# Flood Impact Assessment over Punjab, India Using Remote Sensing and GIS

**Course: MSc Agriculture Analytics**

**Module: Risk Analysis and Modelling**


**Submitted by: Nidhi Chaudhary (202419004)**

**Krupali Bhayani (2024190003)**

**Koneenika Mallick (202419008)**

**B A College of Agriculture**

**Aanad Agriculture University**

**Aanad, Gujarat**


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**Table of Content**

## Introduction

Floods are among the most frequent and devastating natural disasters, causing loss of life, displacement, and damage to agricultural lands, infrastructure, and ecosystems. Punjab, located in northwestern India, is a state that periodically experiences flood events, particularly during the monsoon season due to intense rainfall and river overflow from the Sutlej, Beas, and Ghaggar rivers. The recurring floods have significant implications for agricultural productivity and rural livelihoods, as the majority of Punjab's land area is under cultivation.

The advancement in remote sensing and GIS technologies provides powerful tools for monitoring, assessing, and quantifying the spatial impact of floods. Satellite imagery from sensors like Landsat-9 enables detailed observation of land cover changes, water inundation, and vegetation stress before and after flood events. The present study uses Google Earth Engine (GEE) to perform a flood impact assessment for Punjab, India, comparing pre-flood and post-flood conditions for the year 2025.

This analysis integrates spectral indices such as the Normalized Difference Water Index (NDWI) and Normalized Difference Vegetation Index (NDVI) to evaluate changes in surface water and vegetation cover. Furthermore, area-based quantification of flood extent and vegetation damage has been performed to provide numerical evidence of the flood's magnitude and its ecological implications.

## Objectives

The primary goal of this study is to perform a comprehensive flood impact assessment over the state of Punjab using multi-temporal satellite imagery and geospatial analysis techniques. The specific objectives of the research are outlined and elaborated below:

**To delineate and visualize flood-affected areas in Punjab using satellite-based NDWI difference analysis**

Floods lead to the temporary expansion of surface water bodies, which can be effectively detected through variations in water-sensitive spectral indices. The study aims to apply the Normalized Difference Water Index (NDWI) derived from **Landsat-9** imagery to identify regions that experienced significant increases in surface water extent during the flood period.

By comparing NDWI values before and after the flood, newly inundated zones can be delineated. This enables the creation of detailed flood maps showing spatial distribution and intensity of water spread across Punjab. Such delineation serves as an essential step toward understanding the spatial pattern of flood dynamics and identifying hotspots of inundation that require further management or relief measures.

**To assess vegetation damage resulting from flooding using NDVI temporal change detection :-**

Floods not only cause water accumulation but also lead to severe stress on vegetation, particularly on standing crops. The study therefore aims to compute the Normalized Difference Vegetation Index (NDVI) for both pre-flood and post-flood periods to evaluate the health and density of vegetation cover.

By analyzing the temporal change in NDVI values, it is possible to detect areas where vegetation vigor has declined due to prolonged submergence, waterlogging, or soil erosion. This helps in quantifying the extent of vegetation loss and identifying the most affected agricultural zones, offering valuable insight for post-flood agricultural damage assessment and recovery planning.

**To calculate the total area under flood inundation and vegetation damage in hectares and their percentage relative to the total Area of Interest (AOI)**

Quantification is a key aspect of flood assessment. Beyond visual interpretation, this study seeks to calculate the precise area of land impacted by flooding and vegetation degradation. Using spatial analysis functions within the Google Earth Engine (GEE) environment, pixel-wise calculations of flood and vegetation damage areas are performed and expressed in hectares (ha).

Furthermore, these values are compared against the total area of Punjab (the AOI) to determine the percentage of land affected by each phenomenon. Such numerical estimations are critical for evaluating the magnitude of impact, prioritizing regions for resource allocation, and supporting evidence-based policy interventions.

**To generate map visualizations and statistical summaries to support spatial interpretation and decision-making**

Another objective of the study is to produce clear, interpretable map visualizations and statistical summaries for effective communication of results. The maps include multi-temporal RGB composites, NDWI and NDVI layers, and thematic change detection outputs such as flooded areas and vegetation damage zones.

