International Research Journal of Natural and Applied Sciences
ISSN: (2349-4077)
Impact Factor 8.176 Volume 12, Issue 11, Nov 2025
Website- www.aarf.asia, **Email** : editor@aarf.asia , editoraarf@gmail.com

Flood Mapping and Crop Damage Assessment in Punjab (2025) Using Satellite Data and GIS Techniques.

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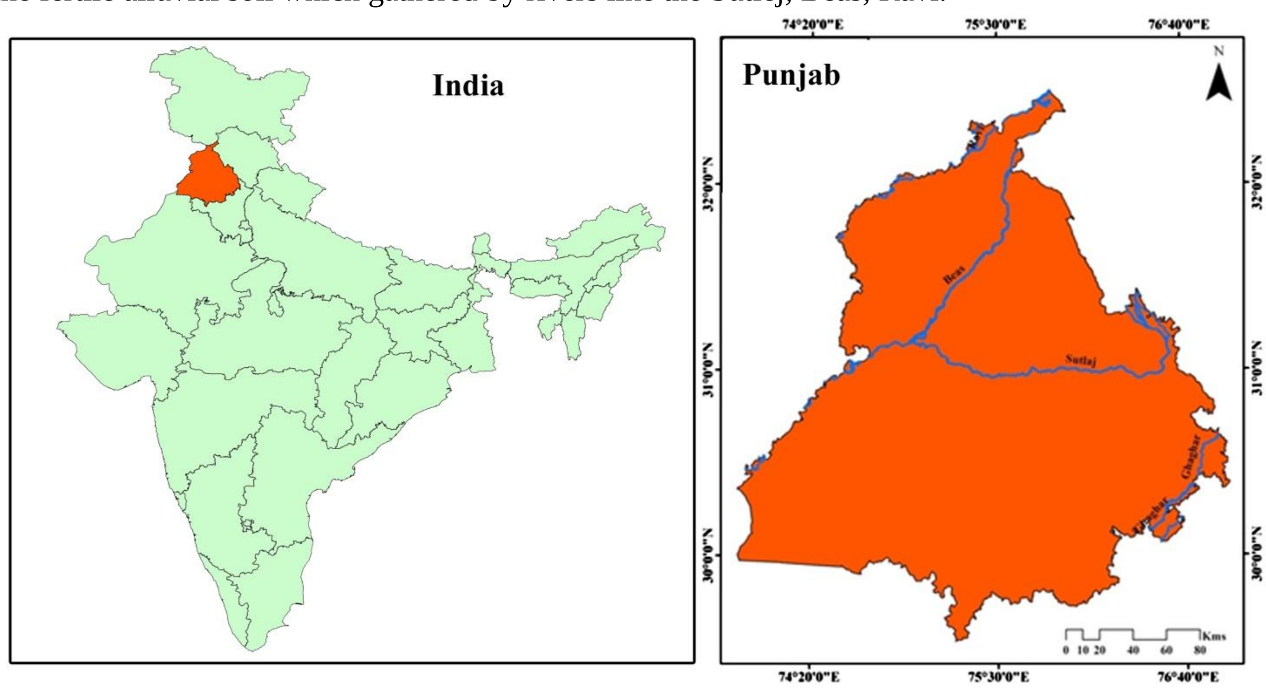
Abstract
This study analyzes flood events in Punjab, India, in 2025 using Resourcesat-2 AWiFS and Sentinel-2 satellite data combined with GIS and remote sensing techniques. Punjab, known for its fertile alluvial plains and major rivers like the Sutlej, Beas, and Ravi, experienced widespread flooding due to factors such as heavy monsoon rainfall, fast-flowing rivers from upland areas, and topography. The study used pre-processing, layer stacking, atmospheric correction, supervised classification, and digitization to estimate land use and flood-affected areas. The results show that approximately 143,320 hectares of area was affected by floods, with paddy (118,135 hectares) and cotton (328 hectares) being the most affected crops. Gurdaspur, Tarn Taran, Firozpur, and Fazilka districts were the worst affected. Weak dams, illegal sand mining, river alluvial deposits, unplanned construction on floodplains, and inadequate drainage infrastructure exacerbate flooding. The study highlights both natural and anthropogenic factors and emphasizes the need for flood management strategies such as floodplain restoration, improved drainage, and warning systems to reduce future risks.

Introduction

Mohapatra and Singh (2003) examined flood problems across India, highlighting regional variability, challenges like dam-break flows and waterlogging, and the need for both structural and non-structural management measures. Gupta, Javed, and Datt (2003) evaluated the economics of flood protection, finding that structural measures alone were insufficient to reduce vulnerability, as flood intensity remained the primary determinant of losses despite partial protection in highly flood-prone regions. Abdallah, Chorowicz, Bou Kheir, and Khawlie (2005) used GIS to link terrain parameters with mass movement occurrences in Lebanon, highlighting lithology and fault proximity as key factors. Manjusree, Bhatt, Begum, Rao, and Bhanumurthy (2015) used decadal historical satellite data from 1998–2010 to assess flood hazard in Bihar, revealing that North Bihar, including extensive cropped areas, is highly vulnerable and highlighting the need for a spatial flood hazard database. At the national level, Singh and Kumar (2017) emphasized that despite structural and non-structural measures, sustainable, river-friendly approaches are essential to reduce recurring flood damages. Vijender (2019) analyzed the 2010 Punjab floods, identifying heavy rainfall and mismanaged canals as primary causes, and emphasized recurring flood patterns every 2–4 years along with lessons learned for disaster response. Sajjad, Lu, Chen, Chisenga, Mazhar, and Nadeem (2021) demonstrated the use of remote sensing to map the 2014 Chenab flood, assessing inundation and damage to agriculture and infrastructure. Arora et al. (2023) applied Sentinel-1 SAR for rapid flood-inundation mapping in the Ghaggar River basin, highlighting agricultural impacts with high validation accuracy. Floods in India pose significant socio-economic challenges, requiring accurate mapping and effective management strategies. Bhageerath et al. (2024) used multi-sensor satellite data to estimate flood duration in Punjab during 2023, producing spatial maps showing a 54-day flood affecting 16 districts. Yaseen (2025) applied remote sensing and statistical methods, including AHP and FAHP, to map flood susceptibility in the Ganga river basin, demonstrating large areas at high risk and emphasizing the importance of hazard management and mitigation strategies. Soral (2025) analyzed the 2025 Punjab floods, identifying climate drivers, upstream hydrological management, and land-use failures as key causes, while highlighting multi-sectoral economic impacts and recommending policy measures to reduce future risk. Shakrullah, Mahmood, Shirazi, Khan, and Din (2025) explored nature-based solutions (NbS) for flood risk reduction in Punjab, Pakistan, emphasizing the role of indigenous knowledge, land-use management, and integrated water strategies in minimizing flood hazards and promoting sustainable regional resilience.Recent studies highlight the multifaceted impacts of floods on socio-economic and environmental systems. Arshad, Chaudhry, Ullah, and Sahi (2025) showed that Pakistan's 2025 floods were exacerbated by climate stressors and governance failures, leading to widespread lossesSagheer, Ahmad, and Chani (2025) applied the Analytical Hierarchy Process (AHP) in Punjab, Pakistan, identifying WASH, healthcare access, and disaster response as major determinants of public health vulnerability. Collectively, these studies emphasize the importance of integrated, data-driven strategies for effective flood risk reduction and community resilience.

