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# Flood Risk Assessment Using Geospatial Techniques: A Case Study of River Ravi-Punjab-Pakistan

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Flooding, an increasingly prevalent environmental hazard, has been worsened by climate change, particularly affecting developing countries. Pakistan is especially vulnerable to hydrological hazards. This study aims to evaluate flood risk using geospatial technology and analyze return periods to assess the impacts of floods on crops. Water is a significant driver of landscape change. Landsat 8 datasets are utilized to examine crop patterns and built-up areas. Return periods of 50, 100, and 250 years are used to define risk zones, with gauges at Jassar, Syphon, and Shahdara considered. Historical images from 1995, 1996, and a recent year are analyzed to track changes in crop and built-up areas. SRTM and Pulsar DEM data are employed to study the watershed. The analysis indicates that over a 150-year period, the probability of a significant flood event is 0.25. This low probability suggests minimal water flow, with only small amounts arriving during the monsoon season, causing minimal disruptions to crops. These probabilities are based on established methodologies. While the probability of a significant flood event over 250 years is very low, it is included for classification purposes. The chance of a flood affecting crop patterns is 0.5, but this may vary if river water levels rise due to other sources. Nonetheless, current data and historical records indicate that the likelihood of floods significantly impacting crop patterns remains very low.

**Keywords:** Hec-RAS, SRTM, DEM, Flood Damage Assessment.

## Introduction:

Floods are natural hazards that cause substantial damage to infrastructure and affect the lives of many organisms. According to Kroon [1], floods result from rainfall variability and snowmelt, which lead to river overflow and temporary inundation of land along riverbanks. Modern technologies and methods now allow for accurate measurement of flood occurrences. Understanding and preventing floods involves complex interactions between natural and anthropogenic factors, with climate change being a significant recent contributor [2].

Flash floods, which occur shortly after heavy rainfall, can cause extreme runoff. Even one hour of continuous rain can lead to disasters due to the interplay of geomorphological, ecological, and hydrological factors, resulting in severe economic, environmental, and human losses. The frequency of flash flood events has increased significantly in recent years [3]. Flood risk involves both the probability of occurrence and potential consequences, combining vulnerability and hazard. Effective flood risk assessment and management are crucial for mitigating the impacts of flash floods [4]. Quantitative assessments using hydrological models are particularly effective, as they provide measurable data [5].

The frequent occurrence of floods, driven by heavy rainfall and snowmelt, leads to runoff and temporary stillness in areas along riverbanks. Understanding floods requires a focus on both natural and anthropogenic factors, with climate change being a major contemporary influence [6]. Coastal and riverbank areas are attractive for habitation, but effective management is essential to minimize or prevent flood damage in these regions. Flood risk management and modeling are key to hazard mitigation, with flood modeling offering a relatively new approach for risk assessment. These measures aim to reduce the vulnerability of people and properties in flood-prone areas [7].

In the Himalayan region, floods and avalanches are common threats. Over the past three decades, South Asia has faced severe flooding, resulting in 65,000 deaths and significant impacts. Monsoon conditions have left 30 million people homeless and caused approximately 2,700 deaths in countries such as Bangladesh, Nepal, and India. Notable events include Mumbai's extreme rainfall of 944 mm within 24 hours in 2005 and a life-threatening flood in Baluchistan in June [8]. While floods cannot be entirely prevented, their effects can be minimized through effective emergency response, relief efforts, recovery management, and efforts to prevent epidemics. Improving flood forecasting accuracy is a growing focus for many countries [9]. From 1980 to 2008, nearly 3,000 flood events were recorded, leading to around 200,000 deaths and economic losses exceeding 4 billion USD [10].

## Material and Methods:

### The Study Area:

The Ravi Stream basin is a transboundary river system shared between Pakistan and India, forming a key part of the Indus River system. Originating in the Himalayan region, the river flows northwest through Himachal Pradesh, India, before entering Punjab, Pakistan. It crosses into Pakistan at Jassar and merges with the Chenab River at Head Sidhnai. The study area is situated between latitudes 32.0910° N and 31.6211° N, and longitudes 74.9428° E and 74.2824° E. Within Pakistan, the Ravi River is the smallest tributary of the Indus basin.

The general elevation of the area ranges from approximately 207 to 213 meters above sea level. The river's catchment area spans about 40,769 square kilometers, with an average annual flow of 628.8 cubic meters per second from Shahdara to Jassar. The total length of the river, combining both Indian and Pakistani sections, is 720 kilometers. The surface soil layer consists of fine-grained alluvial soil deposited by water currents, while the subsoil is a mix of clay and gravel. The region experiences a diverse climate, with temperatures ranging from -1°C to 46°C. Rainfall is distributed throughout the year, with peak precipitation during the monsoon months of July and August, averaging around 620 mm annually. Relative humidity ranges from 45% to 85%, and wind speeds vary between 0.1 and 1.6 meters per second year-round.

