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Article

Analyzing the Ghizer River Flood Using Hydrological Approach ((HEC-RAS) in Gilgit-Baltistan Region, Pakistan

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Abstract: Flood disasters occur when extreme flooding poses a significant threat to human life, infrastructure, and the environment. These disasters result from excessive rainfall, rapid snowmelt, glacier outbursts, or other hydrological events that cause rivers to overflow their banks, inundating surrounding areas. Flooding leads to loss of life, economic hardship, displacement of communities, and environmental degradation. Ghizer region is our focus study area, which is one of the mountainous regions of Gilgit-Baltistan, Pakistan that experiences several disasters, including geological, meteorological, hydrological, and manmade disasters. Among them, floods are the common natural disaster that damages the infrastructure every year. This research study examines the Ghizer River, using the Hydrologic Engineering Center River Analysis System (HEC-RAS) and the Automated Water Extraction Index (AWEI) as analysis models. The HEC-RAS steady flow modeling utilizes to predict river flow behavior in return periods, providing water surface profiles and floodplain inundation maps. The AWEI technique of remote sensing is used to assess the changing morphological pattern of Ghizer River over time. This study focuses on the communities that exhibit heightened vulnerability to flood occurrences in the vicinity of the Ghizer River and to investigate the river's morphological patterns. These advance approaches help for understanding of flood risk zones, early warning system, and disaster awareness. The study covers the period from 1990 to 2023 to analyze historical flood trends and river morphology changes over time.

Keywords: Ghizer River; HEC-RAS; AWEI; DEM; Flood

1. Introduction

Flood disasters are among the most frequent and destructive natural hazards worldwide, causing significant social, economic, and environmental losses. These floods are recognized as devastating natural disasters that result in significant socio-economic losses and claim millions of lives worldwide each year (Bouchard et al., 2023). The increasing frequency and intensity of river flooding, particularly in the Ghizer region, are exacerbated by climate change, rapid urbanization, and deforestation. These events are commonly sensitive to climate change, which alters weather patterns and leads to an increase in both the frequency and intensity of flooding (Breda et al., 2023; Chen et al., 2023; Jonkman et al., 2024). Although the critical need for effective flood management, the Ghizer district lacks essential infrastructure, predictive tools, and governance frameworks to mitigate and respond effectively to flood events. Without a comprehensive understanding of the causes, impacts, and potential mitigation strategies, the region remains vulnerable to recurring flood disasters. Therefore, it is crucial to assess the factors driving river flooding in Ghizer, develop predictive models, and explore sustainable flood management policies to enhance resilience and reduce future risks. The main objective of this study is to analyze river flooding in the Ghizer region by examining its causes, impacts, and potential mitigation strategies, with a focus on predicting return periods and assessing morphological changes in the Ghizer

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River.

In regions such as South Asia and Southeast Asia, monsoon seasons bring heavy rains that frequently result in widespread flooding, displacing communities, destroying infrastructure, and causing significant economic losses (Takahashi, 2024). For instance, the 2020 South Asian floods affected over 17 million people across India, Bangladesh, and Nepal (Relief Web, 2020).

It is known that floods are prevalent and common natural disasters in Pakistan, where about 60% of the land is vulnerable to floods, about 6% to cyclones, and 34% to earthquakes (Nanditha et al., 2023). The Indus River, one of the longest river in Pakistan, is the main source for irrigation purposes and originates from the Western Himalayas, Karakorum and Hindu Kush (H-K-H) (Sarkar, 2022). This region experiences severe climatic conditions in the winter seasons, with temperatures dropping 3° C to 10° C (Moazzam et al., 2022). The climate of Ghizer classified as ranging from arid to semi-arid region, characterized by low to moderate levels of precipitation (Ali, 2023). This area typically receives an annual rainfall amounting to between 500 mm and 800 mm (Abbas & Khan, 2020).

The flow in the River Indus are mainly relies on the melting of snow and glaciers present in extreme northern areas of Pakistan and these snow and glacier melt from the HKH mountain ranges contributes significantly to the flow of the Indus at Tarbela Dam (Lone et al., 2022). According to the previous studies, the flow from the Upper Indus Basin (UIB) contributes more than 70% and originates in areas with a lot of snowfall that are located over 4,000 m elevation. The percentage of the overall annual discharge (Ougahi et al., 2023) shows that snowmelt from the Western Himalayan catchments accounts for around 50% of the runoff (Lone et al., 2022).