These visual products not only enhance the understanding of spatial patterns but also serve as decision-support tools for government agencies, disaster management authorities, and agricultural planners. The associated statistical summaries—including mean, maximum, and minimum values of NDWI and NDVI, and area-based metrics—add quantitative depth to the visual interpretations.

Ultimately, these outputs aim to build a foundation for flood monitoring frameworks, promote data-driven decision-making, and support future preparedness and mitigation strategies in flood-prone regions of Punjab.

## Study Area

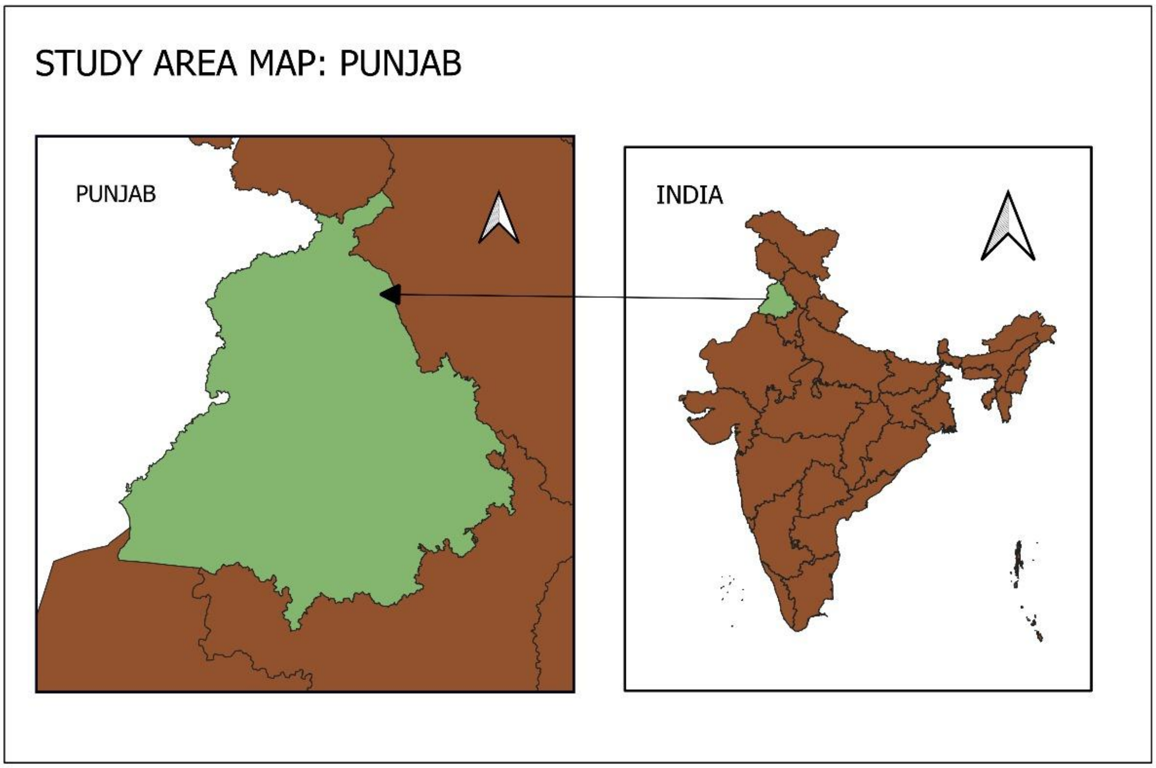


**FIG:1 STUDY AREA MAP: PUNJAB**

The state of Punjab, located in northwestern India, has been selected as the Area of Interest (AOI) for this study. Punjab lies between 29°30′N to 32°32′N latitude and 73°55′E to 76°50′E longitude, covering an approximate area of 50,37,130 hectares (≈ 50,000 $km^2$) as derived from spatial analysis. Punjab's terrain is largely flat, dominated by fertile alluvial plains, making it highly suitable for agriculture. However, this very landscape also makes it prone to waterlogging and flooding during heavy monsoon rainfall, especially in the low-lying regions adjacent to river basins. The state's climate is characterized by a monsoonal pattern with significant rainfall between June and September. This study focuses on the flood period of September–October 2025, following the pre-flood period of May–June 2025.