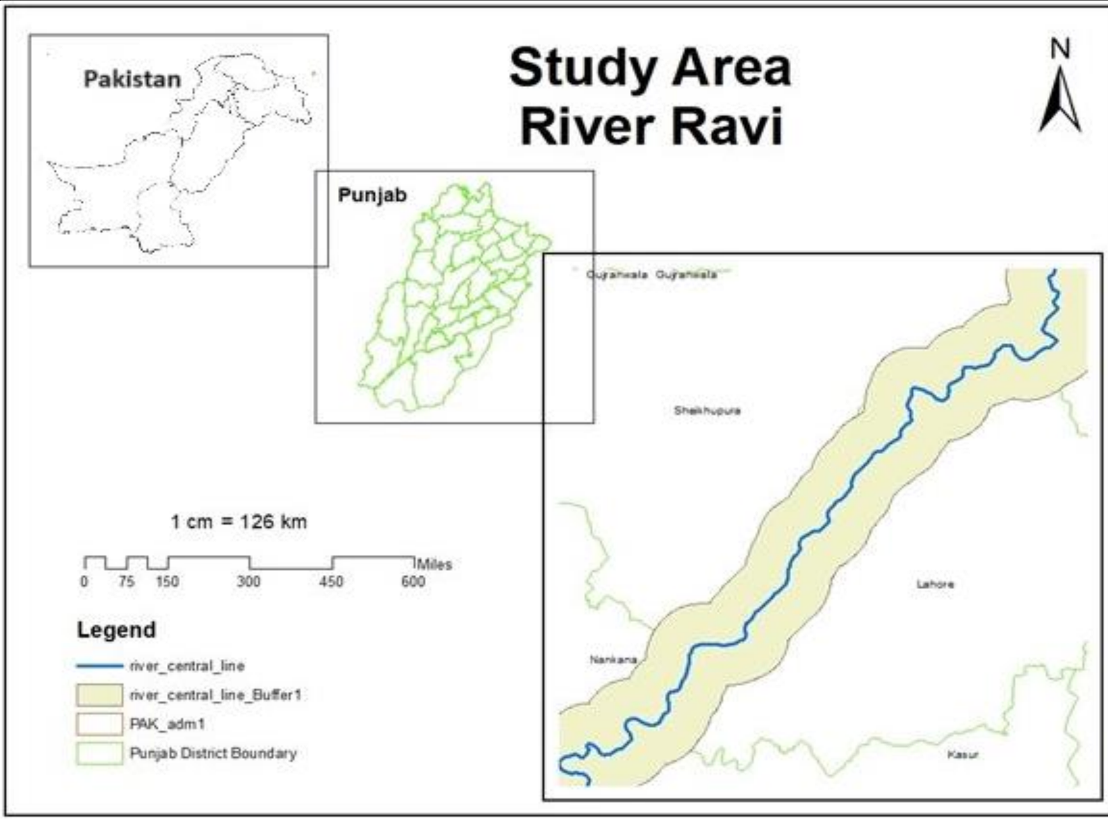


**Figure 1**: Study Area River Ravi, Punjab-Pakistan

**Methodology:**

Methodology is the backbone of any research, making it essential to adopt a framework that effectively supports the hypothesis and yields reliable results. While data collection may seem straightforward, it is inherently complex and requires appropriate methods to be successful. Using incorrect methods can undermine the integrity of the entire research project. To avoid this, researchers must be well-versed in various methods relevant to their field. Additionally, selecting methods should align with the research objectives to ensure coherence between the methods and the study's goals. This alignment is crucial for the success and validity of the research.

**Data Collection:**

Data for the physical vulnerability assessment was sourced from various platforms. Elevation data was obtained from SRTM and Pulsar datasets, while land use and land cover data were derived from Landsat 8 imagery. River network vector files were also utilized. To analyze crop susceptibility and coping capacity, a range of variables was compiled from multiple sources. Data from 1990-2016 was provided by the irrigation department and represented visually using Excel. Information from three main gauges—Syphon, Shahdara, and Jassar—was included. Jassar, where the river enters Pakistan, served as the reference point. Monthly data from the irrigation department was summarized in Excel, and 30 years of data ensured accuracy.

**Physical Vulnerability Analysis:**

The following parameters were used for physical vulnerability analysis in this research:

**Elevation:**

Elevation is a critical factor affecting flood risk. Areas with an elevation of 30 meters are classified into the high hazard category.

**Land Use and Land Cover:**

This parameter includes three categories: cultivated land, water bodies, and dry land. Cultivated land is assigned the highest weight due to its significance.

**Sources of Water:**

Floods can contaminate both drained and well water, making clean drinking water scarce. Various water sources, including taps and rivers, were evaluated.

**Gumbel Distribution:**

Gumbel distribution is employed to model the dispersion of samples, particularly for extreme river levels over the past 10 years. It estimates the probability of floods or other disasters. Maximum values in this method describe severe situations, while high values are used to analyze flood damage.

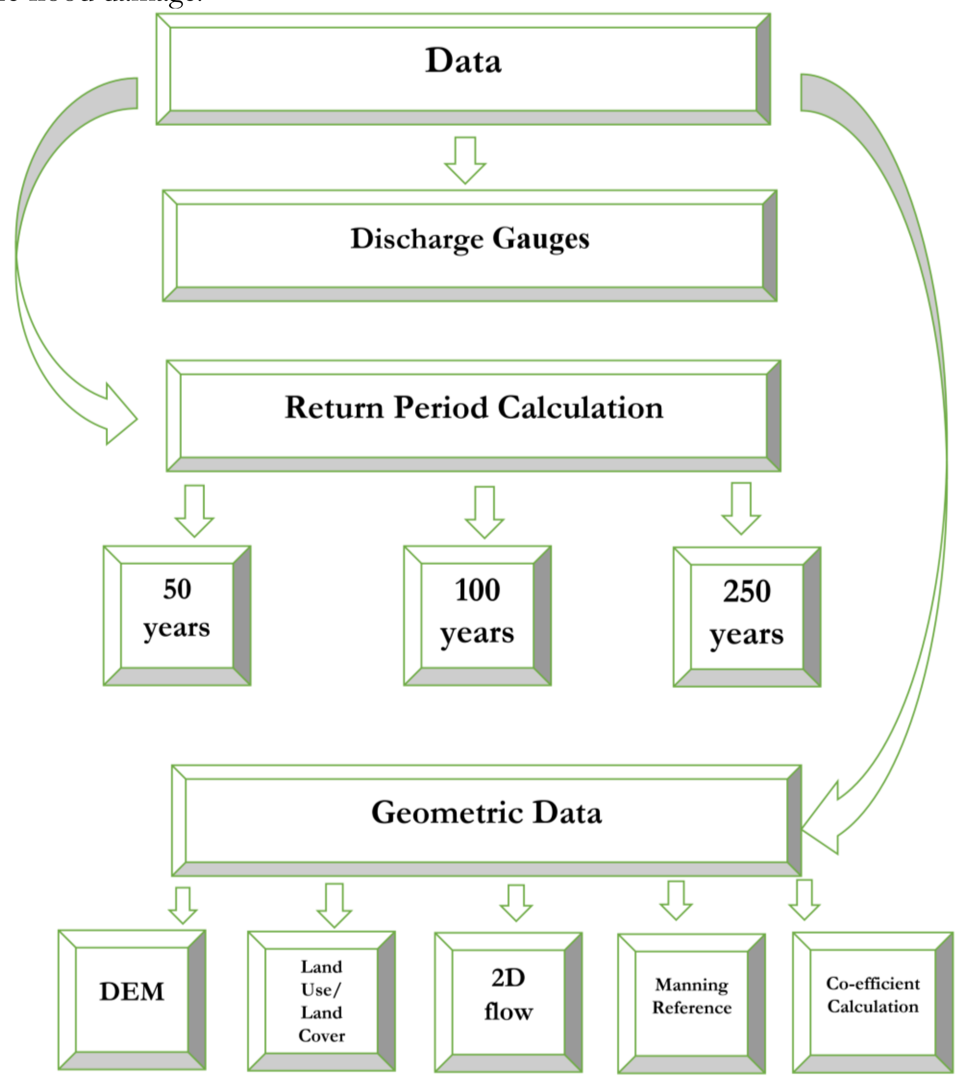


**Figure 2:** Flow Chart of Methodology

**Results:**

Classification is a precise and straightforward method for distinguishing land use and land cover. In the Ravi River study area, this technique was used to assess flood variations and understand flood phenomena. The entire study area, extending from Jassar to Shahdara, was classified into categories of water, bare soil, and vegetation, with a 5 km buffer zone on both sides of the river. This buffer zone helped to confine the study area and evaluate the flood impact. Flow paths were mapped to assess riverine flood vulnerability, considering both the left and right banks to monitor normal flow and potential river outbursts. The sustainability of river embankments in Shahdara, which aim to prevent water from reaching Lahore, was also examined. Built-up areas were excluded from the analysis to ensure an accurate assessment of crop patterns in the study area.