The Indus River Basin (UIB and LIB) receives heavy floods every year, especially during the summer season. It is mentioned that the River Indus received heavy floods in 1973, 1992, 2006, and 2010 (Rizwan et al., 2023). Among them, the flood in 2010 is the most severe kind of flood in the history of Pakistan ever received by the Indus River Basin (Ullah et al., 2023). According to the statistics of United Nations (UN, 2011), the drastic flood caused the death of 1980 people, affected almost 18 billion people, and 1.8 million families lost their homes and became homeless in the year 2010 (Zhao et al., 2021).The upper Indus Rivers are the main reason behind the formation of the Indus River (Bhat et al., 2024). The UIB includes the Ghizer River, Hunza River, Gilgit River, Astor River, and Shigar River (Rather et al., 2024). Among them, the Ghizer River holds its own significance. The Ghizer River Basin (GRB) spans a length of 130 to 150 km (Haq & Muhammad, 2023). It originates from Shandor Lake and Langar (Qasim et al., 2024). It passes through various villages and towns in the Ghizer district before finally entering the Gilgit district. It is formed by the confluence of two major sub-rivers: the Ishkomen River and the Gupis River, which meet at Hatoon village near Hiyam town and give rise to the main stream known as the Ghizer River. Its native name was "Honey Sari".

Globally, the average temperature of the Earth is rising, which initiate changes in weather condition (Minor et al., 2022) and lead to variations in the pattern, magnitude, and trend of rainfall (Tamoffo et al., 2023). These variations in climate have drastic impacts on the hydrological cycle, resulting in floods, Glacial Lake Outburst Floods(GLOF), and Drought among others (Ali et al., 2021). Floods cause significant harm and disruption in flood-prone areas of river basins, making them a global concern (Ziwei et al., 2023). In Gilgit-Baltistan, particularly in the Ghizer district, river floods are mainly cause by high rainfall patterns and the melting of snow and glaciers, which are consequences of climate change (Aslam et al., 2023).

According to the study of Ali et al. (2023), the extreme rainfall in the mountainous region is the main reason behind the changing design of the hydrological cycle, flood hazards, and water management resources (Kanai et al., 2024). The volume and intensity of rainfall in each area of Gilgit-Baltistan are continuously changing, including Gilgit, Skardu, Bunji, Gupis, and Astor (Rashid et al., 2023). It is estimated that these areas will receive higher rainfall than 107.76 mm, 140.64 mm, 69.23 mm, 85.34 mm, and 153.44mm respectively in the upcoming 50 years, which is much more extreme than the situation in 2010. Moazzam et al., (2022) predicted that the annual average total rainfall in Gilgit Baltistan will receive about 111.28 mm after 50 years in future, which is a more alarming situation for the residents of GB. HEC-RAS models, when coupled with characteristic concentration pathway scenarios, project future flood extents. Studies in the Chitral, Hunza, and Astore river basins demonstrated that severe flooding could inundate significant portions of these areas in the coming decades. These projections inform the development of adaptive environmental policies to address emerging flood risks (Ahmad et al., 2021; Mukhtar et al., 2024). The application of the Hydrologic Engineering Center's River Analysis System (HEC-RAS) in Pakistan has significantly advanced flood modeling and analysis, offering valuable insights that influence environmental policies and enhance the understanding of regional climatology.

The results aid in identifying flood-prone areas, improving infrastructure resilience, and developing early warning systems. Additionally, the findings contribute to climate change adaptation and inform sustainable water resource management policies.

Study Area

The study area focuses on the Ghizer River, which flows through the Ghizer District, one of the administrative divisions within the Gilgit-Baltistan region (Rahim et al., 2018). The district is known for its attractive landscapes, including lush valleys, rugged mountains, and glistening rivers and lakes. The valley lies in the Hindu Kush region of Pakistan. covering an area of 12,042 km^2 between latitude 36.0 and 37.0 North and longitude 73.0 and 74.0 East (Haq et al., 2023). The Ghizer valley bounded by different regions on each side (Figure 1). It is covered by the upper Chitral district and Wakhan district of Afghanistan to the North, the Nagar and Gilgit Districts to the East, and the Tangir district to the South. Gupis, Ishkomen, Puniyal, and Yasin are the tributaries of the Upper Indus Basin present in the area, and they combine to form the main river of the district called the "Ghizer River"(Abbas & Khan, 2020).

