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FLOOD INUNDATION HAZARDS OF THE RIVER CHENAB USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM

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Abstract
This research offers an extensive examination of flood inundation using Geographical Information System (GIS) techniques. This innovative research aims to provide more effective flood hazard mitigation strategies for the River Chenab region. The main objective was to integrate inventive geo-innovation approaches into flood risk reduction. We conducted a comparative analysis of flood inundation mapping techniques employed in this study with those used in four other countries. Utilizing GIS techniques for this flood analysis, our study predicted varying degrees of flood risk, ranging from high to moderate. We focused on 21 districts in the Punjab Province, covering an area of 119,853 km², which are closely connected to the River Chenab and susceptible to flooding. In 2016, these districts experienced flooding affecting an area of 7,867 km². After precise calculations, it was determined that the proportion of affected area during flooding was 6.56%. Furthermore, our research pinpointed areas at high risk of flooding, primarily those in close proximity to the River Chenab's floodplain. We also conducted scenario-based assessments to establish time lags between precipitation in the catchment area and subsequent flooding in Pakistan. We have proposed a range of mitigation strategies based on available resources and topographical features identified in our flood risk analysis. These recommendations can serve as a comprehensive framework for flood hazard reduction efforts and their implementation.

INTRODUCTION

Flood is the natural phenomenon that mostly occurred in rainy season, summer, monsoon, and bursting of dam. However, the humans also influenced the natural activities/ process i.e., deforestation, fragile mountain system, and alternatively emission of greenhouse gases and global warming may cause uneven flooding [14]. The magnitude and recurrence of flood disasters may also associate with season, time, and climatic condition [43,37,38] and is significant for flood risk executives and reduce the disaster intensity [4,15] In Pakistan, the intangible loss i.e., humans in 1950s flood was 2910, 1977- 248, 1992- 1834, 1993- 3048, 2003-178, 2007-593, 2010 1961, 2012-455, 2016 153, and 2019- 140 deaths were reported [39,3,1]. The risk is often endorsed to climate factors and the size of the economy in quantitative studies of the chronological evolution [42,45,43].

Floods are the most often happening and harming normal dangers all the world. Almost 90% of the public is affected and exposed to flooding [40]. One of the significant prerequisites of flood debacle the board is the ongoing checking of most extreme flood degree for taking up the quick reaction, short-and long-haul recuperation, and future alleviation exercises ". [44] Considered in the show they demonstrate the seriousness of inundation as well as its flow in reality The flood risk can be assess through various methods i.e., intensity, magnitude, quantity of water, hazard, flood mapping, exposure frequency and deaths [22]. The flood risk is more in the urban areas as compared in the rural areas because of infrastructure, huge number of populations, poor water channels, waste debris, blockages of canals and poor disaster management [32]. The prediction of flood is also important for identification of flood risk and hazard, proposed flood severity and frequency, intensity and loss of agricultural land and crops. For the flood predication a number activities/ process is involved such as flood frequency, intensity, type of flood, rainfall, dams, channel work, flood and blockades that warren and help in designing framework to reduce the flood intensity [12]. Flood involvement planning is tied in with showing occupied regions in view of the rise in water level prompted by precipitation, discharge, or other related plans. [29, 27]. Thusly, flood involvement planning is fundamental through all periods of the disaster risk the executives' cycle, key between them readiness, anticipation, recuperation, and recovery [35,37,20]. Today, PC innovation has expanded access to hydrological information, including precipitation, height, land use along with the land cover, in this manner developing the submission of statistical flood demonstrating methodologies [21,23]. The effective, straight forwardness and admittance to solid flood risk guides and information with which to work on open mindfulness and comprehension of flood hazards agree with a current pattern and ecological models [11]. Creating spatial-based innovation, which incorporates remote sensing and GIS, has advanced the valuation of flood grades through the satellite imagery. A few examinations, for example, [33,9,15] have assisted the study of flood inundation planning through the satellite pictures and surface rise information. In different spots, geospatial information is retrieving either over the top expensive or requires partners with specialized expertise to process and utilize [7]. By and large, riverine flooding and blaze flooding along flood fields stand out.