**Land use Map of 1995:**

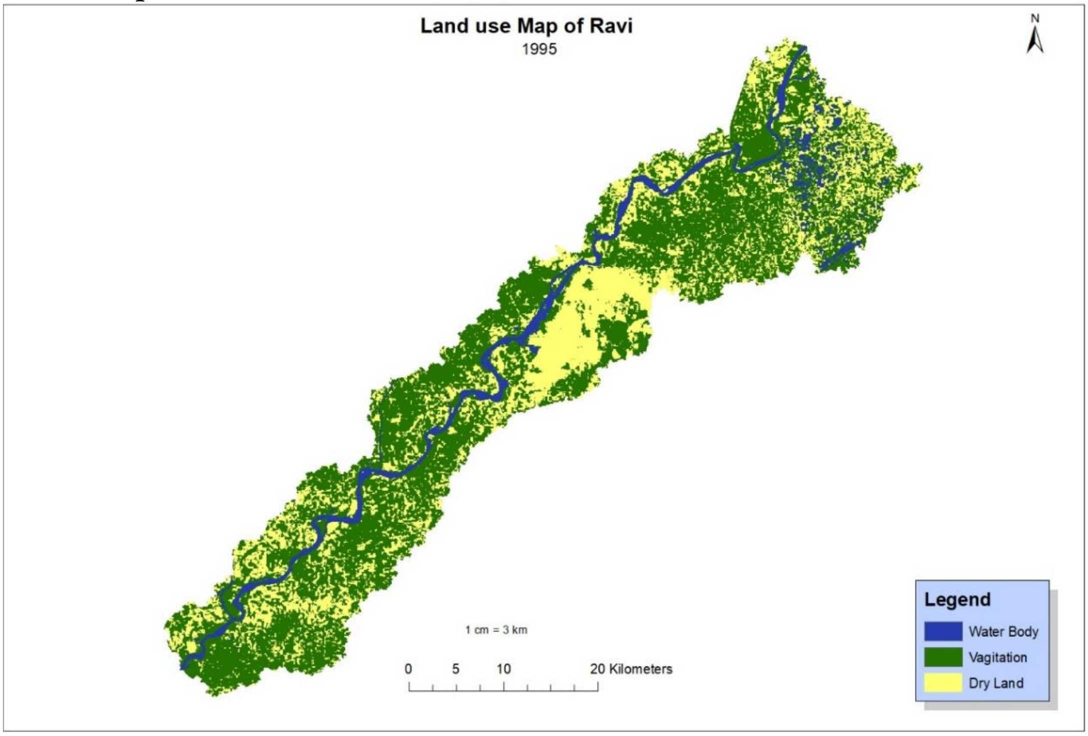


**Figure 3**: Land use map of 1995

**Land use Map of Ravi of 1996:**

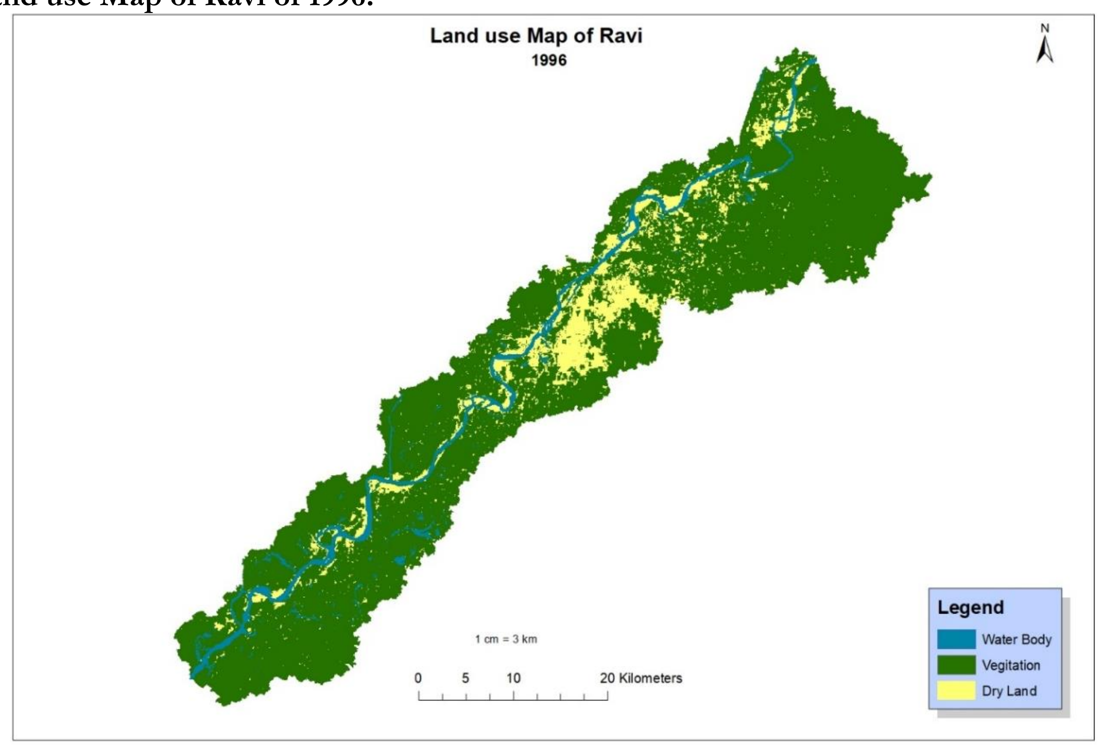


**Figure 4:** Land use map of 1996

**Land use Map of Ravi of 2018:**

First, we calculated the total impact of floods on crops and determined the affected crop areas within our study area. The area was precisely calculated using the intersection method. Additionally, we calculated the return periods for the rivers. To estimate flood hazard and risk, we followed several steps. Initially, we examined various hydrographs for different return periods and assessed the inundated areas with maximum water depths based on flood volume, without considering any losses. These depths were then used to estimate potential consequences. This primarily involved estimating flood hazards corresponding to the specified return periods. We initially focused on areas unprotected from floods. Due to both natural and man-made protective measures, the flood scenario simulations produced varying depths, resulting in reduced damages and losses.