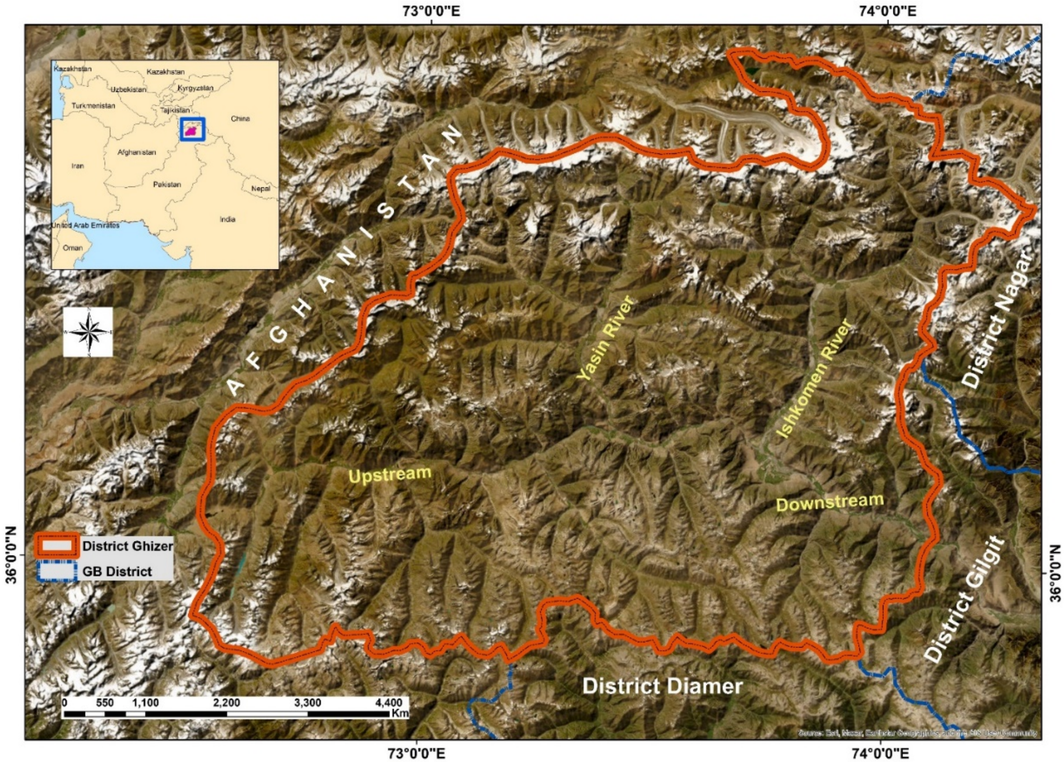

Figure 1. Study region of district Ghizer, Gilgit-Baltistan, Pakistan.

2. Material and Methods

The data used to analyze the Ghizer river floods is based on high-resolution satellite data. This study is subject to certain data limitations, including the availability, and consistency of historical hydrological data from 1990 to 2023.This data consist of Digital Elevation Models (DEMs) with a 30-meter resolution from the Shuttle Radar Topography Mission (SRTM), which provides detailed elevation data essential for accurate flood modeling. Geographic Information Systems (GIS) and Remote Sensing (RS) offer powerful tools for processing, analyzing, and visualizing the data, making them invaluable for flood analysis. The methodology is divided into two sections. The first section focuses on flood analysis by applying the Hydrologic Engineering Center River Analysis System (HEC-RAS) model, using the STRM DEM to simulate steady flow and predict flood events over various return periods. This modeling approach allows for the generation of water surface profiles and floodplain inundation maps, providing a comprehensive understanding of flood risks in the Ghizer region. The second section explains the morphological analysis of the Ghizer River using the Automated Water Extraction Index (AWEI), a remote sensing technique of water index (Laonamsai et al., 2023). AWEI helps to detect changes in the river's morphology over time by analyzing satellite data, which aids in understanding the river's shifting patterns and its influence on surrounding areas. This technique is crucial for identifying areas vulnerable to river erosion, sediment deposition, and other geomorphological changes. The combined use of HEC-RAS and AWEI provides a holistic approach to understanding flood dynamics and river morphology in the Ghizer region, contributing to improved flood risk management and disaster preparedness. Figure 2 illustrates the application of AWEI in tracking river changes over time.

