and 5.88 lakh poultry birds complicates the recovery effort. The disruption to education, which has destroyed or rendered thousands of schools unavailable, will have long-term ramifications for the state's human capital.[9] The already overburdened healthcare system is under peril from watery diseases such as dengue, cholera, and typhoid, which are compounded by destroyed infrastructure and inadequate sanitation.[10]

Flooding is a terrible natural hazard that cannot be completely eradicated. Modelling flood susceptibility is a recent strategy for dealing with disasters. In recent decades, remote sensing and GIS tools have gained popularity for their ability to enhance risk assessment and reasoning.[11]

Satellite image analysis on RS and GIS platforms provided solid results for flood susceptibility and vulnerability mappings, allowing for the use of various models to estimate flood vulnerability rationally.[12] In order to help government authorities and planners create suitable flood control measures and suggest management strategies to lessen flood vandalism in the future, it is essential to create flood susceptibility maps and flood risk assessments.[3]

Literature Review

In this section, we look at previous research and experiments.

Ahmad et al. The study collected cross-sectional data from 398 flood-vulnerable Bait households in three high-risk districts (Muzaffargarh, Rajanpur, and Rahim Yar Khan) using a multistage sample technique. Data was gathered through face-to-face interviews and a well-developed, pre-tested questionnaire.[13]

Sajjad et al. This study analyses the flood generated by the breach of the Taunsa Barrage's east marginal embankment, including its sources, magnitude, and damage. Floods in the Muzaffar Garh district, south Punjab, Pakistan, have caused significant damage to people and property. This study utilised primary data from questionnaires, interviews, and field observations, as well as secondary data from government departments and internet open-source sources.[6]

Munir et al. This study aims to apply a frequency ratio approach to identify flood-prone areas in two Pakistani provinces. The flood inventory map was created using 230 flood location locations in Northern Sindh and Southern Punjab. The ten determining elements include aspect, profile curvature, elevation, slope, normalised difference vegetation index (NDVI), normalised difference soil index (NDSI), distance from road/river, land use/land cover (LULC), and rainfall. This research project involves data collection. This study used the vulnerability frameworks of LVI-IPCC and LVI to compare vulnerability levels in three Bait district households.[14]

Fawakherji et al. This study combines UAV optical imagery with Sentinel-1 SAR to produce more accurate flood maps. Using machine learning algorithms, the method. This method extracts inundated and dry vegetation with high accuracy, reaching up to 97.6% for inundated and 81.9% for dry vegetation. It has the potential to improve flood mapping precision.[15]

Giordan et al. This paper presents and discusses an approach for mapping and estimating flood intensity in floodplains. The proposed methodology takes into account a multiscale and multisensor method based on free or low-cost data and sensors. We used this method to analyse the November 2016 flood in Piedmont (northwestern Italy). We used free satellite data from Sentinel-1, COSMO Skymed, and MODIS to map flooded areas at the basin size, with resolutions ranging from low to medium. We used high-resolution photos from a low-cost aerial platform and remotely piloted aerial system to refine the flooded zone and identify the most affected sector.[10]

Methodology

Our study attempts to improve flood mapping by accurately classifying land covers. This methodology involves three processes to accurately designate land and water areas: data preparation, fusion, and segmentation and post-processing.

The suggested methodology involves preprocessing procedures, including filtering and resampling. This procedure improves the quality of the input data. Next, a machine learning-based classifier is used to perform The input is semantically segmented into four classes: Open Water, Inundated Vegetation, Dry Vegetation, and Others. After segmentation, noise is removed during post-processing to improve output quality. This refinement phase improves the trustworthiness of the results (shown in fig 1).

