Floods and Flood Hazard Assessment in the Floodplain of River Swat, District Charsadda, Pakistan

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This study aims to evaluate flood risks and carry out flood hazard assessment in the floodplain of the River Swat, District Charsadda. This study focuses on two objectives: primarily, to explore the flood situation in the study area, and secondly, to carry out the flood hazard assessment in the floodplain of the River Swat, District Charsadda. The study area is located 27 km north-east of Peshawar city. District Charsadda is part of the Peshawar valley, and the study area covers an area of 1,593 Km2. The gentle slope is from north to south, which plays a major role in making it vulnerable to recurrent flood events. In District Charsadda, the floodplain of the River Swat is highly vulnerable to recurrent flooding during the summer season. There is a lack of flood hazard assessment for management strategies. Therefore, to minimize the negative impacts of floods, flood hazard assessment and management strategies will help reduce the losses resulting from recurrent flooding. There is a need to identify the flood hazard trend in the study area and to generate the flood hazard zonation map. The data are collected from PMD, PIDA, WAPDA, and the Survey of Pakistan. A SPOT recent 2.5m resolution satellite image is used for land use data, and the SRTM data of 90m resolution is used for the generation of a contour map, DEM, and drainage pattern. From the collected data, a hydrograph is created and projected, and the frequency of flood recurrence is determined. To obtain a good picture of the occurrence of floods, the data were also connected with temperature and rainfall characteristics. The AHP method is used to develop a flood hazard zonation map, for which the probability and recurrent intervals of the flood hazard are calculated by using the 24-year data from 1998-2022, and graphed. This clearly shows the recurrence of the flood hazard with specific magnitudes. The physical parameters, including the discharge, amount of rainfall, and elevation data, are used to develop a flood hazard zonation map under a combination of five zones.

Keywords: Floods, Flood Hazard Assessment, Flood Hazard Zonation, GIS, AHP, Mapping

Introduction:

The environmental hazard becomes a disaster when it damages human life and property [1]. Floods often result in havoc to life and property. They can cause drowning, render people homeless, damage infrastructure, wash away standing crops, erode land, pollute drinking water, and spread diseases [2]. The American Planning Association has defined flood hazard as the probability of inundation, which poses a high risk to property, health, life, and expected floodplain assets and functions. Spatially, in terms of economic loss and extent, floods are considered to be the most damaging natural disaster [3].Pakistan is one of the eleven countries that are at high risk of hydro-meteorological induced disasters [4]. Floods are becoming more frequent and intense worldwide, and their effects are predicted to worsen as a result of climate change [5][6]. The EM-DAT (2001-2022) data reveal that during the 22-year time span, the country was hit by floods almost every year. However, the super floods of 2010 and 2022 were the worst in the history of flooding in Pakistan (Table 1)

Table 1. EM-DAT data showing fatalities and affected population (2022 & 2010)

Year	Start month	End month	Total deaths	No. injured	No. effected	Total effected
2022	June	September	1,739	12,865	33,000,000	33,012,865
2010	July	August	1,985	2,063,469	20,000,000	22,063,469

Source: EM-DAT, CRED / UCLouvain, Brussels, Belgium

Scientific research suggests that extreme precipitation events are rising, indicating that severe flooding occurrences will become more frequent in the future [7]. For this reason, it is time to think and plan effectively to mitigate or improve adaptation to climate change exacerbations. Flood hazard assessment is a key management strategy for minimizing the disastrous impacts of flooding. Flood hazard assessment is conducted by using the available data of the indicators, such as temperature data, rainfall data, data on the watershed, as well as the discharge data of the river body at certain gauge stations. All these forms of data together determine the potentiality of flood hazard. Flood hazard assessment serves as an important tool for hazard mapping and zonation in order to reduce the impacts of flooding on the areas to be affected in the future [8].

The development of maps based on previous flood hazards is necessary for the awareness of people regarding future floods. This mapping makes the populace prepare themselves both physically and mentally; however, these flood hazard maps must be transformed into risk maps to elucidate the economic and social losses or damages, thereby enhancing future protective measures. Flooding in the study area is the most devastating natural hazard, causing severe damage to agricultural production as well as infrastructural development [9].