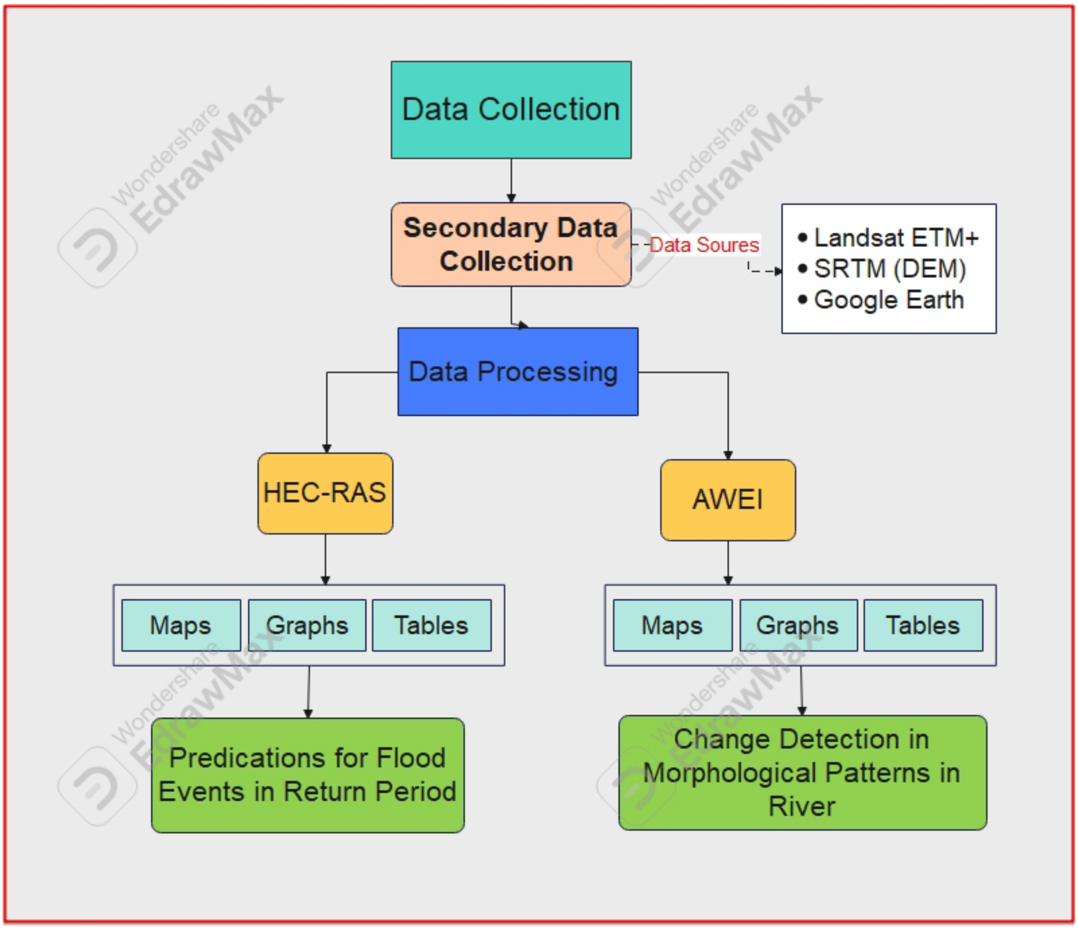

Figure 2. Methodological framework of Hydrological approaches HEC-RAS and AWEI.

Utilizing Satellite Imagery and DEMs

DEM-derived cross-section accuracy is limited by resolution, vertical errors, and interpolation uncertainties but improves with ground validation and higher-resolution data. The accuracy of flood modeling depends on data quality, which may be affected by limited historical flood records, sparse gauging stations, and uncertainties in hydrological inputs. Geospatial techniques like AWEI are influenced by cloud cover, seasonal variations, and resolution constraints, which can impact morphological assessments. Additionally, HEC-RAS assumes steady flow conditions, which may not fully capture dynamic flood behavior. The research examines flooding events in the Ghizer River through the application of the Hydrologic Engineering Center River Analysis System (HEC-RAS) (Ullah et al., 2025). Initially, cross-sections were digitized using Digital Elevation Model, as shown in Figure 3. The river, approximately 130–150 km long, includes 40 cross sections that measure water flow behavior, aiding future flood depth, velocity, and extent predictions. These cross sections help generate floodplain maps and estimate inundated areas during flood seasons.