Study Area

This study area represent that Punjab is an Indian State. It is located in the northwestern part of India. Punjab lies between **29°30′ N to 32°32′ N latitude and 73°55′ E to 76°50′ E longitude**. The total Geographical area of Punjab about 50,362 square kilometers. The total no of district in Punjab is 22.Punjab shares its international boundary with Pakistan in the west and national boundary in the north with Jammu and Kashmir, in the northwest with Himachal Pradesh, in the South and Southwest with Haryana, and in the southwest with Rajasthan. Punjab is known as 'land of five rivers'. These rivers are Ravi, Sutlej, Beas, Chenab and Jhelum. Chenab and Jhelum is now part of the Pakistan. Punjab has now three major Rivers Ravi, Sutlej, and Beas. Most area of Punjab extends in the Indo-Genetic plain. The average elevation of Punjab is 173 to 705 meters above sea level. In the northeast, Shivalik foothills situated where the land is heightened and wavy, the central and southern part is this area is covered by wide flat plains and in the southwest has semi-arid and dry land. Most of landforms of Punjab are based on Flat Plains. These plains formed by the fertile alluvial soil which gathered by rivers like the Sutlej, Beas, Ravi.



Map1: Location map of Study Area (Punjab).

Materials and Methods

Data Acquisition: Satellite data (Resourcesat-2 AWiFS, Sentinel-2), atmospheric and relief data (monthly rainfall and DEM); software used includes ArcGIS 10.8 and Google Earth Pro;the administrative boundary of Punjab (Survey of India) was used as the study boundary.

Pre Processing

Layer Stack: In this Study, layers stacking using for satellite data resource sat2 AWIFS which bands are 2(Blue), 3(Green),4(NIR), 5(SWIR) and sentinel 2B which Bands are 2(blue), 3(green), 4(NIR), 5(SWIR) for making a Multispectral stacked image. This process combines the all single bands into a single composite image. This process does for image processing; image Classification, Digitization and analysis.

Atmospheric correction: It's a process of removing the effects of the atmosphere like scattering, Absorption by Gases, water Vapor, and aerosols from Satellite and remote sensed data.

Subset: Subset refers that it's an area of interest from large dataset. We subset our study area with the help of administrative boundary of study area to better understand the imagery data.

Supervised Classification: This is a process of DIP used to categories satellite imagery into different land-cover like agriculture, forest, water bodies etc. based on spectral information. In this classification we create signature file with the help of training sample data and use maximum likelihood algorithm to create LULC/ Area estimation of Kharif crop. In this Study area we used Resource sat 2 AWiFS satellite data. After preprocessing, this satellite data is used for Area estimating of kharif crop by DIP named supervised classification. We classify this image by supervised classification into four main categories such as Rice, Cotton; forest and others (all remaining crops and non-agriculture land) according to their spectral signatures.

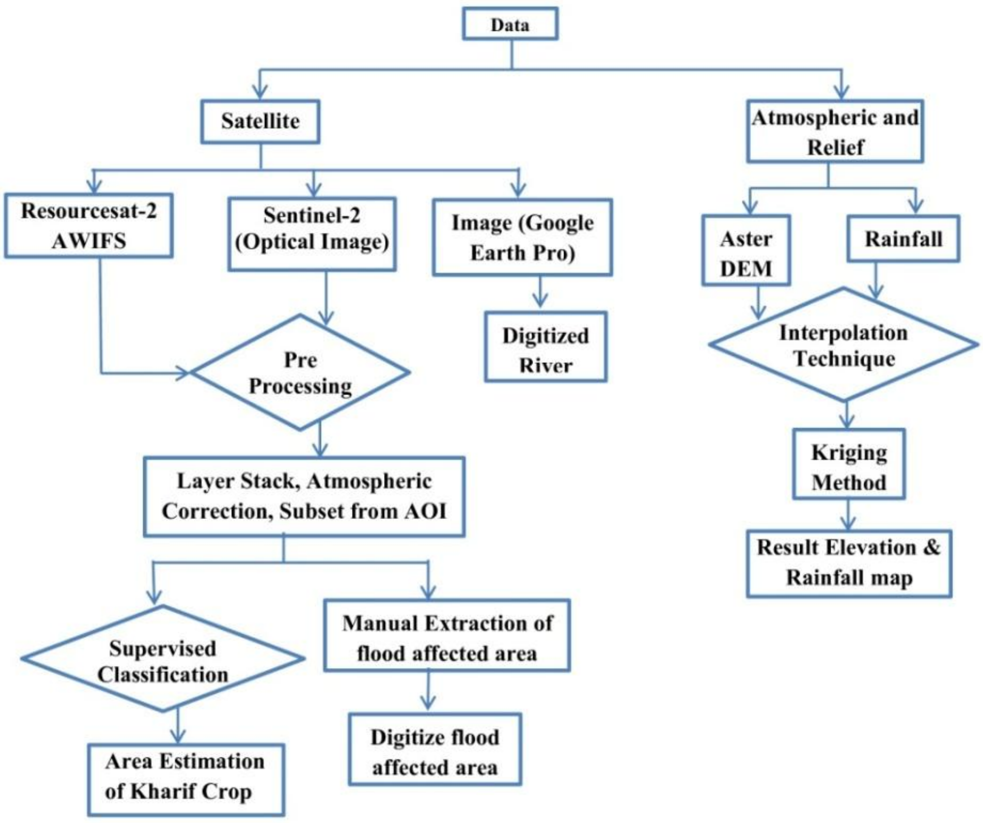


Figure-1: Data and Process Methodology flow diagram.

Digitization: In this study area, Google Earth Pro image data was used to extract permanent riverbeds. Google Earth Pro software is a fundamentally useful tool for mapping because it provides high-resolution data. Permanent riverbeds were manually digitized using this software. Similarly, the Sentinel 2 image was also manually digitized to extract flooded areas caused by the rivers.

Extract from Study Area: After digitizing the permanent river and floodplain, it was extracted from the study area, which allowed us to identify the extent of the floodplain beyond the total area of the actual river.