## Data Used

### Satellite Data

Sensor: Landsat-9 (Collection 2, Tier 1, Level 2)

Spatial Resolution: 30 meters

### Temporal Coverage

Pre-Flood Period: May 1, 2025 – June 30, 2025

Post-Flood Period: September 1, 2025 – October 23, 2025

### Bands Used

SR_B2 (Blue), SR_B3 (Green), SR_B4 (Red), SR_B5 (Near Infrared – NIR)

### Ancillary Data

Administrative Boundary: Punjab state shapefile (uploaded as asset to GEE).

### Derived Indices

NDWI (Normalized Difference Water Index), NDVI (Normalized Difference Vegetation Index)

## Methodology

The flood impact assessment in Punjab was conducted using Google Earth Engine (GEE) a cloud-based geospatial analysis platform. GEE provides access to multi-temporal and multi-sensor satellite datasets and enables high-speed processing of large-scale raster data, making it ideal for dynamic flood mapping and impact evaluation.

### Step 1: Area of Interest (AOI) Selection

The Punjab state boundary shapefile was uploaded as a **FeatureCollection** to define the spatial extent of the study. This AOI served as the mask for all subsequent operations including image filtering, clipping, and statistical computation. For easy visual identification, the AOI was displayed in red outline on the map interface. In addition, smaller administrative units such as district boundaries were referenced (though not used for analysis) to facilitate interpretation of localized flood impacts.

### Step 2: Image Selection and Preprocessing

Two Landsat-9 Surface Reflectance (SR) image collections were retrieved from the GEE catalog to represent pre-flood and post-flood conditions. The following filters were applied:

Filter the data, Pre-flood period: dates preceding the flood event. Post-flood period: dates immediately after flood occurrence.

Spatial filter: limited to the AOI (Punjab state).

Cloud cover filter: images with less than 20% cloud cover were selected to ensure quality. To minimize residual cloud and atmospheric noise, median composites were generated from multiple scenes. This method ensures that the central tendency of reflectance values is represented, thus improving data stability. The resulting composites were clipped to the AOI to enhance computational efficiency and visualization clarity.

**Step 3: RGB Visualization**

For visual inspection and validation, true color composites were generated using the (SR_B4, SR_B3, SR_B2) band combination for both pre-flood and post-flood images. This RGB visualization allowed for manual detection of flood patterns, water spread, and visible landscape changes between the two periods. Visual comparison helped in confirming spectral changes later captured by NDWI and NDVI indices.

**Step 4: NDWI Computation (Flood Detection)**

The Normalized Difference Water Index (NDWI) was calculated to detect surface water and flood inundation zones using the formula:

**NDWI** = Green – NIR / Green + NIR

For Landsat-9 imagery, Band 3 (SR_B3) represents Green and Band 5 (SR_B5) represents Near Infrared (NIR).

Two NDWI images were derived:

**NDWI_Pre:** for the pre-flood condition

**NDWI_Post:** for the post-flood condition

A difference image (NDWI_Change) was then calculated as:

**NDWI_Change** = NDWI_Post - NDWI_Pre

Pixels showing a positive NDWI change (> 0.1) were interpreted as newly inundated areas, representing flood-affected zones. This threshold was selected empirically based on spectral behavior of water bodies and visual verification.

**Step 5: NDVI Computation (Vegetation Health Assessment)**

The Normalized Difference Vegetation Index (NDVI) was used to assess vegetation health and damage due to flooding, computed as:

**NDVI** = NIR – Red / NIR + Red

Here, Band 5 (SR_B5) corresponds to NIR and Band 4 (SR_B4) to Red. NDVI was derived for both pre- and post-flood images:

**NDVI_Pre**: baseline vegetation condition

**NDVI_Post:** vegetation status after flooding

The NDVI difference (NDVI_Change) was then computed as:

**NDVI_Change** = NDVI_Post - NDVI_Pre

Pixels with NDVI_Change < -0.1 were classified as Vegetation Damage Areas, indicating regions where vegetation health significantly declined, possibly due to waterlogging or prolonged submergence.