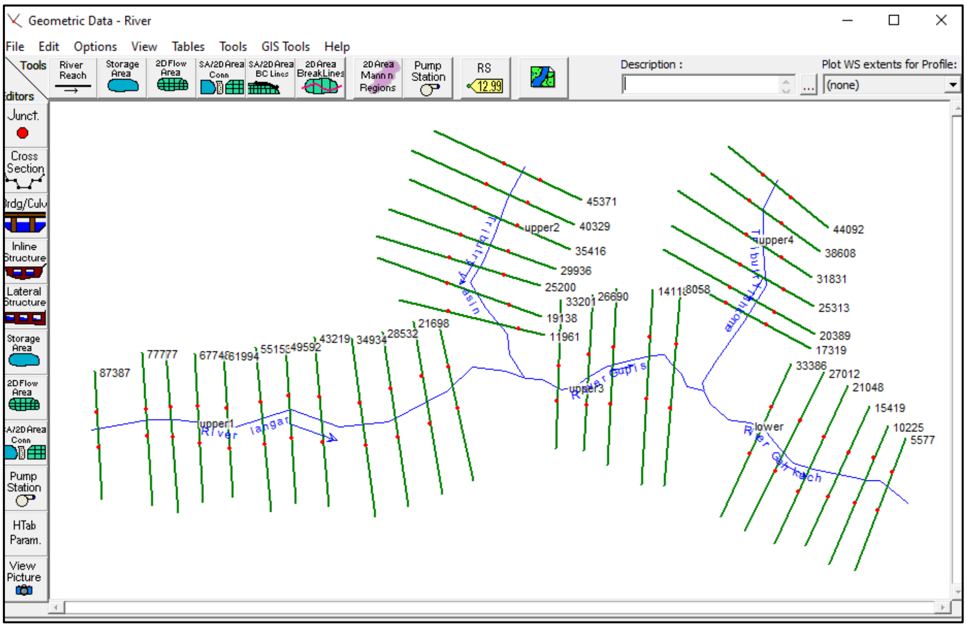

Figure 3. Map of geometry and cross sections of Ghizer River.

In this research, the authors adopted modern approaches for return periods and river patterns, respectively, using the HEC-RAS. The Digital Elevation Model (DEM) is a process of high resolution data source (Schumann, 2021) for analyzing river floods using the HEC-RAS model. The Ghizer River is under consideration in our study to analyze the return period. The depth profile within the framework of return periods denotes the probability of occurrence of extreme events with their depth and intensity. The following formula has been used for the return period (T).

$$= \frac{n+1}{m} \quad \dots \qquad (1)$$

where, "n" is the rank of flood events, "T" is the return period (year), and "m" is the total number of flood event data (points) (Ali et al., 2012; Basumatary and Sil, 2017). In addition, the Landsat 8-9 and Landsat 4-5 version data are used for the process of Automate Water Extraction Index (AWEI) to analyze the water surface of bodies for the required years as shown in Table 1.

Table 1. Summary of acquisition of satellite data for AWEI process.

Satellite Data	Year of acquisition	Number of Bands	Path/Row
L8-9 OLI/TIRS	2014-2022	11	150/35
L8 -9 OLI/TIRS	2010-2014	11	150/35
L4-5 TM	1990-2010	7	150/35

The analysis of return periods of velocity profiles is a fundamental aspect of hydrological regime studies and associated disciplines, providing critical insights into flow dynamics and recurrence intervals of extreme hydrological events. Similarly, this velocity profile can also calculate the characteristics of floods and its impacts on a region over time. For calculating river flow velocity profile Manning's equation is used for open river channels.

$$V = \left(\frac{1}{n}\right) \times R^{\frac{2}{3}} \times S^{\frac{1}{2}} \dots \dots \qquad (2)$$

where, R is the hydraulic radius (m), V is the flow velocity (m/s), n is the Manning's roughness coefficient, and S is the channel slope (m/m) (Song et al., 2016).