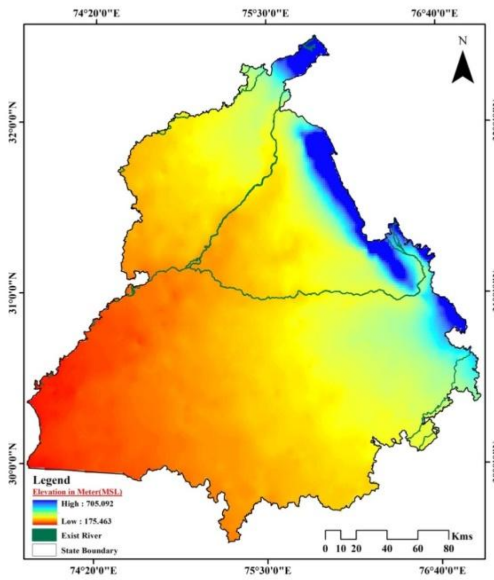
Interpolation & Kriging: In ArcGIS interpolation technique is used for spatial analysis to estimate values at unknown locations from Known data points, transforming them into continuous surfaces using various techniques like IDW, Kriging. But we select Kriging method for our study because it is one of the most commonly used interpolation techniques in ArcGIS. With the help of Kriging method, we analysis DEM and monthly rainfall data.

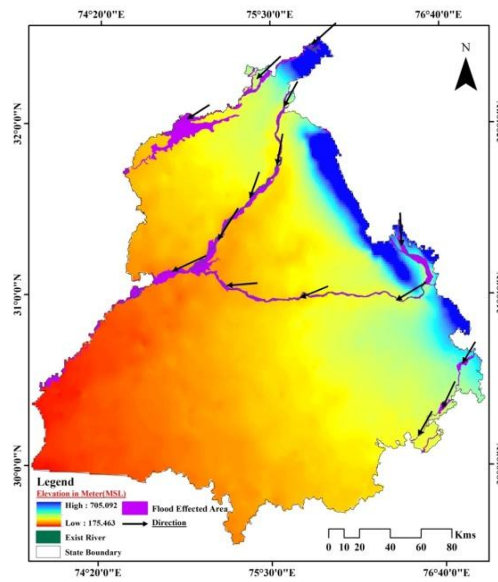
Factors of flood

In this study area, there are mainly two factor of flood.

Slope

The slope of this study area is a major factor contributing to flooding. The elevation map shown that highest elevation is 705m and lowest about 175m according to mean sea level.(Map 2) Punjab is located in the Indo-Genetic Plains, where the land is flat, resulting in a gentle slope, running from northeast to southwest direction.(Map 3) This gentle slope results in a very slow flow of rivers. Punjab's major rivers, such as the Sutlej, Beas, and Ravi, originate in the hills of Himachal Pradesh and Jammu, carrying heavy water flows. When these rivers enter the plains of Punjab, their flow slows down, causing the river banks to breach due to high water levels, leading to flood-like conditions. Therefore, slope is a major factor contributing to flooding.





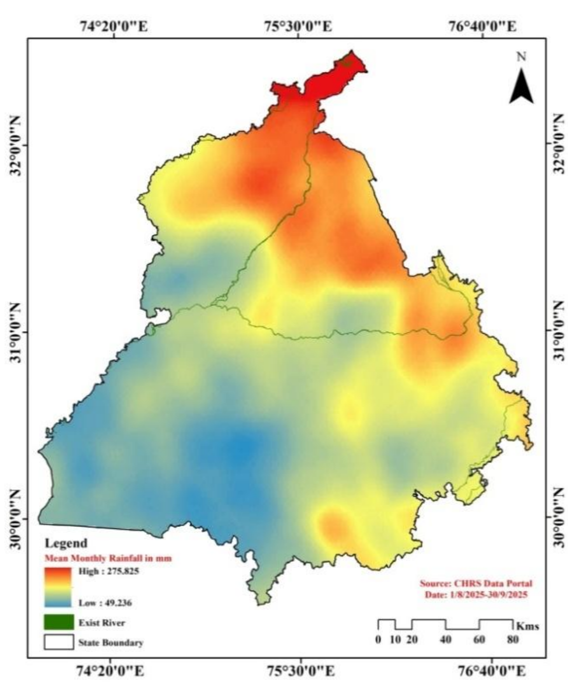
Map2: Elevation map of Punjab

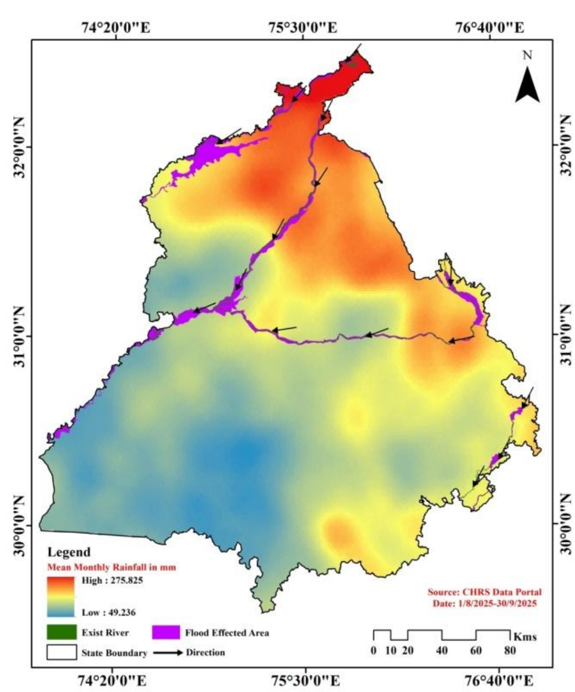
Map3: Elevation map of Punjab with flood Affected area and direction

This Map (Map3)shows that the portion of northeast Punjab that borders Jammu and Himachal Pradesh which is mountainous, resulting in steeper slopes, while other areas have relatively gentler slopes. The central and southwest parts are more prone to flooding than the north and northwest.

Rainfall

In this study area we use mean monthly rainfall data of August and September. According to this data maximum rainfall is 275mm and minimum 49mm.(Map4) During the monsoon season, Punjab and its surrounding mountainous regions(north and northeast regions), such as the Himalayas and Jammu, received more rainfall than the normal rain fall. Rainfall is relatively high in the north and northeast areas of Punjab. Due to the steep slopes and heavy rainfall in this area, rainwater reached the middle, south and southwest areas quickly. (Map 5) This caused Punjab's major rivers, such as the Sutlej, Beas, and Ravi, to overflow their banks and spreading the water to surrounding areas. Most of Punjab's region is flat and has gentle slopes. That's why, when heavy rainfall occurs, water cannot flow quickly and accumulates on flat areas. The accumulated rainwater soaks the soil, preventing it from absorbing the water, leading to disasters like floods. Therefore, rainfall is also a factor of flood.