**Step 6: Area Calculation**

Quantitative analysis of flood and vegetation damage was performed using the ee.Image.pixelArea() function in GEE.

For each classified map (Flooded and Vegetation-Damaged areas): The total area of pixels meeting the defined criteria was summed (in $m^2$). Areas were converted to hectares (1 ha = 10,000 $m^2$). The total AOI area was also computed to express affected regions as a percentage of Punjab's total land area. This provided both absolute (ha) and relative (%) estimates of flood and vegetation impact.

**Step 7: Visualization and Export**

Multiple thematic maps were created to represent the results:

1. Pre-Flood RGB Composite

2. Post-Flood RGB Composite

3. NDWI Pre-Flood

4. NDWI Post-Flood

5. NDWI Change (Flood Extent Map)

6. NDVI Pre-Flood

7. NDVI Post-Flood

8. NDVI Change (Vegetation Loss Map)

9. Flooded Area Map (Binary Classification)

10. Vegetation Damage Map (Binary Classification)

**Each visualization used suitable color palettes:**

Water areas: shades of blue

Vegetation: green to red transition for health decline

NDWI/NDVI change maps: diverging color ramps to highlight variation intensity

The outputs were exported as GeoTIFF files for further GIS analysis and as shapefiles summarizing the statistical results. all maps were finally compiled to facilitate spatial interpretation, impact quantification, and decision-making support for flood management in Punjab.

## Results and Analysis

This section presents the outcomes of the flood impact assessment derived through NDWI and NDVI analysis using Landsat-9 satellite imagery in Google Earth Engine (GEE). The results provide both quantitative and qualitative insights into the extent of flood inundation and vegetation damage across Punjab.

Image Summary, A total of 38 Landsat-9 images were utilized in the study, comprising 21 pre-flood and 17 post-flood scenes. This ensured robust temporal coverage and reduced the influence of transient atmospheric or seasonal noise. The median composite approach minimized the effect of residual clouds and enhanced the reliability of the generated spectral indices.

| **Image Type** | **No. of Images Used** |
|---|---|
| Pre-Flood | 21 |
| Post-Flood | 17 |

The sufficient temporal sampling enhanced the accuracy of pre- and post-event comparisons and provided a stable baseline for change detection.

**Total Area Statistics**

| Parameter | Value (hectares) |
|---|---|
| Total AOI Area | 5,037,130.44 |
| Flooded Area | 27,041.96 |

| | |
|---|---|
| Vegetation Damage Area | 32,750.83 |
| Flooded Area (%) | 0.54 % |
| Vegetation Damage (%) | 0.65 % |

While the percentage of flooded area (0.54%) may appear relatively small compared to the total land area of Punjab, the localized impacts were severe, particularly in agriculture-intensive districts such as Ferozepur, Moga, and Hoshiarpur. These regions experienced extensive inundation of croplands, leading to yield loss and short-term livelihood disruptions for farming communities. Similarly, the vegetation damage area (0.65%) represents the zones where floodwaters either submerged standing crops or caused waterlogging stress, leading to vegetation degradation. The spatial distribution of these areas, derived from NDVI change analysis, highlights the variability in flood impact across different physiographic zones.

**NDWI Analysis**

The Normalized Difference Water Index (NDWI) was used to detect changes in surface water extent between pre- and post-flood periods. The computed statistical summary is as follows:

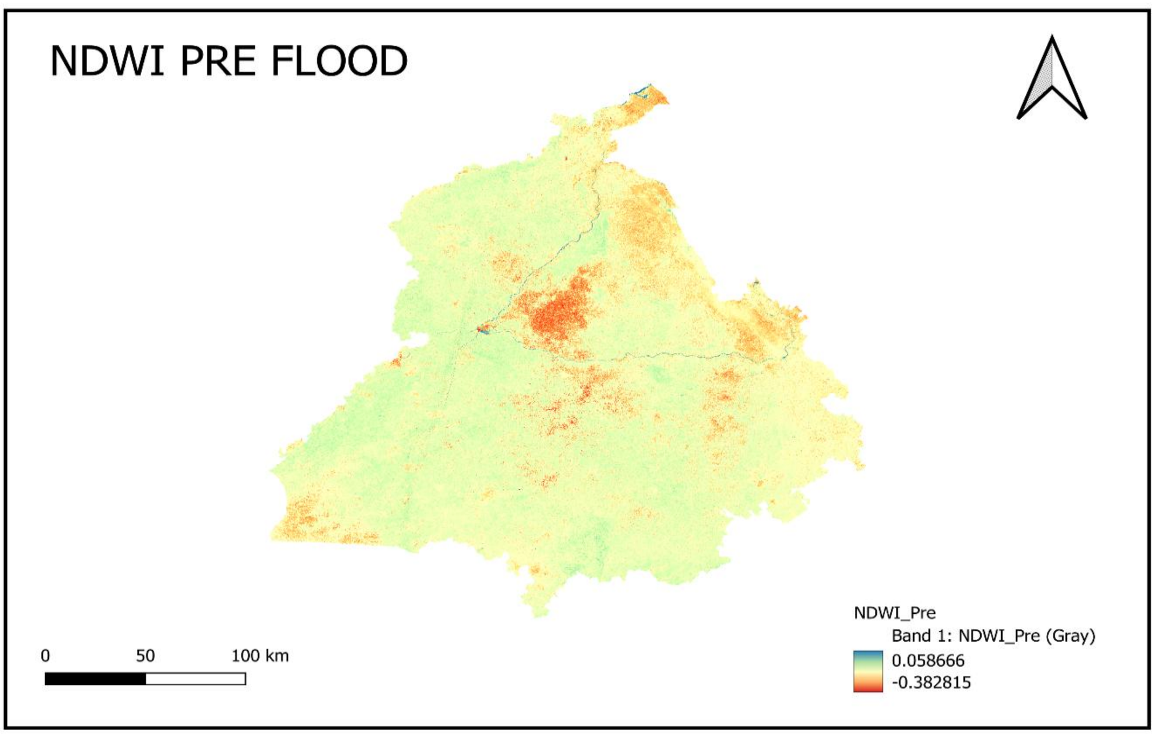


**FIG:2 NDWI PRE FLOOD**

| NDWI Statistic | Pre-Flood | Post-Flood |
|---|---|---|
| Maximum | 0.117 | 0.185 |
| Mean | -0.141 | -0.287 |
| Minimum | 0.443 | -0.774 |

The increase in maximum NDWI value from 0.117 to 0.185 clearly indicates the expansion of water-covered areas after the flood. This rise corresponds to newly inundated surfaces such as riverbanks, low-lying plains, and agricultural fields. However, the mean NDWI becoming more negative (-0.141 to -0.287) suggests that, although flooding increased locally, much of the region retained low water reflectance—a common occurrence in heterogeneous flood patterns where only certain catchments or floodplains experience submersion. The NDWI change map visually confirmed this pattern, showing concentrated flood signatures along major river systems such as the Sutlej and Beas, and in surrounding floodplains where water accumulated post-event.