The satellite remote sensing offers to apply Automated Water Extraction Index (AWEI) to detect water dynamics such as patterns of rivers using satellite data. This method is suitable for monitoring the changes in rivers over time. Usually, the following formula is commonly used for AWEI (Feyisa et al., 2014: Huang et al., 2018).

$$\text{AWEI} = 4 \times (\text{Green} - \text{SWIR2}) - (0.25 \times \text{NIR} + 2.75 \times \text{Blue}) \qquad (3)$$

where,
Blue: reflectance in the blue band
SWIR2 is reflectance in the short-wave infrared band 2
Green is reflectance in the green band
NIR is reflectance in the near infrared

The **blue** illumination indicates areas where land has transitioned to water, while the **green** illumination represents regions where water has been converted to land during flood period. The intensity of these colors reflects the spatial extent and magnitude of the changes (Huang et al., 2018).

3. Results and Discussions:

This study utilizes hydrological modeling to predict flood events and analyze river morphology in the Ghizer River. Due to certain data constraints, the return period was calculated using data from the past few years, spanning from 1990 to 2023. The first section models future floods, providing spatial extent and depth profiles for return periods, consistent with previous flood modeling studies. The second section, using the Automated Water Extraction Index (AWEI), analyzes river morphology changes due to flooding and geomorphic processes, highlighting areas of erosion and sediment deposition.

3.1. Spatial Extent and Depth Profile of Return Period

One-dimensional steady flow analysis predicts flood behavior in the Ghizer River belt, considering return periods of 20, 40, and 60 years. (Figures 4, 5, 6, 7). The cross-sectional plots and graphs indicate that from the Shandoor to Hazal in district Ghizer, the adjacent roads and nearby settlements remain secure. The results show that river overflow associated with 40 year and 60-year return periods reaches up to Hazal village. This is also shown in results of inundation of settlements and large adjoin agricultural lands as well nearby public places. The depth profiles obtained from Yasin to Gupis Valley show that the existing bunds between them are not safe. Additionally, much of the land adjacent to the riverbanks is submerged due to the overflow of water in the river basin. Similarly, the area from Ghakuch to Hazal village is more Vulnerable to 40 years and 60 years' profiles. The following water surface profiles illustrate noticeable irregularities in the river's flow behavior.

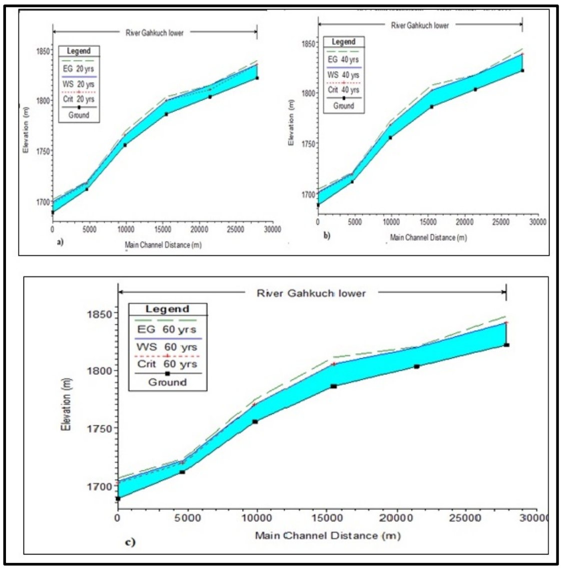

Figure 4. Graphical results of depth profiles of Return period in sub-river, Gahkuch (**a**) depth in 20-years (**b**) depth in 40-year (**c**) depth in 60 year.