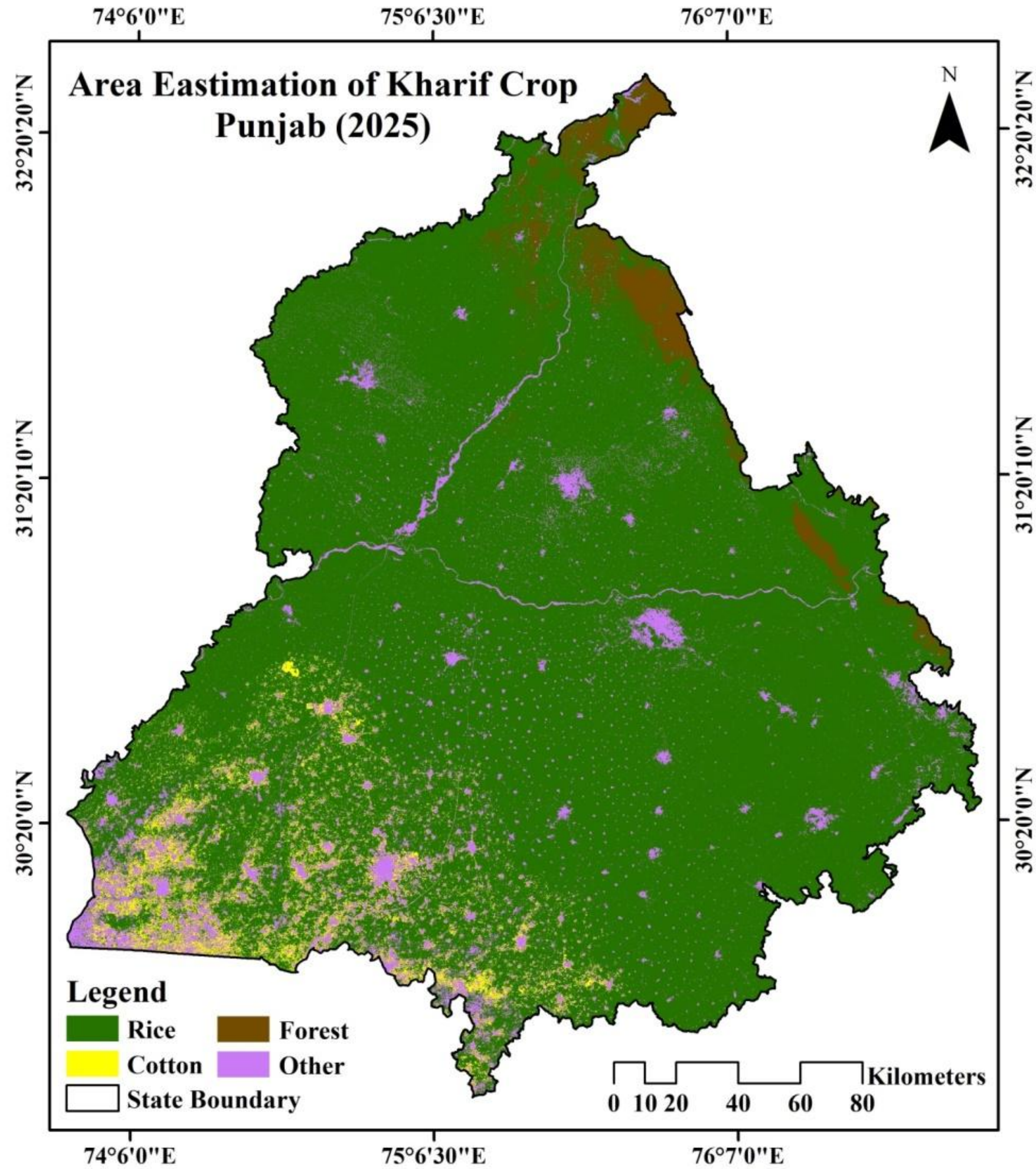


Map4: Rainfall map of Punjab flood

Map5: Rainfall map of Punjab with Affected area and direction

Result and Discussion

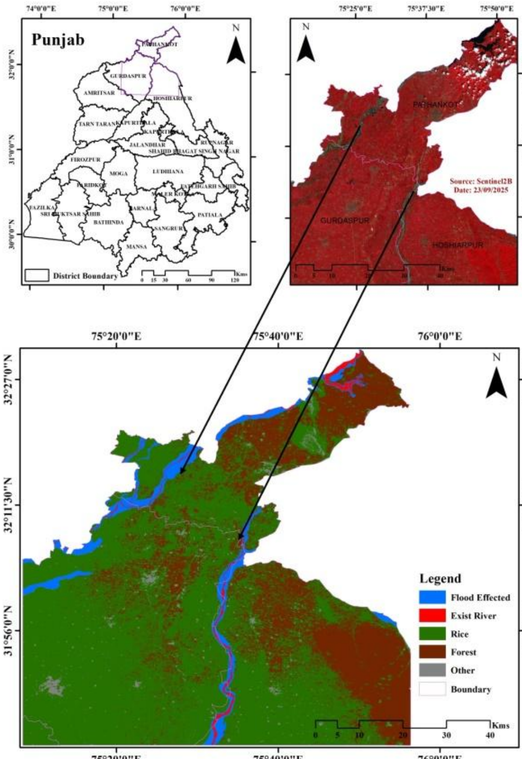
The selected study area is estimating by using Resource sat 2 AWiFS satellite data and GIS and remote sensing technologies. By estimating (Map6) we find main Kharif crops of Punjab like Rice, cotton. Rice is the major crop of Punjab. Rice is grown on most of Punjab's agricultural land. The total area of Punjab is approximately 5,036,200 hectares and rice is cultivated on nearly 42, 87,388 hectares. The second major Kharif crop of Punjab is cotton. Cotton is cultivated on roughly 171873 hectares. On the other hand, 5, 76,938 hectares are forest and other.



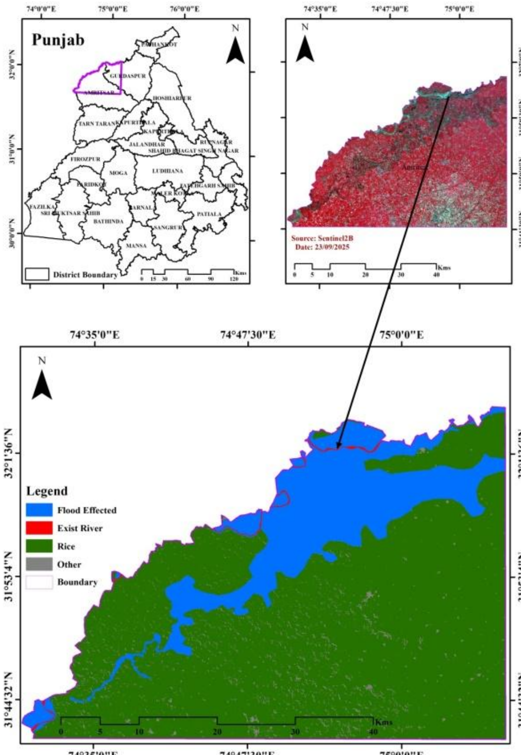
Map-6: Area Estimation of Kharif Crop

Table1: Kharif crops area estimation, Punjab 2025

Kharif crop Area Estimation Punjab (2025)	
Crops/LULC	Area in (hac)
Rice	4287388.15
Cotton	171873.88
Forest	152636.02
Other	424302.37
Total	5036200.42