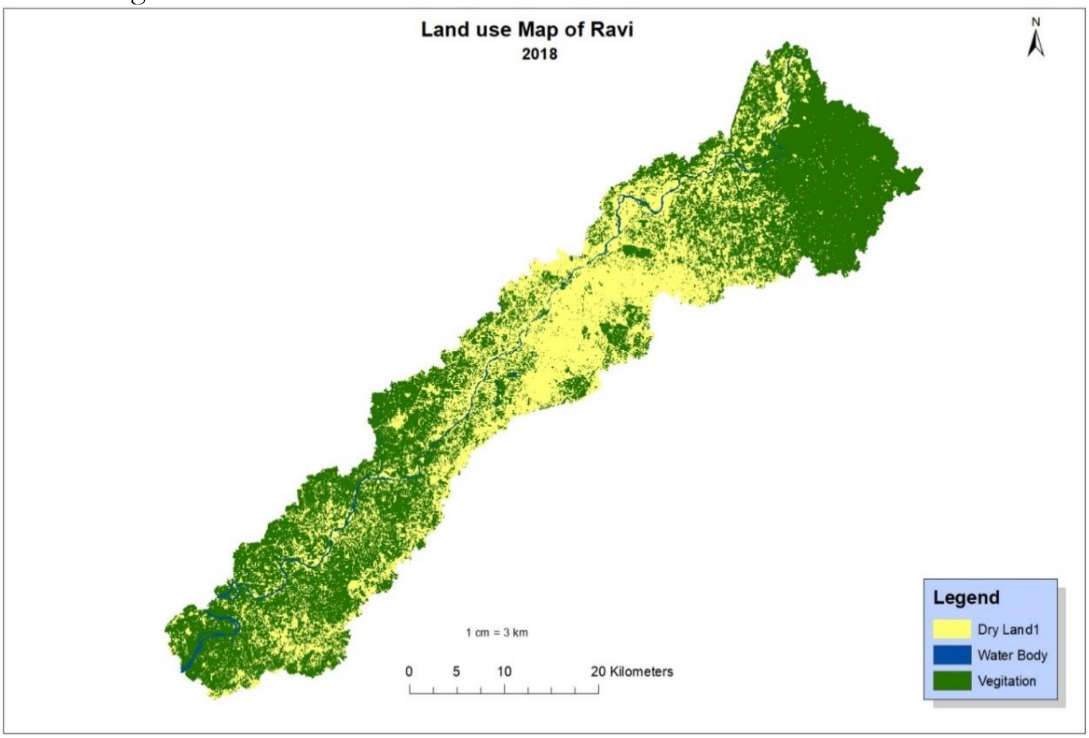


**Figure 5:** Land use map of 2018

Hec-RAS software was utilized to propose three probability scenarios for testing. Historical data was processed in Excel, and curve values were calculated using Gumbel distribution and Manning's coefficient. We derived three probability scenarios, although the recommended approach involves testing at least 5-6 return periods, such as 10, 25, 50, 100, and 500 years. For this study, we considered return periods of 100, 50, and 250 years to comprehensively address the range of potential damages and occurrence magnitudes.

Figure 6 displays the land use map of the flood-prone area, the flood hazard map for a 50-year return period, and the flood danger map. Different shades indicate varying water depths, while other colors represent total damage in units. The map and flow chart are self-explanatory and can be practically applied. The flow chart incorporates geoinformation, hydraulic computations, and crop data, proving highly useful. Risk zones are categorized as follows:

- **Green:** Represents an extremely low-risk zone where water surge is minimal, and the impact on crop patterns is negligible. This classification is based on the Manning process and corresponding results.
- **Light Green:** Indicates a low-risk zone where crops may experience some impact from riverine floods. This area is represented in the 50-year return period map and calculates the overall effect.
- **Yellow:** Denotes a medium-risk zone with moderate water surge, especially near the river. Crops in these areas require additional care to avoid significant damage.
- **Orange:** Shows a high-risk zone with substantial crop impact during riverine floods. The return period in this area is higher, necessitating farmer training and information to manage the situation effectively.

- **Red:** Indicates an extremely high-risk zone where even a minor surge can cause severe damage. Although rare in this area due to the Ravi River's typical water levels, any significant surge could result in serious consequences.