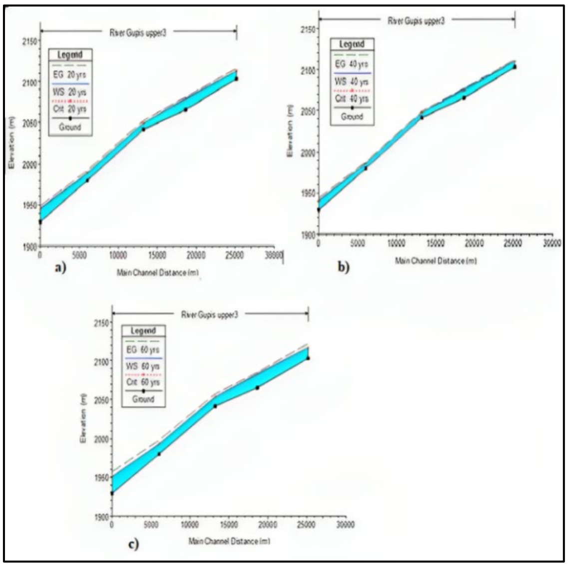

Figure 5. Graphical results of depth profiles of Return period in sub-river, Gupis (**a**) depth in 20-years (**b**) depth in 40-year (**c**) depth in 60 year.

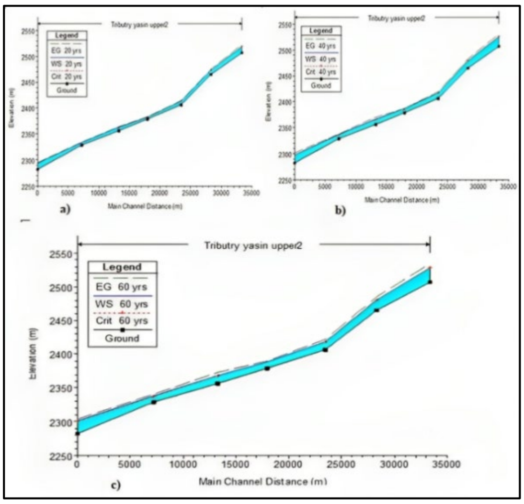

Figure 6. Graphical results of depth profiles of Return period in sub-river, Yasin (**a**) depth in 20-years (**b**) depth in 40-year (**c**) depth in 60 year.

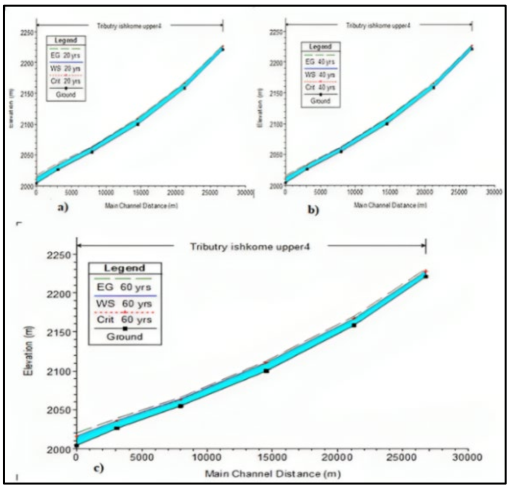

Figure 7. Graphical results of depth profiles of Return period in sub-river, Ishkomen (**a**) depth in 20-years (**b**) depth in 40-year (**c**) depth in 60 year.

The Figure 8 shows the spatial extent and vertical profile of predicted flood in the given years which is ranging from 0 to 60 m average of the Ghizer river in different return periods. The depth of the river increases due to the discharge of water from upstream, leading to a rise in water levels in certain areas. This may result in the inundation of adjacent settlements in the near future. The spatial extents of the flood in the river channels are vary from area to area. The downstream area, such as Gahkuch, experiences a high volume of water due to flooding. As shown in the map below, the maximum predicted flood levels in the downstream region result from an increase in river volume, which will extend inundation over different return periods. The results have two zones are highlighted in each predicted year to show the change clearly and the zone are; Gahkuch and Yasin zone of the main river.