That extreme damages by floods or landslides could be the reason of strong, short-lived storm cells which range few kilometers is pinpointed by recognizing for higher spatial and chronological resolution data. Any loss of resolution in the hazard or exposure data sets tends to unintentionally capture these objects within the inundated floodplain [40]. Inundation demonstrates there are many times significant vulnerabilities in deciphering the genuine degree of inundation from satellite information as a result of the varieties in backscattering and picture dots that can emerge from highlights like waves and rising designs and vegetation [31]. Similarly, the river Chenab is also one of the important tributaries of Indus River located in the western region of Punjab Province, where a number freak flood occurs every year. This river originated from Jammu Kashmir and then enter into Punjab flood plain areas. By observing heavy and freak flood in River Chenab every year which causes various tangible and intangible losses. Therefore, the current study was carried out to explore the flood inundation and flood plain through GIS. The study is also interested to design framework for the flood flow and risky zones throughout the river Chenab.

Flooding accounts for approximately 40% of all global natural hazards and is responsible for half of all fatalities resulting from natural disasters [43]. Over the past decade, various methods have been developed to simulate and analyze different types of floods and inundations. An essential parameter in these simulations is the Manning roughness coefficient, which comprises both a river-specific component and a land cover component within flooded areas.

Geographical Information System (GIS) has emerged as a highly effective tool for assessing flood risk in flood-prone regions. Recent advancements in GIS technology have demonstrated its ability to integrate various established techniques and factors for flood risk prediction [34]. These advancements provide valuable insights into the severity and spatial-temporal distribution of flooding. In essence, presentation markers offer specific information about the potential risks to various elements at risk [5]. While the extent of inundation is not typically a direct output in flood routing models, it is often indirectly estimated through predictions of water surface elevation, flow depth, or stored volume within specific model elements.

This research leveraged GIS effectively to conduct its investigation into flood risk, aligning with the best practices in the field.

1.1 Flood Inundation Mapping in Pakistan

The recurrence of floods in Pakistan, particularly during the years 2010-2014 and 2015, indicates that flooding has become a recurring phenomenon in the country. The lack of effective coordination among the organizations responsible for flood management, partly due to technical limitations such as the fragmented early warning systems, disaster preparedness measures, emergency response, and essential flood relief measures, has exacerbated the situation [1, 6, 19]. Floods in Pakistan are primarily triggered by concentrated and sometimes amplified precipitation, often exacerbated by snowmelt resulting from hot weather conditions. These events have led to significant financial losses, with Pakistan experiencing a total financial loss of over US$ 39.165 billion in recent years [28]. During 22 major flood events, approximately 12,178 lives were lost, nearly 198,230 villages were damaged or destroyed, and an area of almost 616,599 square kilometers was affected. The floods in recent years have been the most severe in the past 81 years in the region [35, 37].

Surprisingly, there has been a lack of research on assessing flooding using spatial analysis specifically in the Chenab River region in Punjab, Pakistan. This section explores the implications of inundation and flood submersion, shedding light on the methodologies employed in this study [15]. Additionally, we delve into some theories related to individual stress coping mechanisms in the context of flood inundation. "Rainfall in the country exhibits high spatial variability, with 59.3% of the total area classified as rangeland, receiving less than 200 mm of annual rainfall" [40].

1.2 Flood Protection Facilities in Pakistan

The current flood management strategy encompasses the regulation of flood flows through the operation of three major reservoirs, namely Tarbela, Chashma on the Indus River, and Mangla on the Jhelum River. Additionally, it includes the safeguarding of critical private and public infrastructure, urban and rural settlements, and adjacent agricultural lands situated along the riverbanks through the construction of flood embankments, spurs, and other relevant interventions. Furthermore, the strategy involves the implementation of a Flood Forecasting and Early Warning System, as well as the coordination of rescue and relief measures during flood situations [3, 40, 43]. The Provincial Irrigation Departments (PIDs) are responsible for maintaining approximately 6,807 kilometers of flood protection embankments and around 1,410 spurs along the main rivers and their tributaries. A breakdown of these existing flood protection facilities by province is provided in the table below:

Table 1: Existing Flood Assurance

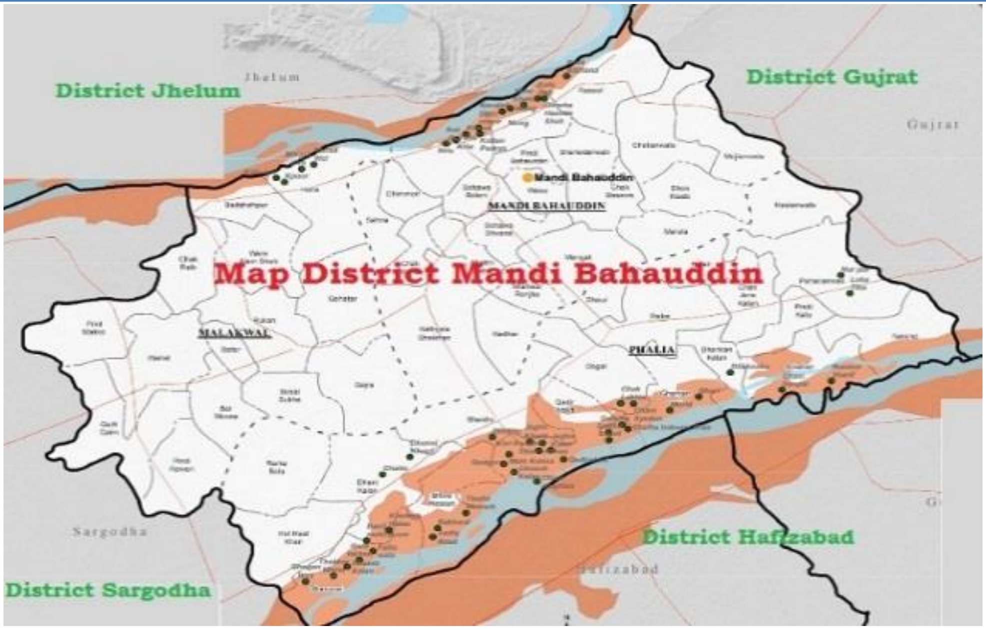
Pakistan's Province	Dikes	Spurs (No.)
Punjab	3,440	498
Sindh	2,399	49
Kyber Pakhtunkhwa	360	189
Balochistan	699	687
Sum	6,898	1,423

(**Source**: Ministry of Water and Power)

1. MATERIALS AND METHODS

2.1 Study Area

The Chenab River is a significant waterway that traverses both India and Pakistan, primarily located in the western part of Punjab province. It spans from 30°8' to 32°40' N latitude and 73°36' to 73°37' E longitude. The central towns of Phalia and Malikwal within the tehsils are situated at distances of 22.5 and 28.5 kilometers (approximately 14.0 and 17.7 miles) from Mandi Bahauddin, respectively. The total area covered by this region is 2,673 square kilometers (1,032 square miles). The study encompasses the localities of Mandi Bahauddin, Phalia, and Malikwal Tehsils.



The Chenab River originates in the Kuloo and Kangra regions of Himachal Pradesh, India. The two principal rivers contributing to the Chenab—the Chandar and the Bangar—originate at an elevation of nearly 16,000 feet. These rivers converge at Tandi in the state of Jammu and Kashmir. Along its lengthy journey from its headwaters, the Chenab River is fed by numerous tributaries, gaining significant volume before reaching the Kashmir region. It enters Pakistan near Sialkot, in proximity to the village of Diawara.

Fig 1. Location map of River Chenab and associated flood plain areas in the Punjab province

Within the Punjab province's alluvial plains, the Chenab and Jhelum Rivers converge at Trimmu. Sixty-four kilometers beyond Trimmu, the river maintains its direction. Upstream, at Punjnad, the Satluj River merges with the Chenab. The following are among the river Chenab's key features: Marala, Khanki, Punjnad, Trimmu, and Qadirabed Barrage; Marala–interface Canal. Up River of Marala Barrages, India has built Salal Dam in Jammu around 41 miles. Identifying the pathway to fresh equations for rapid two-dimensional flood modeling was accomplished via the urban template.