Part1



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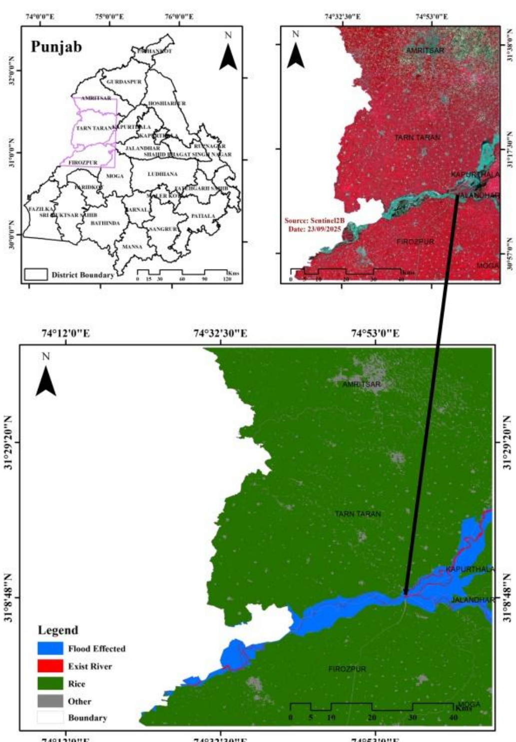

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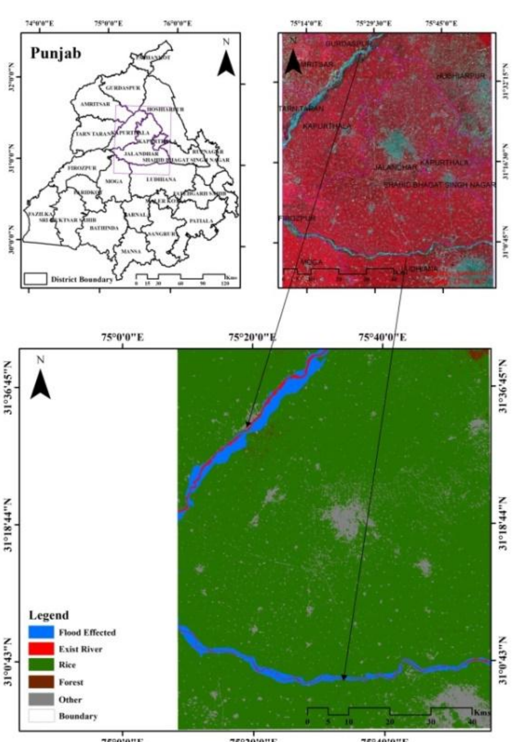
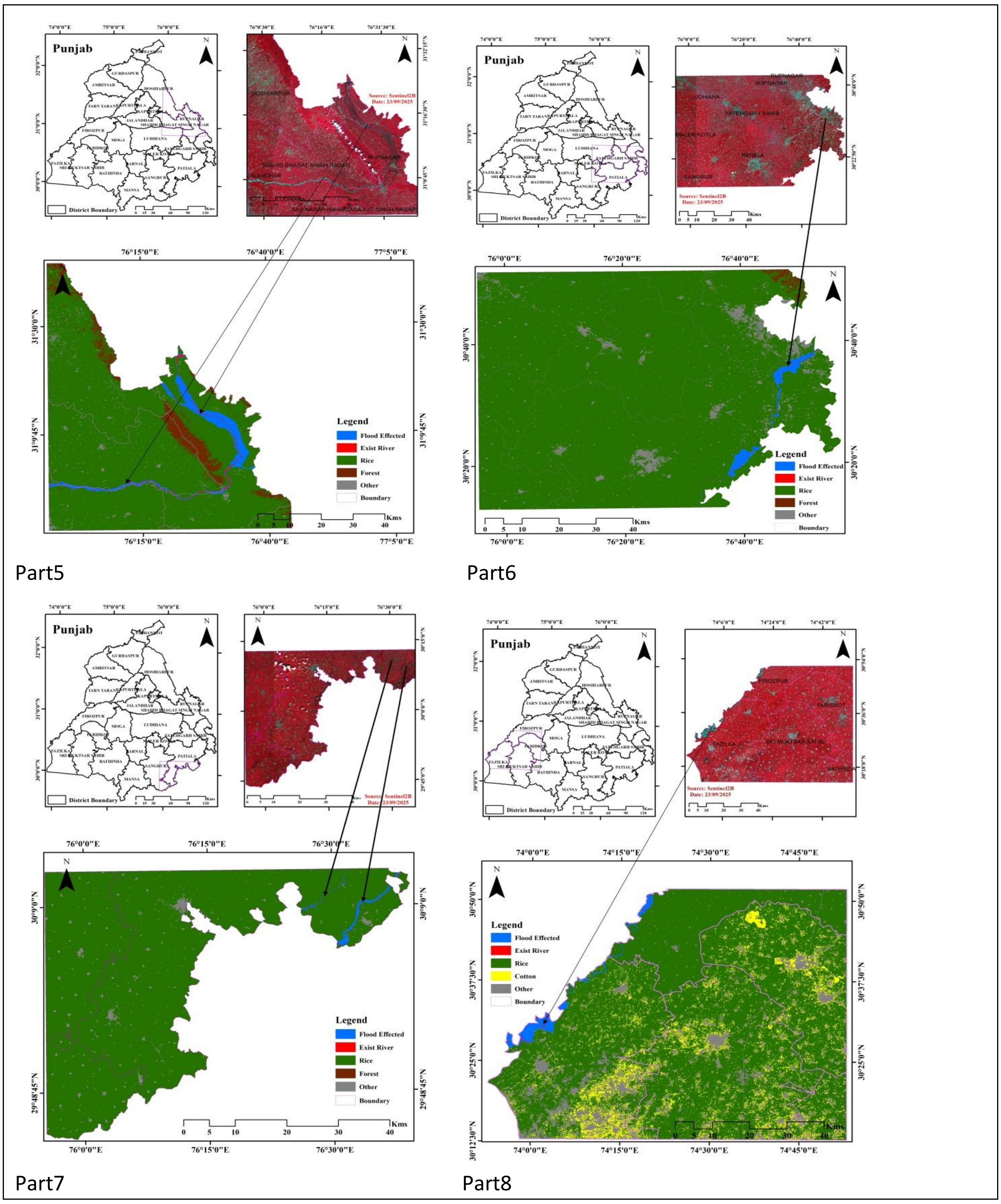