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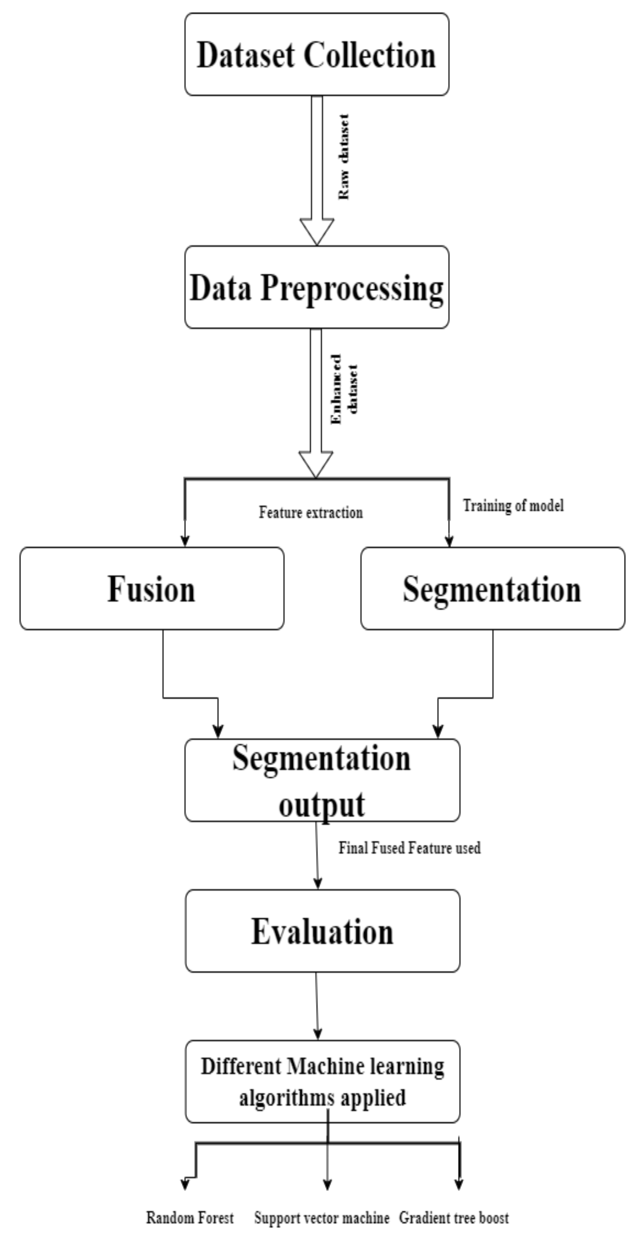

Figure 1.Proposed Methodology

Flood Hazard & Risk Mapping with GIS and Remote Sensing

Identifying high-hazard areas is a key challenge in flood management. A hazard is described as a natural, technical, or civil threat to people, property, and the environment. Risk is the likelihood of a hazard occurring during a specific time period. Flooding is a natural danger that is measured in terms of hundred-year floods. Creating accurate danger maps is a recent problem in flood management.

Various methodologies have been used to map the potential hazard. Basically there are three different methods for hazard zoning. The first method uses a binary model to determine if a danger is present in a given raster cell. The second strategy is to rank distinct locations of an location based on the severity of the hazard present. The final approach assigns 'hazard' values to each raster cell based on a multivariate model of river flooding and associated dangers.

Flood depth is regarded as the most crucial indicator of the severity of the hazard. Flood risk maps are generated based on the predicted depth of flooding. The estimation is frequently obtained from hydrological and remotely sensed data. To determine flood depth, the phenomenon of river flooding is divided into two categories: 'non-source flood' and 'source flood'. 'Non-source flood' refers to flooding caused by a well-distributed rainstorm over a vast area, whereas 'source flood' refers to inundation caused primarily by overbank flow, affecting places near the river channel. The two essential properties of overland flow have substantial significance for developing the GIS model. For 'non-source' floods, all raster cells or vector points with an elevation below the water level are considered 'inundated'. For source floods, it is necessary to simulate the path of overbank flow from the main channel to the adjacent floodplain to accurately estimate the affected area.

Multi-date SAR images can be an effective alternative to high-resolution DEMs for flood mapping on flat terrain, particularly in monsoon Asia. For instance, many dates

Radarsat images were employed in monsoon Asia to track flood development from genesis to peak. This procedure visualises the path of flooding from the river channel to low-lying portions of the floodplain, complementing the flow approach. Direction simulation. While multi-date images can be used as an alternative to low-direction simulation, they have significant limitations in determining flood depth. Accurate topography data on local floodplain morphology is necessary for this process. Flood depth is determined primarily by the intersection of floodwater and slope. For gently sloping topography, the resolution of terrain data determines the accuracy of anticipated flood depth.

Some Issues with Remote Sensing Applications in Monsoon Asia

This section discusses the limitations of using remote sensing for flood management, after providing an overview of its development and methodology. Some of the issues, such as agriculture Assessments of structural damage are common in monsoon Asia, a region primarily reliant on agriculture.