2.2 River Chenab Flood Plain Areas

The surging floodwaters from the River Chenab have inflicted immense destruction upon the rural districts starting from Marala Headworks. This deluge has not only breached roads but has also inflicted damage upon several structures and facilities. The onslaught of this high-water surge has also begun affecting the regions of Kashmir and Punjab.

Flood plain Area District	Latitude and Longitude
Sialkot	32.49 ºN, 74.53ºE
Gujrat	32.57° N, 74.07° E
Gujranwala	32. 9° N and 74.11° E
Muzaffargarh	30.07° N, 71.18° E
Chiniot	31.72 ºN, 72.98ºE
Hafizabad	32.07ºN,73.68 ºE
Mandi Bahauddin	32.58 ºN, 73.49 ºE
Khanewal	32.42 ºN,73.57ºE
Jhang	31.26° N, 72.31° E

Faisalabad	31.41°N, 73.07° E
Lodharan	29.68°N, 71.66° E
Multan	30.19°N, 71.46° E
Sargodha	32.08° N, 72.67° E
Dera Gazi Khan	30.03° N, 70.64° E
Toba Tek Singh	30.33° N, 72.08° E
Jalal Pur Jattan	32.64ºN,74.20ºE

Table 2: Geographical position of Flood Inundated area's

2.3 Methods

The accessibility of satellite data for remote sensing (RS) and the development of strategic policies have significantly expanded the utilization of GIS and RS in Preparing flood vulnerability maps is an important task. As a result, different modeling methods have been put forward to assess flood disasters. Wide-ranging applications have been discovered for GIS and RS techniques in flood analysis [33, 6, 10].

Additional data sources included Shapefiles with information on regions, towns, major roads (G.T. roads), settlements, channels, and areas affected by floods, all for this purpose. The study area's different layers of information were created using a geographical map as a base, including administrative boundaries, rivers, land use, and land cover regions. Point shapefiles containing town names were among the files acquired from the Urban Planning and Development Unit, along with polygon shapefiles of main channels, rivers, and distributaries.

Employed to assess flood risk near rivers in areas prone to flooding, the GIS method shows robustness in Pakistan. By leveraging a DEM as input, tools such as stream direction, flow accumulation, and channel networks were developed within the ArcGIS ecosystem using Arc Hydro tools. Measurements of discharge and stage obtained through hydraulic methods serve as suitable data for flood inundation modeling, along with inundation extent data gathered through ground surveys and aerial photography, as well as satellite images.

Outdated techniques for design flow estimation and reliance on 1D modeling are common issues in current flood assessment methodologies. By employing unit hydrographs (Dawood, G. et al., 2011), GIS technology has been leveraged for flood management.

Data pertaining to geographical features including boundaries and divisional markings. On maps, data concerning towns, rivers, canals, and other components is shown alongside geographical feature boundaries and divisions. Providing insight into flood events, the map displays flood-prone areas and flood flow. The maps were created at a scale of 1: A Digital Elevation Model was employed to identify flow direction, flow accumulation, and flow paths across a span of 100,000 km. Categorized according to their features, the study area is divided into 15 sub-regions, all connected to the River Chenab. Flow patterns within regions are visualized through Figure 3, highlighting boundaries, towns, affected areas, principle channels, branch embankments, and inhabited regions. Areas of flood extent are depicted in various representations.