Part4

Parts of Index Map of Flood Area & Kharif Crop Area, Punjab



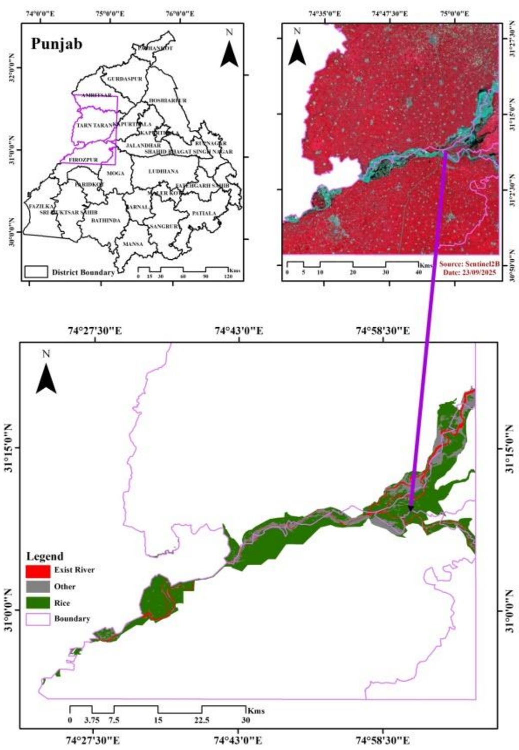
Parts of Index Map of Flood Area & Kharif Crop Area, Punjab

Map7:Index Map of Flood Area & Kharif Crop Area, Punjab

As a result, we concluded that the flood-affected area of Punjab is spread more in the areas around the rivers. We examine that Floods occurred through rivers in 15 districts of Punjab. Gurdaspur, Amritsar, Tarn Taran, Firozpur, Fazilka are the most flood affected districts of Punjab. The flood affected area of Punjab is manual digitize by using sentinel2 image. By digitization we examine the flood affected area of Punjab which approximately 143230 hectares. Total area of exist river such as Ravi, Sutlej, Beas and Ghaghar is nearly 12961 hectares. (Table 2) In this map blue color shows the flood of Punjab which is caused by the rivers and near the rivers. And red color shows the exist river (map11)

Table 2: Flood area with crop estimation area

Flood area & Kharif Crop Area of Punjab (2025)	
Class LULC	**Area in (hac.)**
Flood Area	143230.57
Exist River	12961.34
Rice	416710.31
Forest	149810.36
Cotton	171592.75
Other	391895.09
Total	5036200.42



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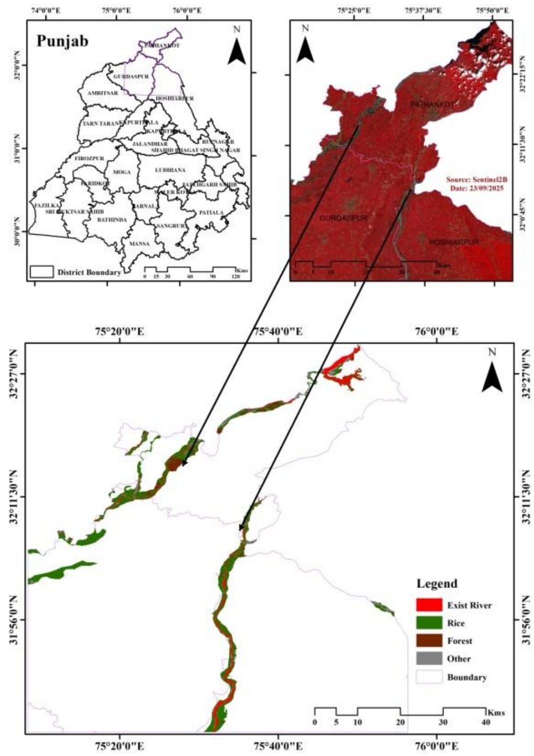

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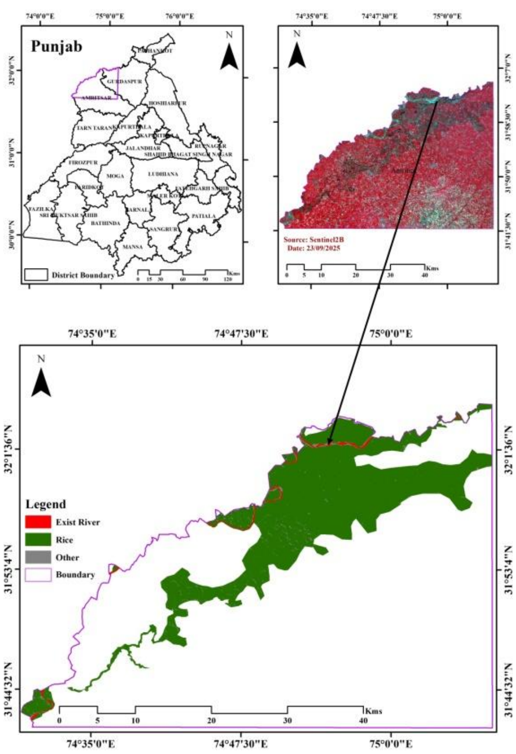

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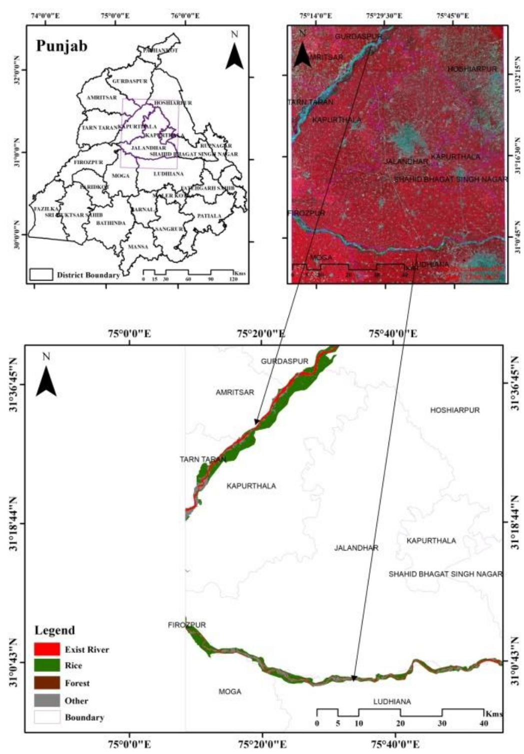
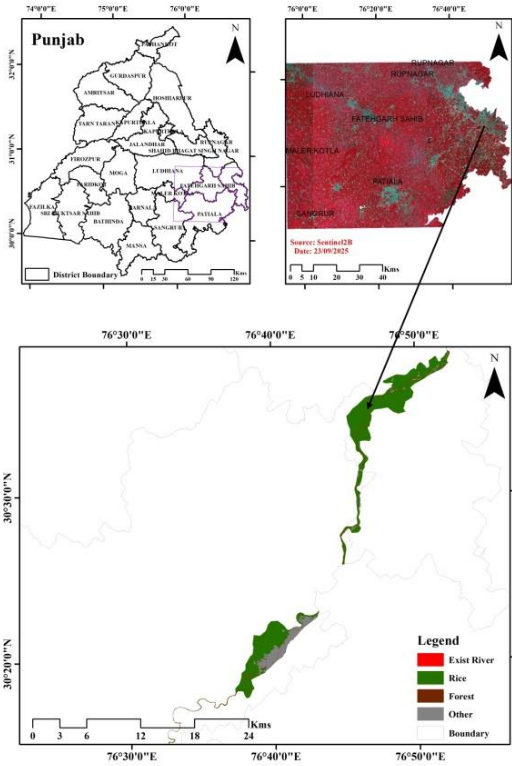
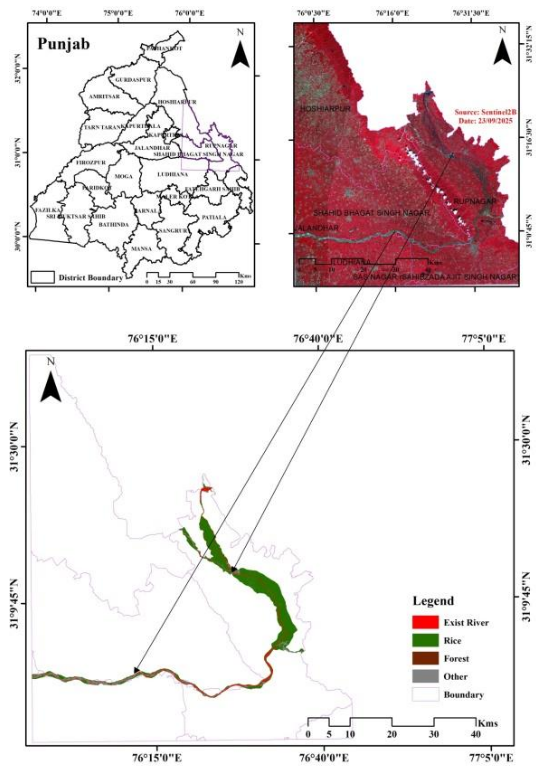