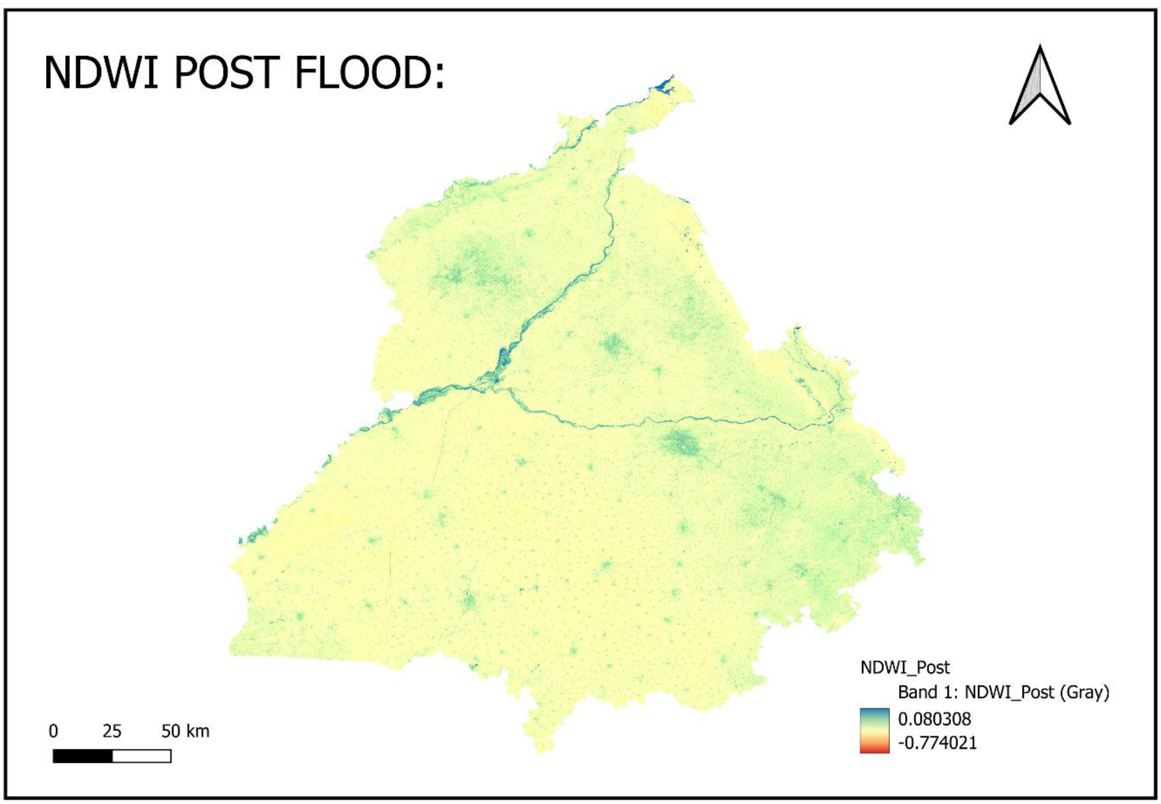


**FIG:3 NDWI POST FLOOD**

### NDVI Analysis

The Normalized Difference Vegetation Index (NDVI) was analyzed to assess the flood's impact on vegetation health. The following table summarizes NDVI statistics:

| NDVI Statistic | Pre-Flood | Post-Flood |
|---|---|---|
| Maximum | 0.480 | 0.776 |
| Mean | 0.120 | 0.302 |
| Minimum | -0.119 | -0.160 |

Interestingly, NDVI values show an overall increase post-flood, particularly in the maximum and mean values, reflecting vegetation regrowth or enhanced soil moisture in some areas following rainfall and flood recession. Such improvement typically occurs in semi-arid landscapes where post-flood soil moisture replenishment stimulates new vegetation growth. Nevertheless, spatial NDVI difference analysis revealed pockets of vegetation loss (NDVI change < -0.1), primarily in low-lying agricultural fields and flood-prone zones. These areas correspond to locations of crop damage or prolonged water stagnation, where plants either drowned or suffered stress due to oxygen deprivation in the root zone. Thus, while average NDVI increased across the state, local vegetation decline zones served as critical indicators of flood-induced agricultural loss.