Material and Methods:

The Study Area:

The District of Charsadda is situated 27 kilometers north-east of the main city district, Peshawar. It is bounded in the north by the District Malakand, in the west by the Mohmand Agency, in the east by Mardan, in the south by Nowshera, and in the south-west by Peshawar (Figure 1). Geographically, the District of Charsadda extends from 34° 02’ to 34° 27’ North latitude and 71° 28’ to 71° 55’ East longitude. The total area of the district is 1,593 Km2. Geomorphologically, the District of Charsadda is part of the Peshawar valley. Generally, the slope is from north to south, being steepest in the upper reaches, while least gentle in the south-central part of the district. The topography plays a crucial role in rendering it prone to such catastrophic disasters. As a result, floods frequently harm it.

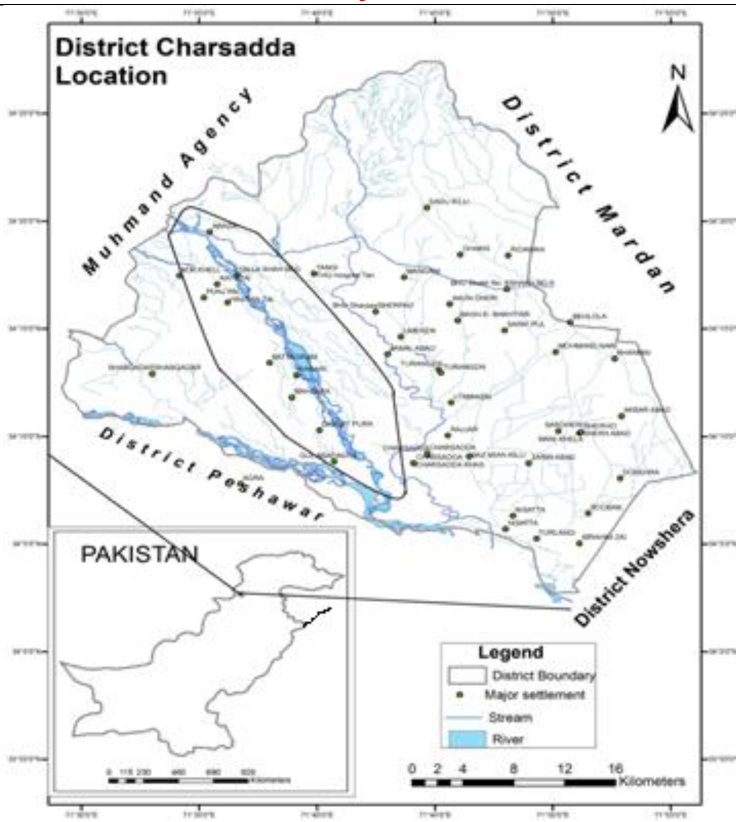

Figure 1. Location map of the District Charsadda

The River Swat in District Charsadda runs roughly 28 km from Munda Headworks to Khiali Bridge, reaching a relatively mild bed slope of 1 m in 210 meters with a gravelly bed (Figure 2). It has always encroached on private land and enlarged its cross-sectional area to an average width of about 900 meters. Downstream of Munda Headworks, the River Swat enters the Peshawar valley (District Charsadda), a gently sloping floodplain, where it braids into numerous channels and finally converges with the River Kabul at Garhi Momin at the southern edge of District Charsadda.

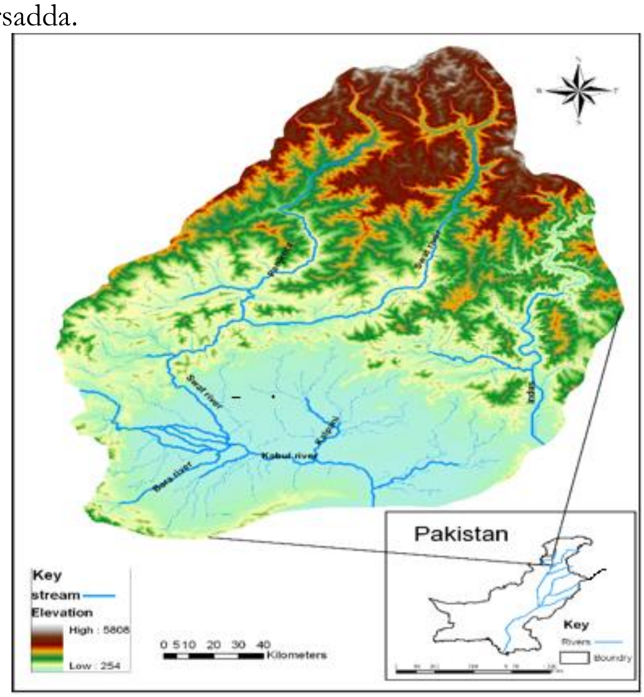

Figure 2. Elevation Model of the Drainage Basin of the River Swat

Data Acquisition and Analysis:

This study focuses on two objectives: primarily, to explore the flood situation in the study area, and secondly, to carry out the flood hazard assessment in the floodplain of the River Swat, District Charsadda. In order to achieve the stated objectives, data were collected from both primary and secondary sources. This section explains the tools and techniques used for the data collection. The research methodology, including data collection methods and tools, and the use of Geographic Information Systems (GIS) in flood hazard mapping for management are examined in this part (Figure 3). Additionally, the methodology outlines the data compilation and processing processes as well as the associated graphs. The secondary data acquisition and processing were done in the following ways:

Hydro-Meteorological Data:

In contrast to the River Swat's discharge data, the hydrological data comprised the study area's temperature and rainfall data. The Pakistan Meteorological Department provided the temperature and precipitation data for every weather station located in the headwater area of the River Swat. It was interpolated using spatial analysis. This interpolation was done using the spatial analysis tools followed by the interpolation technique in ArcGIS version 10.8. Additionally, discharge data were acquired from Surface Water Hydrology, WAPDA headquarters, Lahore, and the Provincial Irrigation and Drainage Authority (PIDA), Works and Services Department, Peshawar. Using the collected data, a hydrograph was created and projected, and the frequency of flood recurrence was determined. To obtain a good picture of the occurrence of floods, the data were also connected with temperature and rainfall characteristics.

Topographical Data:

Using topographical sheets of the entire drainage basin with a Representative Fraction of 1:50,000, drainage systems were created to prepare spatial databases. The information gathered from these topographical sheets was also used to create the elevation point map.

SRTM Data:

The Shuttle Radar Topographic Mission (SRTM) data of 90-meter resolution was also used. These data were used for the generation of the Digital Elevation Model and the drainage pattern of the study area.

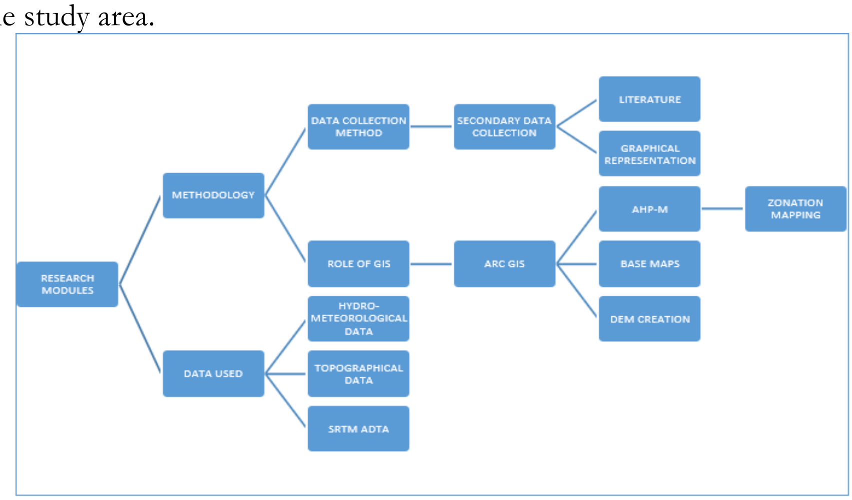

Figure 3. Research Process and Flow Diagram

In order to continue the investigation, the necessary data was a necessary first step. In District Charsadda, the floodplain of the River Swat is quite susceptible to frequent flooding throughout the summer. Significant harm is done to infrastructure, standing crops, and human and animal casualties nearly every year. There is a lack of flood hazard assessment for management strategies. Therefore, flood hazard assessment and hazard zonation mapping for management strategies will help reduce the losses resulting from recurrent flooding.

GIS Techniques:

The role of GIS cannot be neglected in the flood modeling field of research because, one platform that offers analytical solutions and various mapping and modeling techniques that can be used for floodplain planning and decision-making is the Geographic Information System (GIS). Moreover, GIS is a user-friendly system. It is a sensible platform for multidisciplinary databases of flood hazard assessment and mapping.