Dependence on Digital Elevation Models in Flood Management

Most research using remote sensing for inundated area delineation and flood risk assessment employs digital elevation models (DEM) to visualise the interaction of

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floodwater with terrain. The flood depth is Raster elevation is derived by subtracting each cell's height from its water level.

DEMs simulate flood depth based on discharge data and are typically compared to actual flooded areas from satellite images. The spatial extent of inundation is treated to a method of cross. This technology is anticipated to produce a more accurate flood map compared to pure hydrological modelling. The fundamental limitation of this strategy is its reliance on the accuracy of the DEM. Accurate DEMs are nearly impossible to obtain in monsoon Asia's featureless plains. Recognising the amount of inaccuracies in the DEM is crucial in hydrological modelling, especially in flat flood plains where a 1 m vertical mistake can result in flood estimation errors of hundreds of square kilometres. The issue has been addressed in terms of its significance in floodplain mapping. Accurate DEMs for flood depth investigations require high-resolution satellite images or aerial photography to ensure precision.

LIDAR (Light Detecting and Ranging) sensors are a recent advancement in distant sensing for flood-related problems. This technology is widely used in industrialised countries, particularly in the United States, for generating DEMs for flood-prone areas. LIDAR sensors can recognise vertical changes in landforms and provide highly accurate DEMs. This sensor can also measure flood depth. While LIDAR sensors can achieve vertical accuracy of 5 cm or better, mapping at that resolution remains challenging. GPS systems have limitations in locating planes and sensors; hence, LIDAR-generated DEMs are released with an accuracy of 15 to 25 cm RMSE. Furthermore, the accuracy reduces steadily with increasing density of vegetation cover on the ground. LIDAR data, while more expensive than SAR images, is frequently the only viable choice for flood mapping on flat flood basins.

The intensity of laser pulses determines the resolution of LIDAR data. Increasing the intensity of laser pulses will significantly raise the cost of the survey.

Agricultural Damage Assessment

Flood damages are divided into two categories: material and intangible. Intangible damage includes the loss of historical monuments and heritage places, whereas tangible harm is caused by direct contact with floodwaters, etc. Flood-induced illness epidemics are considered intangible damages. Accurately estimating agricultural damages is crucial in monsoon Asia. Asia's economy is heavily reliant on agriculture, as the population is predominantly rural. Monsoon floods often disrupt the economy by ruining standing paddy. This issue is peculiar to monsoon Asia, while damage to urban areas and infrastructure is a worry for governments in wealthy countries. Therefore, in this In this part, we will focus on studies that use remote sensing to assess agricultural damage.

Erosion of topsoil due to a flash flood and deposition of flood-borne coarse sand reduce the fertility of soil very severely and thus have a negative impact on agricultural economy. The process of change detection is found useful to monitor this kind of damage to agricultural land. The most widely used procedure is to monitor the change in brightness value (VB) at a particular wavelength or different bands to identify the erosion caused by a flood. Several change detection techniques like Spectral Image Differencing (SID), Tasselled Cap Brightness Image Differencing (TCBID), Principal Component Analysis (PCA), and Spectral Change Vector Analysis (SCVA) are employed for the purpose of detecting the erosions due to

flooding, but for Landsat TM data, SCVA is found to yield the most accurate results.

Problem of Temporal Resolution in Flood Management

Devastating floods are generally low-frequency, high-magnitude natural phenomena. Flash floods occur within a very short interval of time, and the peak stage remains only for a couple of hours, but the most extensive and severe damage takes place during that time. With the current Radarsat resources, it is very difficult to capture the spatial extent of a flood at its peak. Thus, attempts have been made to extrapolate the extent of inundation at the peak of a flood from an image acquired at a later stage of the event. Some GIS algorithms in ARC/INFO are promising to perform this extrapolation from an image that captures some standing water only at a time when the flood peak had already passed. The method of 'least accumulation cost distance' can provide a viable solution to this problem. This principle simulates flow direction from the river channel to the floodplain based on the assumption that water flows through the path where the work done in doing so is least.

Conclusion

Flooding remains a serious and growing concern as a result of climate change and human-caused environmental stressors. The 2025 Punjab floods highlight the widespread and multi-sectoral destruction that can result from a lack of robust planning. Effective flood management must shift towards proactive measures that are backed by RS- and GIS-based modelling, which aids in the identification of high-risk zones and informs better decisions. Infrastructure strengthening, land-use planning improvements, and the incorporation of scientific assessment methodologies are critical for mitigating future flood impacts and protecting vulnerable areas.

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