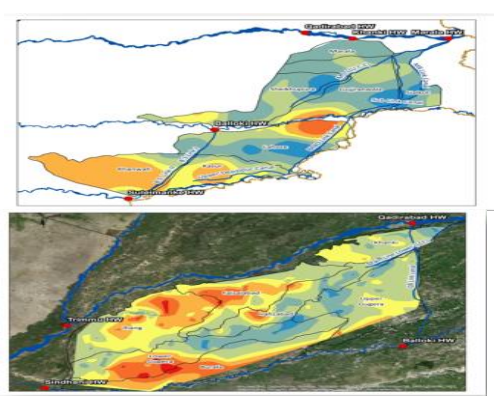


Figure 3: Zone Streams

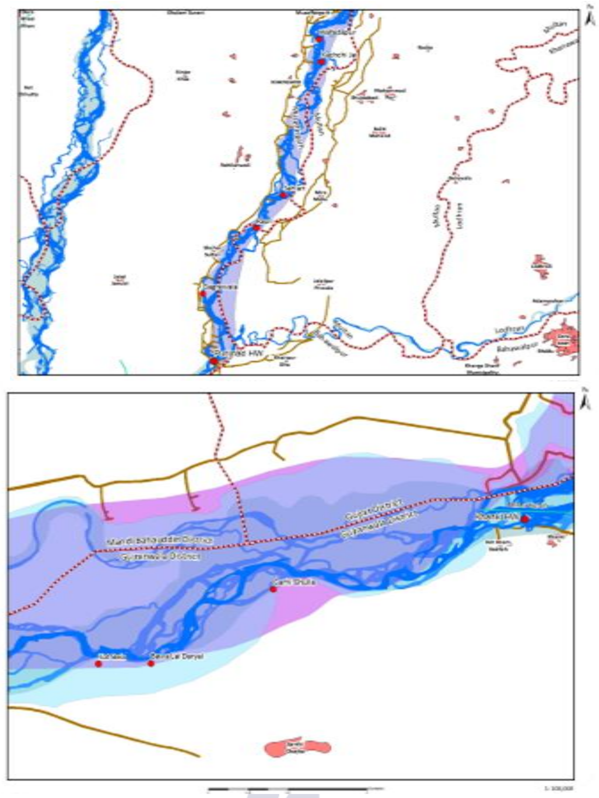


Figure 4: Maps showing the flow direction, flow accumulation and flow fill

2. RESULTS

In my research, I focused on creating comprehensive maps that cover nearly the entire region along the River Chenab. These maps serve a dual purpose: to provide a detailed overview of the River Chenab's extent and to pinpoint areas susceptible to flooding. The Punjab Province comprises a total of 36 districts, covering an area of 205,344 km². For this study, I specifically selected 21 districts closely linked with the River Chenab, known to be prone to flooding. These 21 districts collectively occupy 119,853 km² of land. During the 2016 flood event, approximately 7,867 km² of this area was affected, accounting for 6.56% of the total area.

To validate the accuracy of my flood risk assessment for these districts, I conducted an analysis of the 2016 flood inundation. The analysis revealed that out of the 130 settlements in Punjab, 35 were impacted by the flooding. I proceeded to calculate the affected areas of these settlements using ArcGIS tools, generating shapefiles representing various polygons. By merging these flood polygons with the respective districts, I obtained the final results.

Furthermore, I also conducted an analysis to identify time lags based on different scenarios. This analysis aimed to determine the intervals between precipitation events in the catchment area and the occurrence of flooding in various regions of Pakistan.

Overall, the maps I created provide a comprehensive overview of the entire River Chenab region and serve as valuable resources for assessing the extent of the river and identifying areas at risk of flooding. In summary, Punjab Province, with its 36 districts covering 205,344 km², saw 21 selected districts with a close connection to the River Chenab, totaling 119,853 km² in area. During the 2016 flood, 7,867 km² of this region was affected, constituting 6.56% of the total area.

3.1 Flood Affected Regions Graphical Portrayal

After shape records quality table sent out and diagram drawn between complete locale region and flood affected region. The accompanying visual chart created. In 2016 flood incredibly impacted areas were Jhang, Toba Tek Singh, Chiniot, Mandi Bahauddin, Sialkot, Dara Ghazi Khan, Hafiz Abad, Nankana Sahib, and Khanewal are shown in graph.

3. DISCUSSION

As evident from the maps, it becomes apparent which regions and their associated settlements bore the brunt of the flood's impact. It is also evident which areas in Punjab have been repeatedly struck by flooding, highlighting their vulnerabilities. After careful examination of the maps, three specific regions were identified as being highly susceptible to floods: Mandi Bahauddin, Chiniot, and Hafizabad.