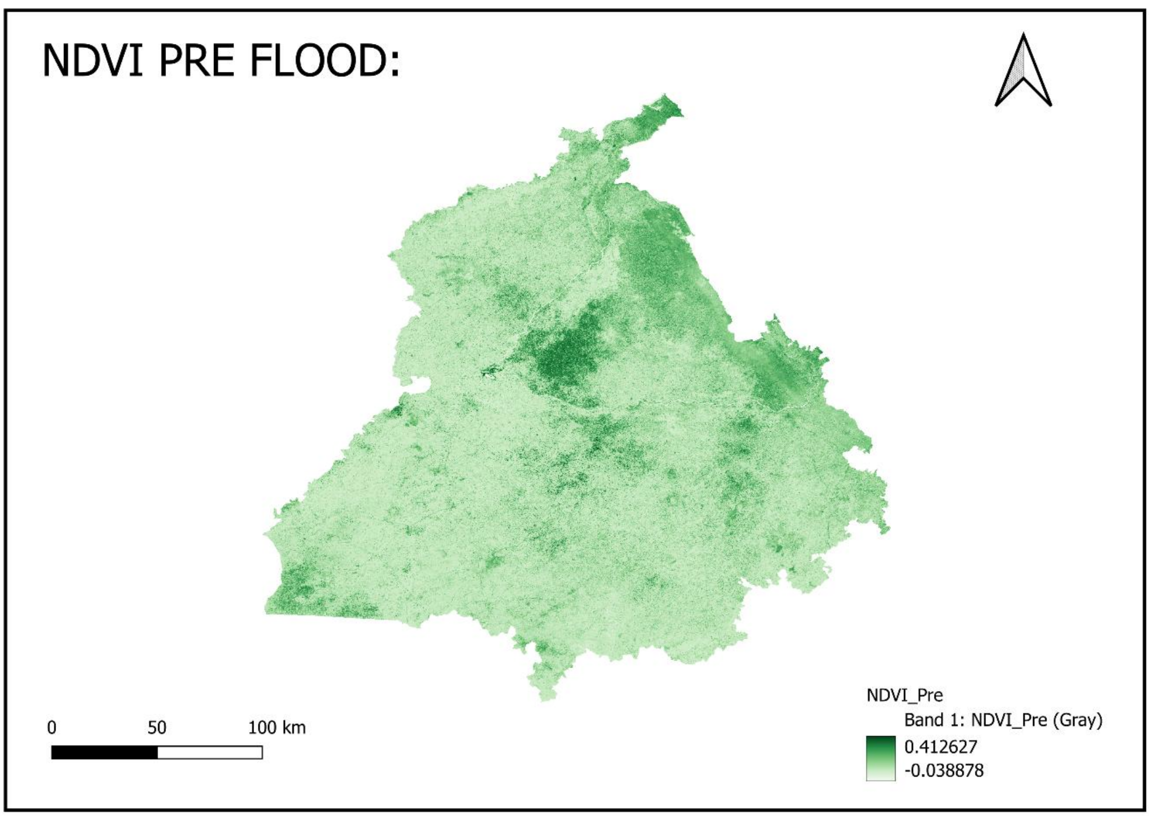


**FIG:4 NDVI PRE FLOOD**

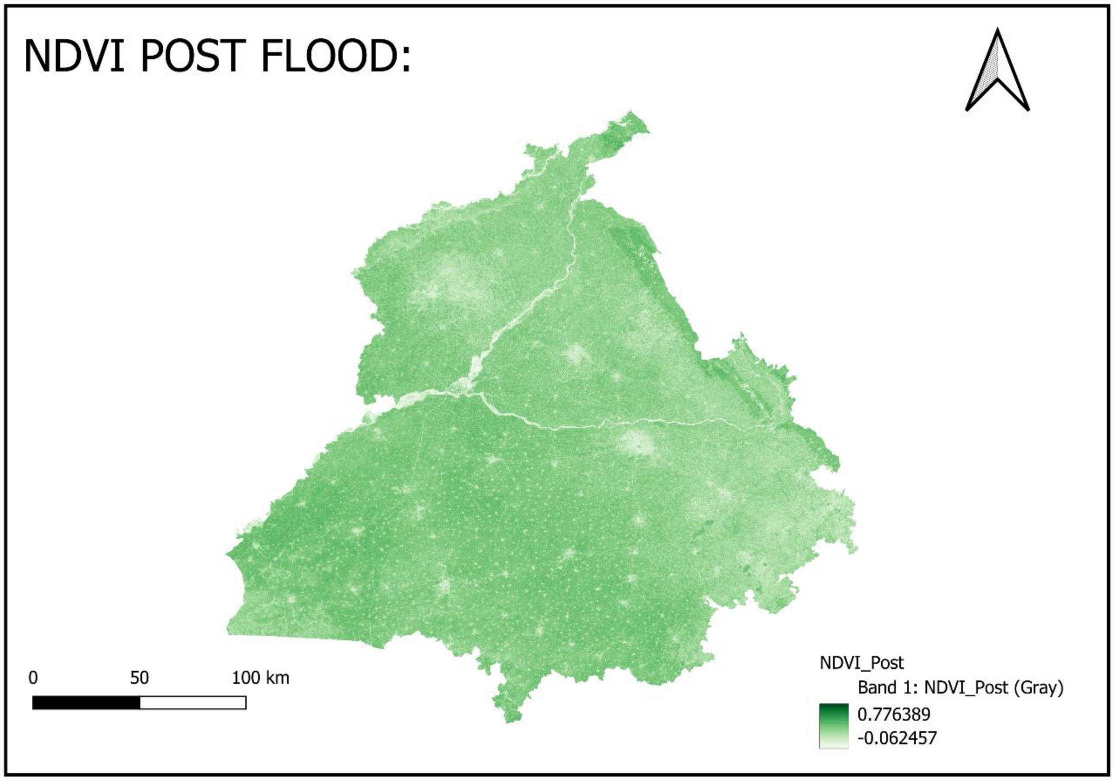


**FIG:5 NDVI POST FLOOD**

**Spatial Interpretation**

Thematic maps derived from NDWI and NDVI change detection provided a clear spatial understanding of flood dynamics:

Flooded Area Map (NDWI Change > 0.1): Highlighted newly inundated areas concentrated near river channels and basins.

Vegetation Damage Map (NDVI Change < -0.1): Revealed regions of reduced vegetation vigor, largely overlapping with flooded cropland zones.

Comparative Overlay: The overlay of both layers confirmed strong spatial correlation between flood extent and vegetation stress, validating the effectiveness of dual-index analysis.

The combined use of NDWI and NDVI not only delineated physical flood zones but also quantified the ecological and agricultural impact, offering valuable insights for disaster response, recovery planning, and land management.

## Conclusions

This study successfully demonstrates the effectiveness of remote sensing techniques integrated with Google Earth Engine (GEE) for large-scale flood impact assessment across the Punjab state. Through the use of multi-temporal Landsat-9 imagery and spectral indices such as NDWI and NDVI, both hydrological and vegetation-related impacts of flooding were quantitatively and spatially analyzed.

The key findings and conclusions are summarized below:

1. Dual-Index Integration:

The combined use of NDWI (Normalized Difference Water Index) and NDVI (Normalized Difference Vegetation Index) proved to be an efficient approach for detecting both surface water inundation and vegetation stress caused by flood events. This dual analysis enhanced the reliability and interpretability of flood mapping results.