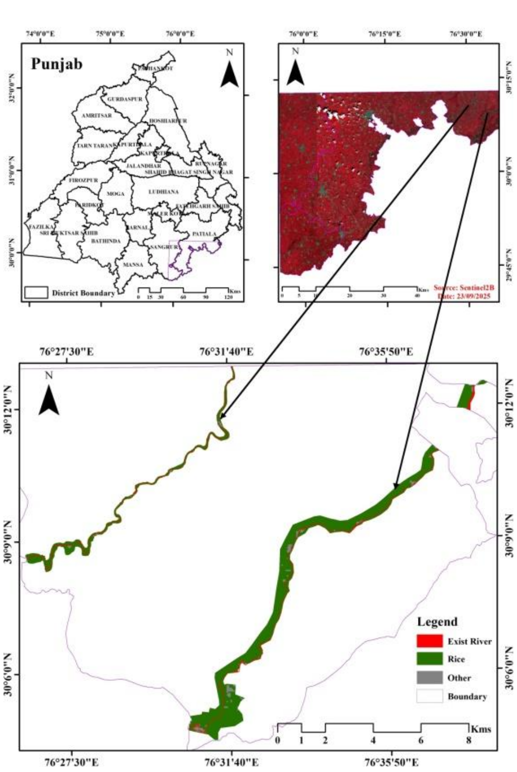
Part4

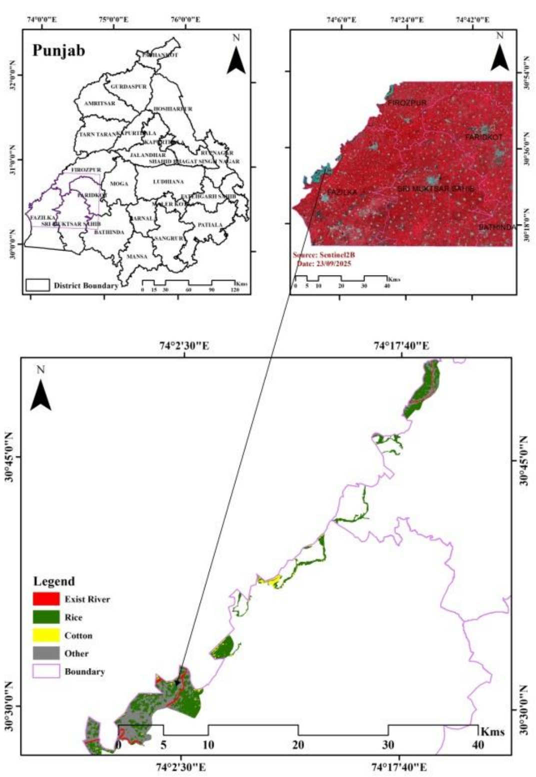
Parts of Index Map of Flood Effected Area, Punjab