Analysis, Results, and Discussion:

The two terms, i.e., hazard and disaster, are sometimes used interchangeably for any natural phenomenon occurring, but, in actuality, there lies a difference between the two. A hazard is a natural event, such as an earthquake, tsunami, or drought etc., but it becomes a disaster whenever it results in damage to human life and property. According to the American Planning Association, any event, either physical or man-made, that can cause harm to human lives in terms of physical structure, socio-economic conditions, fatality, or casualties/deaths, etc., is termed a hazard. There lies a set of causative factors (natural or cultural), physical conditions, and different characteristics (such as magnitude and severity) that are responsible for the identification of the hazards. Three indicators describe the potential of the specific hazard. These indicators are as follows: 1) severity, 2) probability of occurrence, and 3) velocity (i.e., the speed of the hazard at which it occurs). A hydrological event that has the strength of causing damage to human life and property is called a flood hazard [10]. A hazard is considered to be the probability that is reached by a particular natural event with a specific threshold of intensity [11].

In Pakistan, the existing Flood Risk Management has been the result of a long history of flooding experience. According to [12], in Pakistan, there is a pressing need to understand the spatial discrepancies of natural hazards, which requires effective risk management in order to reduce loss of life and property. It requires both structural and non-structural measures. The structural measures include the construction of flood protection embankments and spurs. The non-structural measures include flood warning and forecasting, which are essential parts of an all-encompassing flood management program. Early warnings can prevent fatalities by allowing people to evacuate the flooded region, minimize damage to important structures by allowing preparations to be made beforehand, and notify authorities in charge of maintaining and running flood control facilities.

Real-time flood fighting is not included in flood management plans [13]. In order to route peak discharge at different critical breaching points from areas of high economic importance towards places of low socio-economic relevance, a standard flood preparedness plan must be developed as part of flood management planning. For this reason, the hazard zonation map is required, which is the graphical representation of flood characteristics along with the topography.

Morphological Setting of River Swat:

The River Swat is one of the eastern tributaries of the River Kabul and originates when the two rivers, i.e., the River Gabrial and the River Ushu, converge at Kalam in the Hindu Kush mountains towards the north of Pakistan. The river flows on its journey through two other districts, i.e., Lower Dir and Malakand, before it converges with the River Kabul in the District Charsadda near Nisatta. The total length of the river is approximately 200 miles from the place of its origin to its confluence with the main stream of Kabul. Munda Headworks are situated near Shabqadar Deri, approximately 35km northwest of Peshawar. The Headworks lie at 34°19' latitude and 71°34' longitude. The height of the Munda Headworks is some 368 meters above sea level. Two canals have also been taken out of the River, namely the Upper Swat Canal and the Lower Swat Canal. The total length of the two canals is 526 and 193 miles, respectively. The Upper and Lower Swat Canals together irrigate approximately an area of 16,000 acres (65,000 hectares).

Hydrological Setting of the Study Area:

Hydrologically, District Charsadda is drained by the River Kabul, the River Swat, and the River Jindai (Figure 4). From the headwater areas to the Munda Headworks (Charsadda), where the Swat River ultimately enters the Vale of Peshawar and converges with the Kabul River at Nisatta, the research area stretches. Before entering the Peshawar valley, the Munda Headworks were constructed at Munda. The mean monthly discharge at Munda varies from 15,000 cusecs to 100,000 cusecs depending on prevailing climatological conditions.

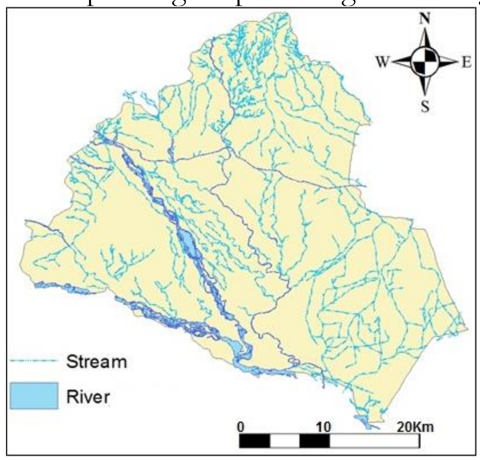

Figure 4. Hydrological Map of District Charsadda

Flood Hazard Assessment:

Floods, when they occur as a natural disaster, can be more devastating due to climate change. Globally, climate change is significantly altering hydrologic processes and climatic conditions, leading to an increase in the frequency of extreme weather events due to ongoing warming. [14]. Rainfall is significantly impacted by climate change, and its patterns become more unpredictable. It can be very rainy and prone to flooding in some places [15][16]. For this reason, flood hazard assessment for extreme flood events is important [17]. Effective mitigation measures and management based on future predicted climate require an extensive overview to make use of recorded data. This data includes the mean monthly rainfall concentration period, the topography, and the land use. These data help in forecasting and flood hazard assessment under future climatic conditions [18].

Hazard assessment is the process of identifying, analyzing, and evaluating natural or man-made hazards that could potentially cause harm to people, property, the environment, or livelihoods. Flood hazard assessment is essential to disaster risk reduction (DRR) as it helps stakeholders, planners, and local authorities to better understand and predict flood-related risks. It offers the framework for creating early warning systems, land use planning, and efficient mitigation techniques. Flood hazard assessment usually takes a multidisciplinary approach that includes historical, hydrological, meteorological, and spatial analyses. Conducting a comprehensive flood assessment requires detailed analysis of rainfall patterns, assessing previous flood occurrences, estimating flood frequency, and mapping river systems and low-lying areas. In summary, a flood hazard assessment provides a comprehensive understanding of flood risks by integrating statistical modeling, spatial analysis, and actual data. These assessments enhance communities' and local governments' ability to respond to flood risks and develop long-term resilience when incorporated into disaster risk reduction plans.

Flood hazard assessment is conducted by using the available data of indicators, such as temperature data, rainfall data, data on the watershed, as well as the discharge data of the river body at certain gauge stations. All these forms of data together determine the potentiality of flood hazard. Flood hazard assessment serves as an important tool for the modeling of the risk zones [19]. The assessment of flood hazard is an important component of flood modeling, and it requires the historical data of flood occurrences. This flood hazard assessment leads to important information required for the risk assessment, i.e., the spatial distribution of the areas to be affected in the future by the floods [8]. Maps based on past flood hazards must be created to raise public awareness of potential future floods. This mapping helps people prepare emotionally and physically, but in order to improve the protection mechanisms that will be used in the future, these flood hazard maps need to be transformed into risk maps. This will give a clear image of the economic and social losses or damages [20].

Flood Hazard Zonation Mapping:

The present research has focused on the development of an independent hazard zonation map for the floodplain of the River Swat, District Charsadda. This required both the physical and the social factors in order to develop the comprehensive zone-based map. Such maps are created using various analytical and decision-making procedures. The Analytical Hierarchy Process (AHP) was employed for the assessment and creation of the flood zonation maps. The values for each factor were first determined using this procedure. Following summation and division of these calculations, the resulting values were ultimately given a weight. The employment of this AHP modeling was assisted by a few specific parameters. The physical parameters included the climatological/hydro-meteorological data. The methods that were employed using the AHP method were also more logical and efficient. To create the necessary maps, these AHP-method techniques were combined with ArcGIS procedures.

AHP Method for Flood Hazard Zonation Mapping

Flood hazard is defined as a hydrological occurrence that has the potential to cause harm to both human life and property [10]. Three factors influence this flood hazard, which help to explain its severity and magnitude. These criteria include the likelihood that the hazard will occur, its severity, and the speed at which it occurs.

Parameters for Flood Hazard Zonation Mapping:

Drainage System:

The entire drainage basin of the River Swat and its significant right-hand tributary, Panjkora, which flows through the Hindu Kush Mountain range in northern Pakistan, are the main subjects of this study (Figure 5). The drainage basin of the River Swat covers an area of about 14,000 km2. The River Swat takes its origin from the Ushu and Gabral streams, originating from the glaciers of Swat-Kohistan. The two streams merge close to Kalam and become the River Swat downstream. After that, it flows south through a small gorge until it reaches Madyan [21]. However, downstream from Madyan, the river enters a broad valley and meanders and braids into numerous distributaries. Throughout the course, the River Swat receives several tributaries from both left and right banks. Gahil and Mankial (near Kalam), Daral (at Bahrain), Chail (near Madyan), Barnai, Arnowai, and Jambil are the prominent ones.