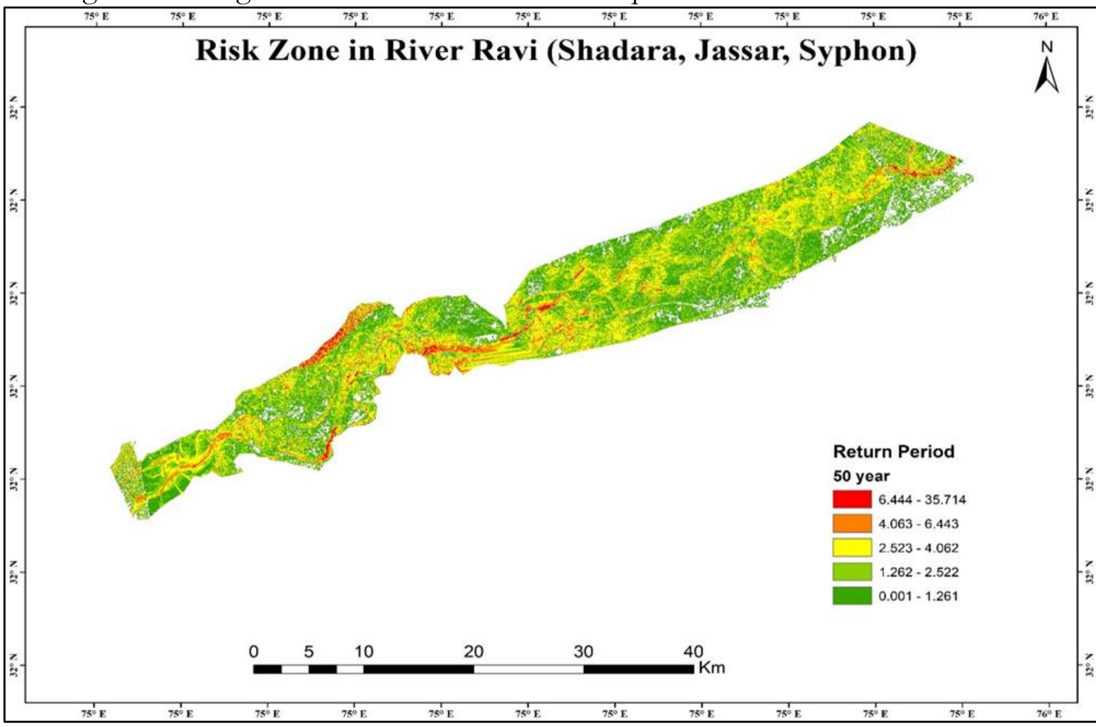


**Figure 6**: Flood Risk Zone in River Ravi of 50 years

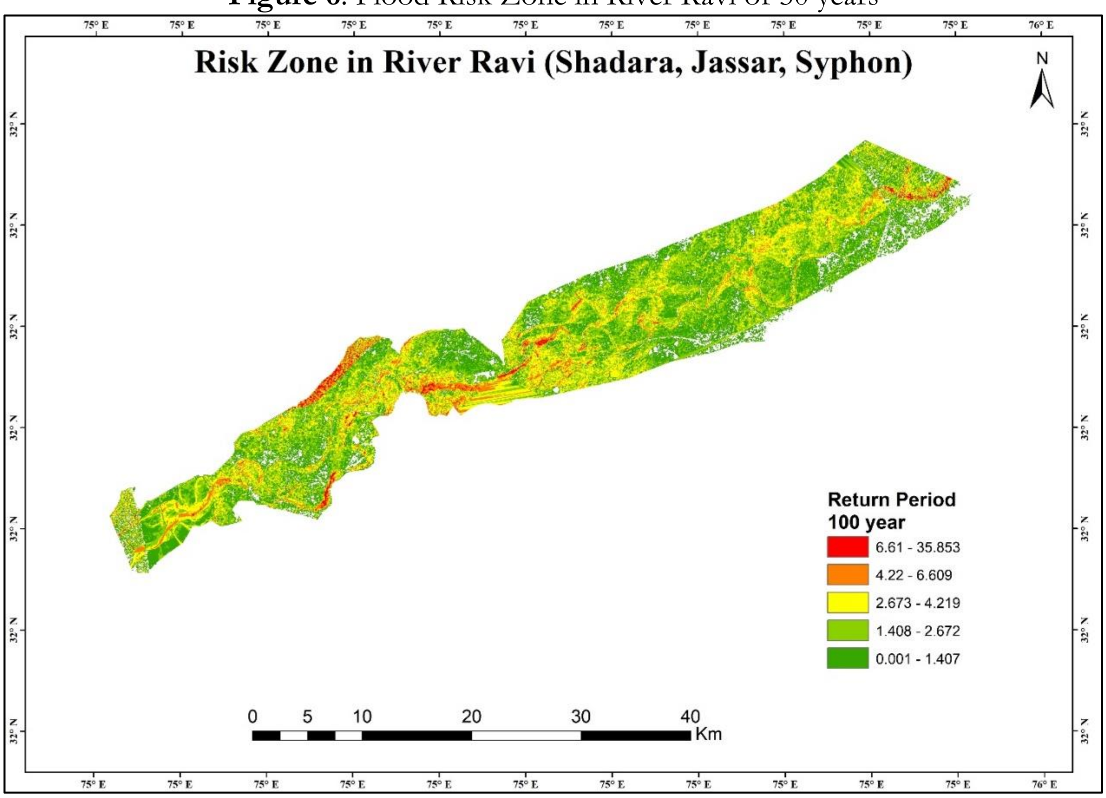


**Figure 7**: Flood Risk Zone in River of 100 years

In Figure 7, the land use map of flood-prone areas, the flood risk map for a 100-year return period, and flood mapping for various risk assessments are presented. The land use map includes elevation details, with different shades representing water depth classes and other colors indicating maximum damage in units. Flow charts show gauges used as reference points. The results are self-explanatory and applicable for further research. The figure demonstrates that the flood risk for a 100-year return period is not significantly different from that of a 50-year return period due to the relatively low water levels in this area.

- **Green:** Represents a very low-risk zone, with probabilities ranging from 0.01 to 0.14. This risk level predominates in our study area and can be managed effectively.
- **Light Green:** Indicates a low-risk zone within the river boundaries, with ratios between 1.48 and 2.67. This risk level is manageable and unlikely to cause severe problems.
- **Yellow:** Denotes a medium-risk zone, with results generated using the Gumbel distribution and calculated based on the Manning procedure.
- **Orange:** Shows a high-risk zone with ratios between 4 and 6. This risk level is not prominent in our area and does not typically result in serious issues.
- **Red:** Represents an extremely high-risk zone based on calculated ratios. This is not a significant concern in our area and can be managed with simple measures.

Farmers and residents should be educated about these risks and provided with strategies to mitigate damage from riverine floods.

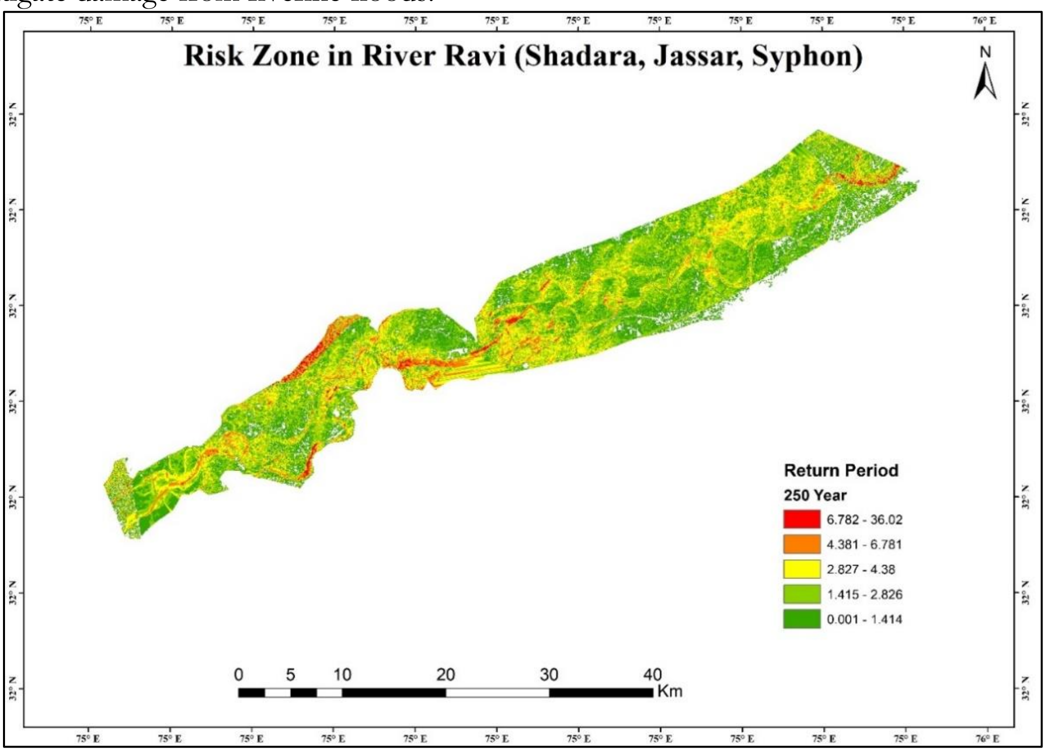


**Figure 8**: Flood Risk Zone in River Ravi of 250 years

Figure 8 displays flood-prone areas, including hazard maps for a 250-year return period. The map categorizes risk levels with varying color tones, representing the extent of maximum damage in units. The flow chart integrates all necessary data for comprehensive analysis.