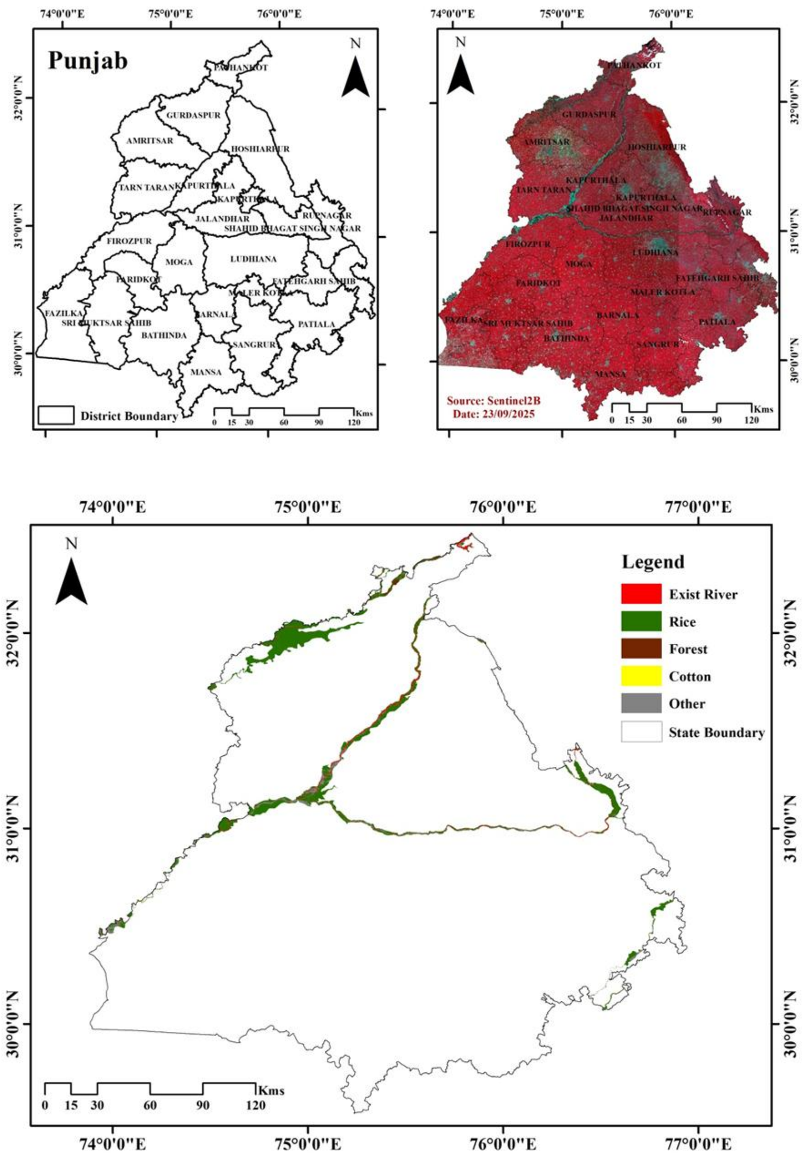
Part5 Part6





Part7 Part8

Parts of Index Map of Flood Effected Area, Punjab



Map8: Index Map of Flood Effected Area, Punjab

Agriculture was severely affected by the floods in Punjab in 2025. Agriculture is the main source of Punjab's economy. Many crops were damaged due to the floods, including rice. Punjab's soil texture and water availability make rice a major crop. Rice is a commercial crop in Punjab. Approximately 1,18, 135 hectares of rice crops were damaged by the flood. Cotton is Punjab's second main crop. Cotton grown in south and southwest part of Punjab. (map11) 328 hectares of cotton crops were damaged by the floods. In addition, 2,816 hectares of forest and 22,040 hectares of other land were affected. (Table3). Approximately 15 districts in Punjab were flooded through rivers, affecting the agricultural areas around the rivers. Most of the crops were damaged due to floods in Gurudaspur, Amritsar, and Tran Taren District in Punjab where rice is cultivated in large quantities. Apart from this, cotton and rice crops were affected in Fazilka.

The 2025 floods affected not only agriculture but livestock, infrastructure such as roads, canal houses and government buildings, economy and environment are also affected. The floods severely damaged infrastructure such as roads, canals, homes, and government buildings, disrupting transportation and essential services.

Table3: Damage kharif crops by flood, Punjab 2025

Affected Area by Flood Punjab(2025)	
Crop Name	**Area in (Hac.)**
Exist River	**12961.34**
Rice	**118135.17**
Cotton	**328.18**
Forest	**2816.67**
Other	**22040.36**

Apart from this, excess water was released from Bhakra and Pong dams built in Himachal to prevent the dam from breaking but due to this the low lying areas of Punjab were flooded. Many rivers and drainage channels of Punjab are filled with garbage and waste. Due to blockage of drainage channels, water could not flow and water accumulated in the fields. Hence the flood situation worsened due to lack of cleaning and maintenance of drains and rivers. Climate change is also a reason for floods. Due to global warming, the intensity and irregularity of monsoon increased. After a long period of drought, there was sudden rainfall and a situation of flash flood arose. Hence the flood in 2025 was the result of climate and human-induced action. Apart from this, it also shows human negligence, weak management, climate change and climate change policies.

Reasons of flood 2025

1. Excess water released during heavy rainfall from the Bhakra dem and pong dem which are located in Himachal Pradesh and the Ranjit Sagar dem in Punjab's Pathankot district, into the major rivers of Punjab such as Sutlej, Beas, and Ravi to prevent dem branches. However, the highwater flow caused the excess water to accumulate in downstream area, causing flooding.

2. The embankments along rivers like the Sutlej, Beas, and Ravi were weak in many places. Illegal sand mining occurs in Punjab. This illegal sand mining weakened the banks, causing them to break. Therefore, weakened embankments also contributed to flooding.

3. In 2025, excessive and heavy rainfall occurred during the monsoon season. Scientists believe this was primarily due to climate change. Due to global warming, the intensity and irregularity of monsoon increased Climate change has caused rainfall to become more frequent and unusual. Sudden heavy rainfall in the upper reaches of Himachal Pradesh and Jammu and Kashmir caused rivers in Punjab to overflow. This excess rainfall also caused flooding.

4. Due to accumulation of silt in the rivers, their capacity to carry water has reduced. Many rivers and drainage channels of Punjab are filled with garbage and waste. Due to blockage of drainage channels during rains, water could not flow and water accumulated in the fields. Hence the flood situation worsened due to lack of cleaning and maintenance of drains and rivers.
5. Due to people building houses, farms, industries and other structures on the natural flood plains of the rivers, the natural space for water to spread near the rivers got reduced, due to which even with slight heavy rains, water started entering the cities and villages. Moreover, natural drainage channels like seasonal drains and chuyes were blocked by illegal constructions, garbage and concrete structures, preventing the natural flow of water.

6. In many areas of Punjab, roads and highways lacked adequate culverts and drainage, resulting in dams that held water. Rapid urbanization and concrete surfaces have reduced the ground's ability to absorb water, causing most of the rainwater to run off and accumulate on the surface. Additionally, the cities' old and inadequate drainage systems could not handle the heavy rains, further exacerbating waterlogging.

Solutions

1. By increasing vegetation and green areas, the water absorption capacity of the land can be improved, while by preventing uncontrolled sand mining in rivers, their natural flow can be protected. Expansion of rainwater harvesting systems, construction of small check dams, ponds and water-retaining structures also help in controlling water flow and reducing floods.
2. Restoring the natural floodplains of rivers and removing illegal constructions on them is essential to ensure that natural space for water to flow is maintained. Natural drainage channels like drains and drains should be kept clean and free from encroachment and garbage so that the flow of water is not obstructed.
3. It is also very important to maintain smooth water flow by constructing adequate and wide culverts under roads and highways. Modern and efficient drainage systems should be developed in cities, and regular cleaning of drains and sewers should be ensured so that rainwater can drain out quickly.
4. Early warning systems that provide timely warnings and scientific land use planning are essential for long-term flood prevention.

Conclusion

In this study area, we used Resource Set 2 (AWiFS) and Sentinel 2 satellite data along with GIS and remote sensing techniques to analyze floods in Punjab in 2025. After preprocessing, we used supervised classification for area estimation and digitization to assess the flood-affected area. The study found that Punjab's land mass, the distribution of rainfall (which was higher in the northern and northeastern regions), and rapid river runoff were the main causes of floods. Apart from the natural causes, human factors like weak embankments, illegal sand mining, siltation in the river, and human settlements on the natural flood plains of the river have further aggravated the flood situation.

In the study, we analyze the flooding caused by rivers and the flood situation in the area around the rivers. Analysis of this study area reveals that approximately 143320 hectares of area is affected by floods. This area is located around rivers like Sutlej, Beas, Ravi and Ghaggar. Punjab's agriculture was most affected due to the floods. Nearly 118135 hectares of rice and 328 hectares of cotton were damaged. These are the major crops of Punjab. The districts of Gurdaspur, Tarn Taren, Firozpur, and Fazilka were the worst affected by the floods. The 2025 Punjab floods were the result of both natural causes such as heavy rainfall, slope, and climate change, and man-made causes such as encroachment and inadequate management.

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