Downstream of Amandara Headworks, the River Swat receives a right-hand tributary called the Panjkora River just a few kilometers upstream from Munda Headworks. The eastern Hindu Kush mountains' Dir-Chitral and Dir-Swat are part of the catchment region for the River Panjkora, which flows through the center of the Dir Valley. The River Swat flows through the middle of the Swat Valley between the Dir-Swat and Swat-Kohistan. Bank erosion is a consistent problem.

In the District of Charsadda, both natural and artificial networks of water channels exist. The River Kabul follows the southern boundary of the district and passes from north-west to south-east for almost 25 km. The Kabul River forms a physical boundary with the Districts of Peshawar and Nowshera in the south. Similarly, due to the District Charsadda's north-to-south slope, the River Swat flows through its western half in a nearly north-south direction. The River Swat flows into the district. A Headworks has been erected at Munda for flood control and water diversion for irrigation purposes, termed the Lower Swat Canal. Fluvial morphological features such as river training, meander formation, braided channel, and bars are seen along the entire course of the River Swat, which flows downstream of Munda Headworks in a gently sloping plain area in the District of Charsadda. Because the study area is a fertile area of the Peshawar Valley and is well-known for its productive agricultural output, it is densely populated, and human encroachment is a common occurrence in the Swat River floodplain. The southernmost point of the district is where the Swat and Kabul rivers ultimately meet. Similarly, the District of Charsadda is divided into two equal parts by the Jindai River, which rises in the Malakand hills to the north. It receives some seasonal torrents from both the left and right banks along its journey. The district's heavily populated area is traversed by the Jindai River. The river frequently experiences deadly flash floods. Major towns on the Jindai River's bank include Rajar, Charsadda Khas, Turangzai, and Utmanzai. Every time this dazzling river has flooded, it has severely damaged standing crops, communities, lives, and other assets. At the village of Prang, a few kilometers downstream from the site where the rivers Kabul and Swat converge, the river finally empties into the Kabul River.

The Provincial Irrigation and Drainage Authority (PIDA), Works and Services Department, Peshawar, and Surface Water Hydrology, WAPDA Headquarters, Lahore, provided the River Swat discharge data. The temperature data and precipitation data of the study area were obtained from the Pakistan Meteorological Department.

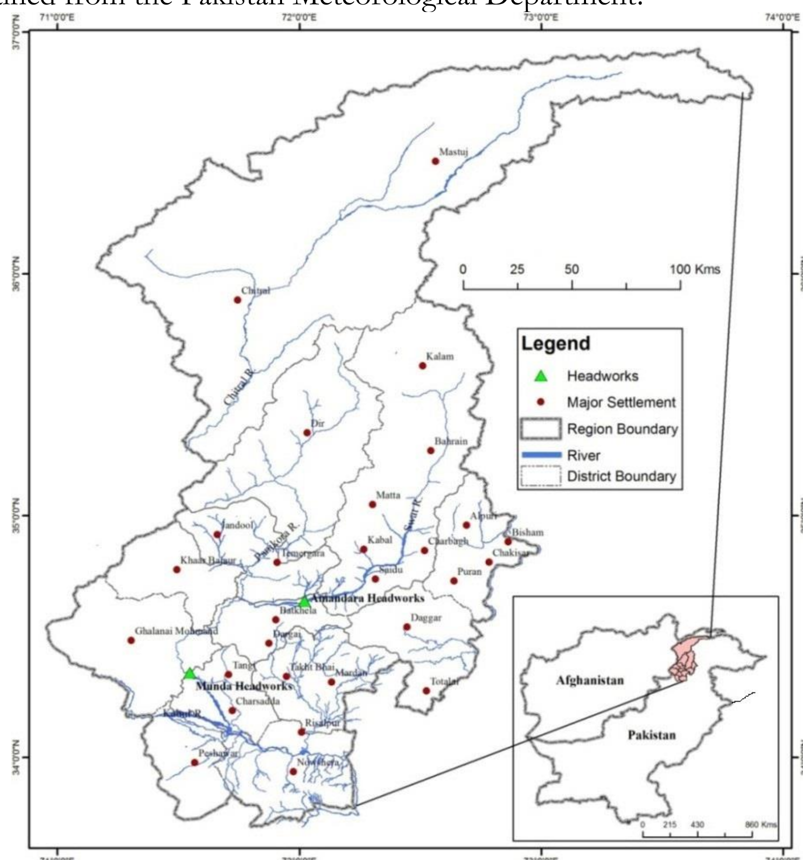

Figure 5. Drainage Basin of River Swat

Digital Terrain Surface of the Study Area:

First, the parameters were established to create the flood hazard map for the River Swat floodplain in the District of Charsadda. The research area's Digital Elevation Model (DEM) was created using the SRTM 90m resolution. The District Charsadda digital terrain surface is shown in Figure 6. It was obtained from the Shuttle Radar Topographic Mission (SRTM) data, having 90-meter spatial resolution. The terrain is stretched with a linear scale of a maximum of 983 meters and a minimum of 281 meters. The higher elevation is reported from the northern part of the district, and the lowest is in the south. Therefore, the River Swat flows from north to south. The figure further indicates that there is very little change in slope angle, mainly due to the floodplain of the River Swat and its tributaries, and part of the fertile Peshawar valley. It is because of this gently sloping area that the study region is known as one of the fertile agricultural hearts of Pakistan. It has also attracted a large section of the population, and the region is densely populated. This feature has caused the natural levees to overflow whenever the discharge surpasses the river's carrying capacity, resulting in significant damage to infrastructure, standing crops, agricultural land, and human casualties. The river was closed in several locations to redirect irrigation canals. Its vulnerability to such severe flood events is mostly due to its topography. As a result, floods frequently harm it.

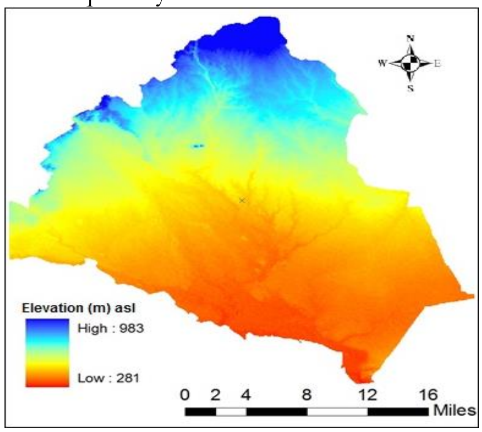

Figure 6. Digital Terrain Surface of District Charsadda

For the development of a flood hazard map, the probability and recurrent intervals of the flood hazard were calculated (Table 2). After calculating the two, the trend line (Figure 7) or the time series for discharge was graphed. Flood Return Period (Figure 8) was calculated using the equation:

R N+1/M (Eq.)

N=50 years record (number of years recorded)

R 50+1/1= 51 (per year chance is 0.5%)

R 50+1/2= 25.5 (chances per year 3.9%)

Table 2. Rank-wise highest recorded discharge at Munda, 1929-2022

Year	Peak discharge in Cusec	Rank	Recurrence Interval in Years	Chances per year (%)
2022	260,000	2	47.5	2
2010	300,000	1	82.0	1.2
1929	159,000	3	41.0	2.4
1965	119,000	4	27.3	3.7
1962	112,000	5	20.5	4.9
1967	101,000	6	14	1
1966	98,000	7	13.7	7.3
1975	97,000	8	11.7	8.5
1986	76,000	9	10.3	9.8
1964	65,000	10	9.1	11.0
1976	65,000	11	8.2	12.2
1972	62,000	12	7.5	13.4
1974	62,000	13	8	14.6
1978	60,000	14	3	15.9
1990	47,000	15	5.9	17.1
1985	40,000	16	5.5	18.3