**Green:**

Represents an extremely low-risk zone as depicted on the map. The scale and ratios used for risk mapping are consistent across the 50, 100, and 250-year return periods, indicating that the risk is manageable. The green color signifies a very low-risk area, with zonation based on established classes and standard color schemes.

In our study area, while the risk is very low, it is crucial to implement measures to manage riverine floods, which can damage crops and disrupt lives. Residents, especially in Shahdara, live along riverbanks and are thus vulnerable to changes in river flow. The primary focus is on assessing the potential impact on their lives, given their reliance on agriculture and the consequences of disruptions to their daily routines.

**Return Period:**

**Table 1**: Probability of Flooding and Return Period

| | |
|---|---|
| 1% Chance | 100 Years |
| 0.25% Chance | 250 Years |
| 0.5% Chance | 50 Years |

**Results Overview:**

The major results based on the implemented methodologies are as follows:

- **100-Year Return Period:** The probability of flooding is relatively low, calculated at 1%.
- **250-Year Return Period:** The probability decreases further to 0.25%.
- **50-Year Return Period:** The chance of flooding is approximately 0.5%.

These results were classified into three zones and assigned percentages according to the equations used. Achieving these findings involved considerable effort and precision.

Figure 9 illustrates the flow direction in the Ravi River study area. The initial area was selected, and the flow direction was measured using various tools in ArcGIS. The primary objective was to identify the area used in deriving the final results. The map is designed to be self-explanatory.

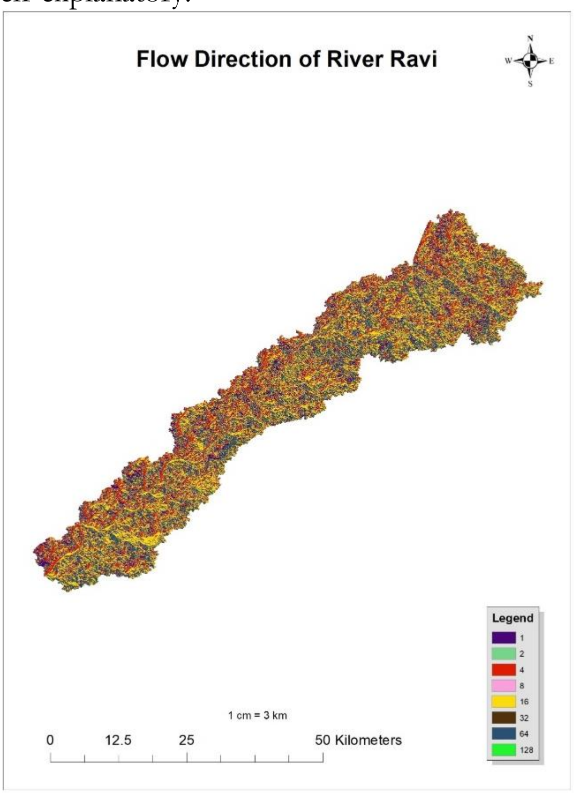


**Figure 9**: Flow Direction in Targeted River Ravi Catchment

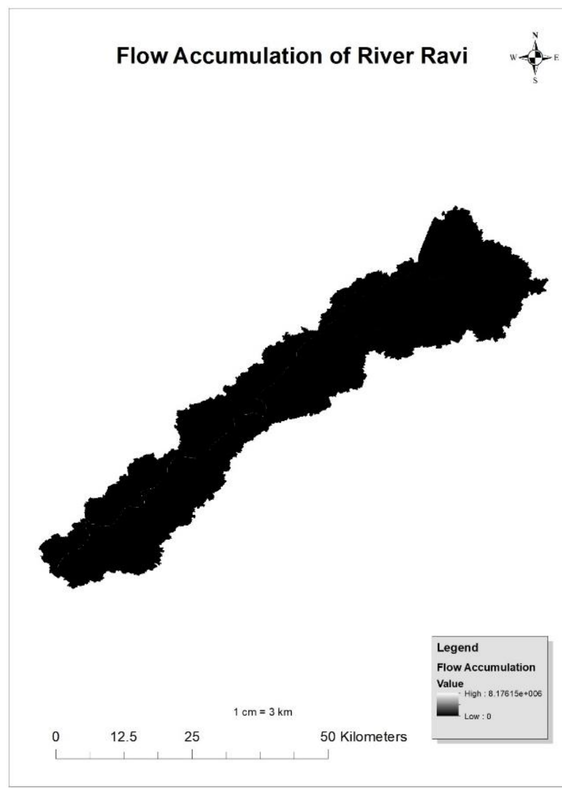


**Figure 10**: Flow Accumulation in Targeted Ravi River Catchment

Figure 11 displays the stream order for the selected area within the Ravi River watershed. The watershed encompasses all water bodies, and a query was applied to enhance visibility by increasing the value for a clearer view. This higher value ensures precise measurement of the watershed. The blue line outlines the total watershed within our study area and highlights the tributaries of the Ravi River.