2. Quantified Impact:

The study identified approximately 27,041.96 hectares of land under flood inundation and 32,750.83 hectares of vegetation damage across Punjab. These figures, though representing a modest 1.2% of the total study area, signify considerable localized impacts on agricultural productivity and rural livelihoods, particularly in flood-prone districts.

3. Spatial Distribution and Local Sensitivity:

The flood-affected regions were primarily concentrated along major river systems such as the Sutlej, Beas, and Ghaggar, and in adjacent low-lying floodplains. Spatial patterns of NDWI and NDVI changes highlight the sensitivity of agricultural landscapes to monsoonal flood events, reinforcing the need for localized mitigation strategies.

4. Data and Platform Efficiency:

The Landsat-9 SR dataset, with its 30-meter spatial resolution, offered sufficient granularity for state-level analysis. The GEE platform significantly streamlined the workflow by enabling cloud-based computation, temporal filtering, index calculation, and area estimation—eliminating the need for local storage or heavy processing infrastructure.

5. Operational Feasibility:

The semi-automated workflow developed in this study can be replicated for future flood events, making it an efficient and scalable model for continuous monitoring, early warning, and rapid damage estimation. Overall, this research underscores the value of integrating remote sensing indices with cloud-based geospatial platforms to generate timely, spatially explicit, and data-driven insights for disaster management and environmental monitoring.

## References


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