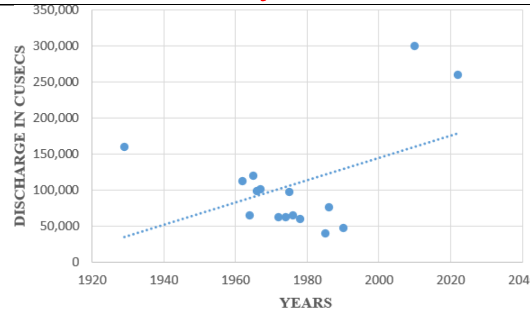

Figure 7. Trend Line Showing River Swat Highest Discharge at Munda, 1929-2022

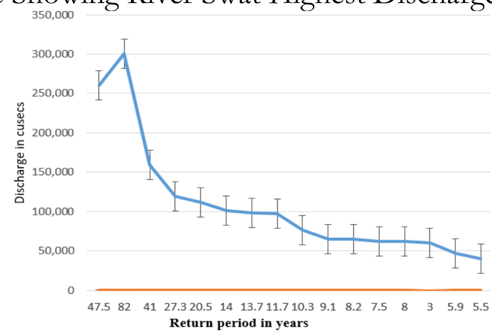

Figure 8. Flood Frequency and Reoccurrence Interval at Munda, 1929-2022

The recurrent interval and the probability (Figure 8) clearly showed the recurrence of the flood hazard with specific magnitudes. There is a strong and profound correlation between flood hazard and physical parameters like discharge, rainfall, humidity, and the area's relief. Using physical characteristics such as elevation data, rainfall, and discharge, a flood hazard map was created for the study region under a combination of five zones. Ultimately, the AHP and ArcGIS methods were used to create the hazard map. First, each parameter's value was established. Subsequently, the summation and division processes were applied to all of the set values. Then, to assign weight, the resulting values were combined. Lastly, using ArcGIS techniques, the flood hazard map (Figure 9) was created, defining the very high hazard zone, high hazard zone, moderate hazard zone, low hazard zone, and hazard-free zone (Table 3).

Table 3. Area-Wise Calculations for Hazard Zonation

Hazard zone	Area under effect (sq km)
Very High Hazard Zone	46.87
High Hazard Zone	95.98
Moderate Hazard Zone	124.53
Low Hazard Zone	57.94
Hazard Free Zone	5.12

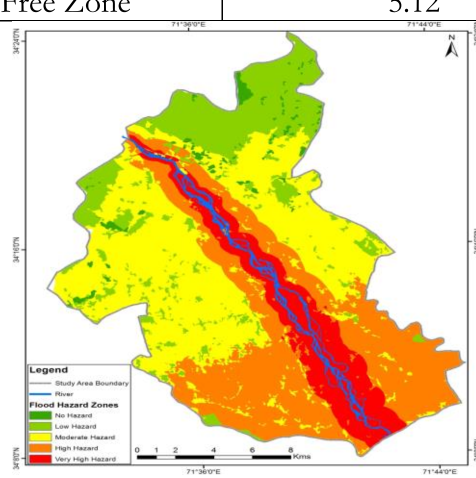

Figure 9. Flood Hazard Zonation Map of the Study Area

Conclusion:

This study was carried out to conduct a flood hazard assessment in the floodplain of the River Swat, District Charsadda. The study area has a history of catastrophic floods and is extremely vulnerable to them, especially during the monsoon season. Increased rainfall and glacial lake outburst floods are recent trends that enhance the risk of flooding in rivers and cities. Another important aspect is climate change, which makes extreme rainfall events more frequent and intense.

Therefore, it has a high recurrence interval. It was found that the higher the discharge, the greater the flood damages to standing crops, infrastructure, animal losses, and human casualties were recorded. For this reason, in this study, an attempt was made to spatially conduct a flood hazard assessment in the floodplain of the River Swat, District Charsadda, and provide policy guidelines to decision makers in reducing the impacts of recurrent flood disasters. The river network is prominently displayed in blue on this map, which shows the flood hazard zones of a defined study area. Green indicates "No Hazard," light green indicates "Low Hazard," yellow indicates "Moderate Hazard," orange indicates "High Hazard," and red indicates "Very High Hazard."

Very high hazard (red) zones predominate in the central portion of the study area, which runs parallel to the river. This suggests that the regions closest to the river are the most vulnerable to flooding. A belt of high-hazard (orange) zones surrounds this core, acting as a buffer between the regions with extreme and moderate hazards. These zones may experience occasional flooding during heavy rainfall or river overflow events.

A significant portion of the map is made up of moderate hazard (yellow) zones, which are farther from the river and indicate a lower but still considerable risk of flooding. While no hazard (green) zones are scarce and mostly found in the far north and isolated patches elsewhere, low hazard (light green) zones are scattered mostly in the northern and some peripheral areas, indicating negligible risk.

The study area boundary is outlined in gray, providing context for the spatial extent of the flood assessment.

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