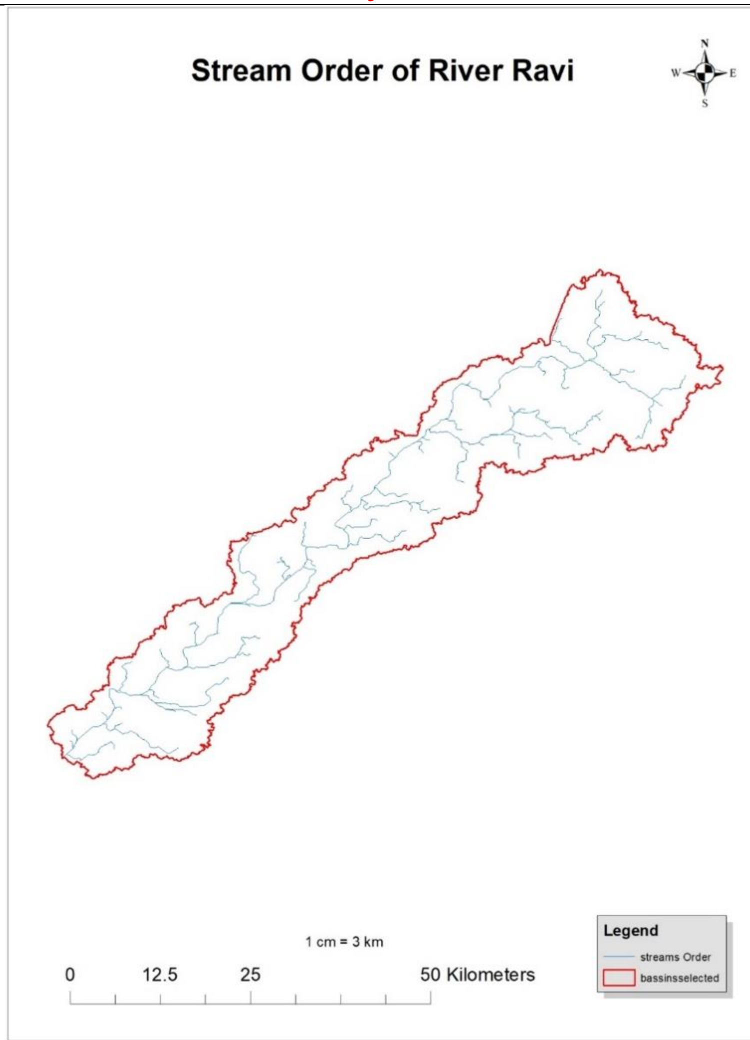


**Figure 11**: Stream Order in Targeted Ravi River Watershed

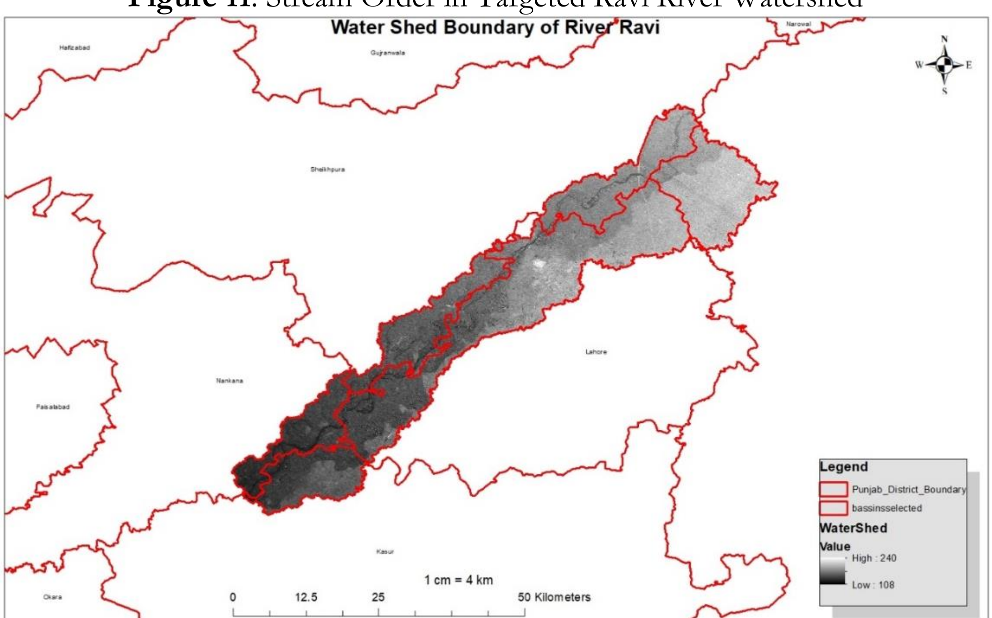


**Figure 12:** Watershed Boundary

Figure 12 illustrates the watershed overlaid with district boundaries. The watershed was first calculated, followed by the addition of district boundaries for enhanced clarity. The final layout showcases both the watershed and district boundaries, with values categorized in the legend as High and Low.

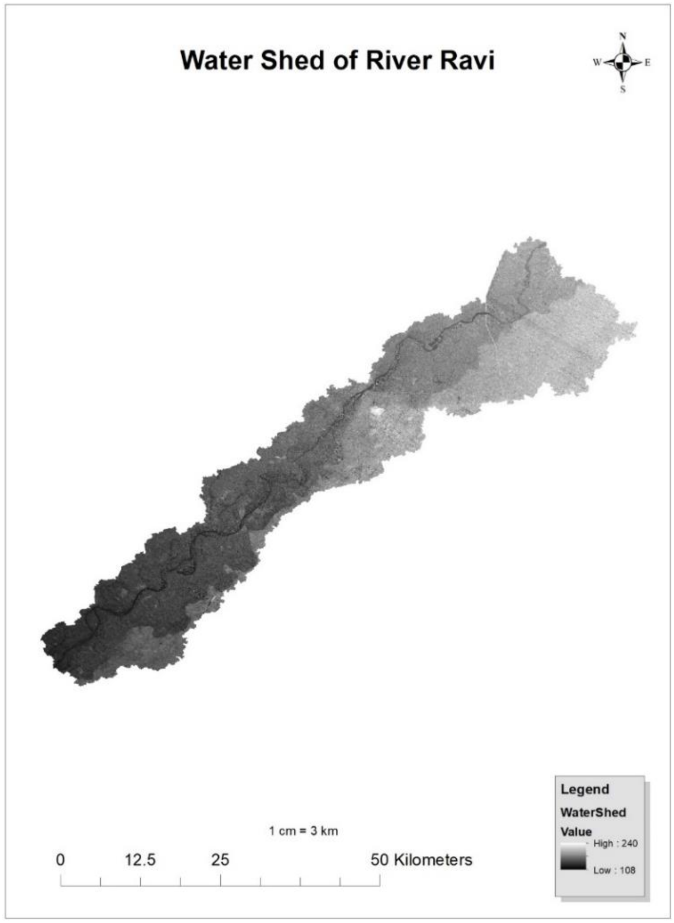


**Figure 13**: Watershed Map

The watershed map highlights values categorized as high and low, with the highest value recorded at 240 and the lowest at 108. These values are detailed in the legend and are represented accordingly on the map.