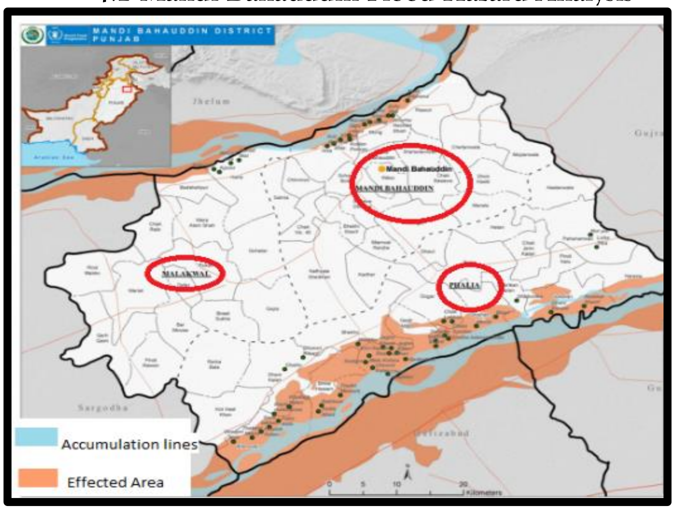
4.1 Chiniot Flood Hazard Analysis

In the provided figure depicting Chiniot, it is evident that the flow accumulation lines exhibit weakness, which explains why the Chiniot district was susceptible to flooding. This observation is further substantiated by the maps, which clearly indicate that the Chiniot district experienced flooding in 2016 [40]. This particular district is situated to the northwest of the River Chenab, and the impact is particularly pronounced in three tehsils: Chiniot, Lalian, and Bhawana, as highlighted by the red circles on the map [21].

Chiniot Flood Hazard Analysis

Total area of Chiniot =2643 km²
Effected area of Chiniot by flood = 687 km²
% damaged area =26 %
Total population of Chiniot = 965124
Population affected by flood = 45000
% effected Population =46.6%
Number of Villages affected=148

4.2 Mandi Bahauddin Flood Hazard Analysis



Accumulation lines are shown weak in the given figure of Mandi, this is the reason of floods in Mandi Bahauddin district. It's clear in the maps that Mandi Bahauddin district is really affected in 2016 by flood [7,11]. The height of the district above the sea level is 220 meters and River Chenab is 39 km away in the south. 3 tehsils of the district effected Mandi Bahauddin, Phalia and Malikwal

Table 3: Effected area and population of Mandi Bahauddin District

Total area	2673 km²
Effected area	545 km²
damaged area %	20.39 %
Total population	1160552
Population effected by flood	35000
% population effected by flood	3,0 %
Number of villages effected	104

This proposed flood inundation framework offers a promising solution to mitigate flood risks in the affected areas. In order to effectively address these risks, it is imperative that the flood monitoring system be both swift and applicable, as underscored by previous research [1, 3, 9]. When we compare the extent of flood damage in the past with the results of the present study, it becomes evident that the damage has decreased significantly. This reduction can be attributed to the government's concerted efforts to safeguard land, property, infrastructure, livestock, and more from potential future floods through various flood monitoring applications and related projects.

The positive outcomes of this approach underscore the importance of flood control measures along the River Chenab, which were initiated a few years ago. This methodology has yielded favorable results, leading to a reduction in both the frequency and severity of flood events in the affected regions.

4. CONCLUSION

Floods are natural calamities, and we have limited control over their potential damage. We can acquire data beforehand to prepare, and we can reduce their disastrous effects when they occur. It's challenging to pinpoint specific areas at high risk of flooding in Punjab. However, from the results, it becomes evident that both the North and South regions in Punjab, Pakistan, face a significant risk of flooding.

These regions also happen to have higher population densities compared to other areas. While the eastern and western parts of Punjab have experienced flooding, their impact has generally been less severe. The "Provincial Disaster Management Authority (PDMA)" has taken the responsibility of formulating development guidelines on behalf of Punjab and also plays a vital role in providing flood warning systems.

Our conclusion can be divided into two phases:

5.1 Monitoring

The study we did tells us about the areas which are at high risk of flooding and also clear the accumulation lines which are weak and caused flooding in the related areas. Also tells about the situations of head works and if there is any development and change required to control flood so we can do the steps of safety measures to secure from floods.

5.2 Management

When a flood strikes an area, it becomes our responsibility to initiate safety measures promptly. These measures are crucial for securing the affected area and minimizing the level of damage, ideally implemented in advance or as soon as the flood event is detected.

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