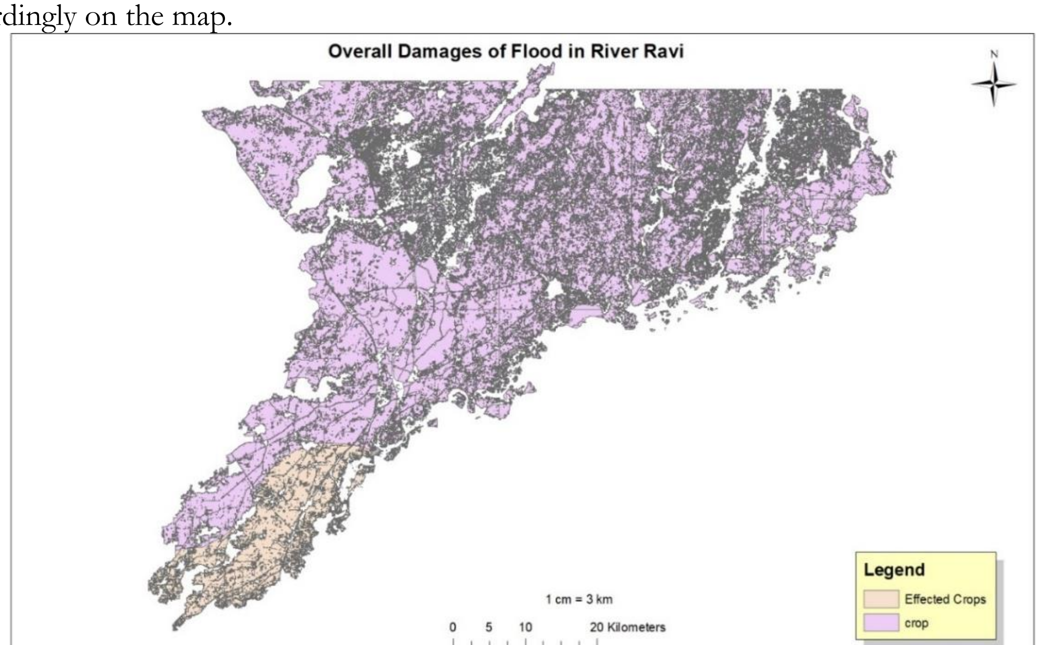


**Figure 14:** Affected Crops

**Discussions:**

Figure 14 illustrates the total area of crops affected by riverine flooding. Crop data, obtained from the Soil and Fertility Department, was classified using the Gumbel distribution. A 5 km buffer along the river was applied to assess potential impacts on crops. The results indicate a significant impact, with substantial areas affected. Even minor changes in pH or sediment deposition can greatly affect crop health. The attribute table provides detailed values, showing that major crops, particularly wheat and rice, are notably impacted. Rice, which depends on water, suffers from reduced fertility due to siltation in river water. The high level of affected crop area reflects both past decade records and future projections. Without effective management, soil fertility loss could severely impact vegetation along the riverbanks.

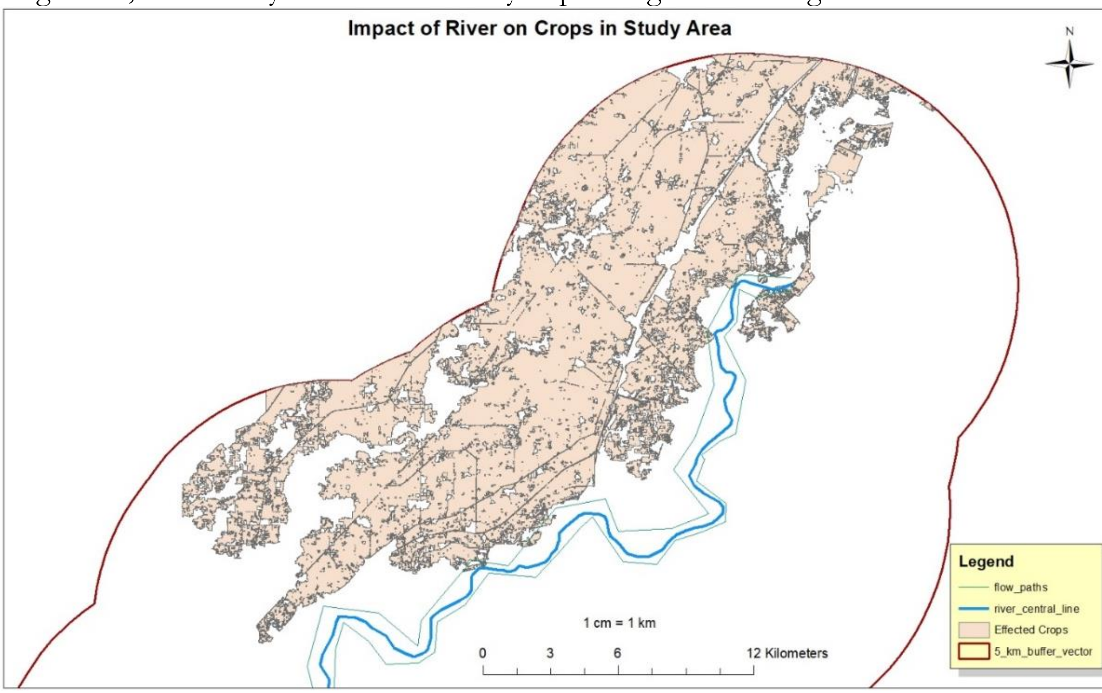


**Figure 15:** Impact of Crops in Study Area

Figure 15 illustrates the impact of riverine flooding on crops. The analysis indicates that floodwater, which often carries debris, can severely damage crops due to their sensitivity to impurities. Using the Manning procedure, we calculated the total affected area as 24,000 hectares, with the most severely impacted area being 240 hectares. The extent of the damage is detailed in the pre- and post-flood classifications. Recent tile analysis reveals a significant decrease in water bodies and an increase in barren land.

Dynamic models were used to realistically simulate flood-affected areas. We merged all polygons and applied a 5 km buffer to the study area, focusing mainly on Narowal and Shahdara. Managing this area proved challenging due to the sensitivity of crops to even minor water layers. Population safety is ensured by embankments and low water levels. After merging polygons and applying the Manning procedure, the results were accurate and useful for various authorities. Given that agriculture is a major livelihood, effective crop management and farmer training are essential.

**Conclusion:**

Rivers frequently overflow during heavy rainfall in upper catchment areas. This study employs HEC-RAS, a 1D and 2D mathematical model, to simulate these catchment areas and evaluate the impact of riverine floods on crops. Return periods were determined using the Gumbel distribution and Manning's coefficient, with a focus on their effects on crops and associated uncertainties in flood damage and losses. Data from the Irrigation Department, analyzed with HEC-RAS, indicates a 1% chance of flood impact on crops over 100 years. The probability decreases to 0.25% over 150 years and remains low at 0.5% over 250 years. These calculations, grounded in rigorous techniques and historical data, suggest minimal flood effects on crop patterns. Precautions and awareness programs are in place to further mitigate potential damage.

**Policy Recommendations**

Based on the findings, the following measures are recommended to improve flood modeling and management, particularly in vulnerable urban and rural areas:

- **Construction of Dams:** Implement dams for controlled water release to mitigate flood impacts.
- **Conduct Surveys:** Regular surveys in flood-prone areas to monitor and manage risks.
- **Farmer Awareness:** Educate farmers on preventive measures to protect crops from flooding.
- **Government Funding:** Allocate funds for rehabilitation and flood management efforts.
- **Install Meteorological Radars:** Set up radars for accurate flood measurements and forecasts.
- **Public Awareness Programs:** Increase awareness programs to help people protect their crops.
- **Further Research:** Continue research on the Ravi River to monitor water table changes and their effects on crops.

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