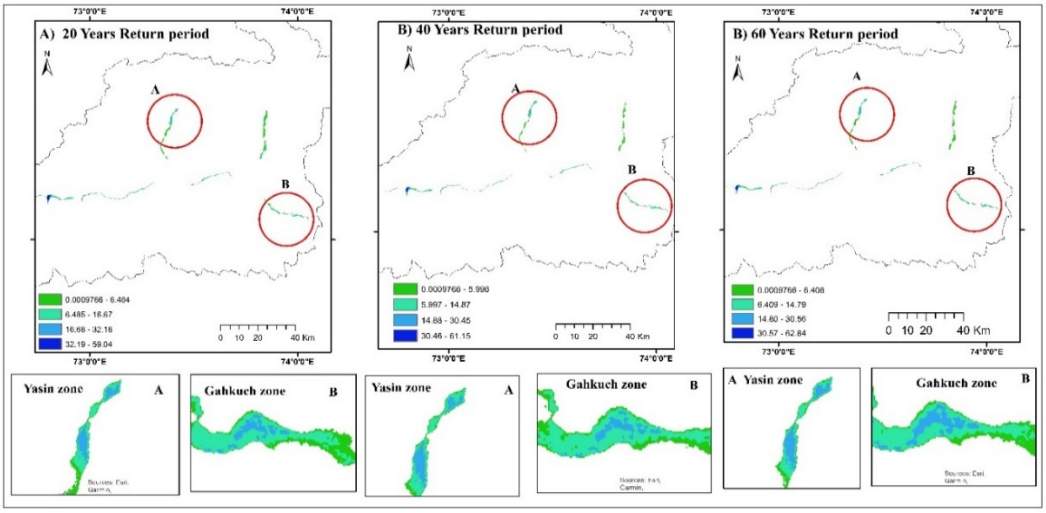

Figure 8. Map of Ghizer River, spatial extent and vertical profile of Return period.

3.2. Spatial Extent and Velocity Profile in Return Periods

The average velocity of the river over banks are increases with the passage of time, and by using steady flow analysis, it is possible to predict the river flood in certain return periods as the velocity remains constant over time. The average velocity for each part of the Ghizer river belt varies due to the inflow and outflow of water in each catchment. By using the HEC-RAS results, the average velocity of river flood for the Ghakuch belt rises on average in the return period, as Figure 9 reveals that the average velocity will increase in next 40 and 60 years. The red and green dotted lines revealed the pattern of river in Gahkuch zone as the graph pointed to increasing order of the river velocity. Similarly, Figure 10 shows that the river's velocity exhibits a distinct pattern, decreasing to a certain m/s over the next 40 years, followed by an increase after 60 years in the sub-river area of Gupis within the Ishkomen belt. In Figure 11 the velocity profile for the 60-year return period in sub-river Ishkomen exhibits the highest flow velocities, peaking at approximately 10 m/s near the upstream section (0 m) and progressively declining downstream, with minor fluctuations observed between 15,000 m and 25,000 m. The 40-year and 20-year return period profiles display similar trends, though with comparatively lower velocities throughout the channel. Overall, the graph demonstrates that higher flood return periods are associated with increased flow velocities, particularly in the upstream reaches, while downstream velocities diminish due to factors such as energy dissipation, frictional resistance, and channel widening. Figure 12 predicts the river's increasing velocity in the Yasin belt, as shown through a graphical process in HEC-RAS. In Gahkuch, it is evident that the flow moves at a high velocity, as it is considered a downstream reach. This section is responsible for maximum water overflow, causing inundation in adjacent settlements and agricultural land. The Velocities plots for each tributary of river Ghizer also presents how these trends show irregularity with the passage of times.

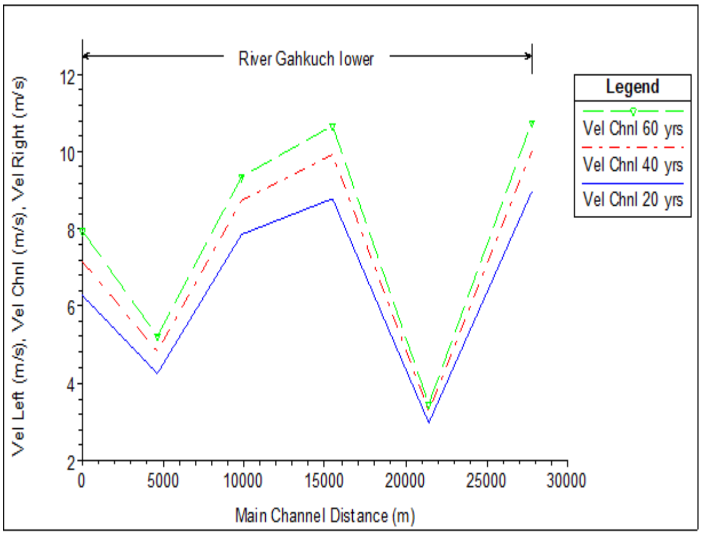

Figure 9. Graphical results of velocity profile for sub-river, Gahkuch.

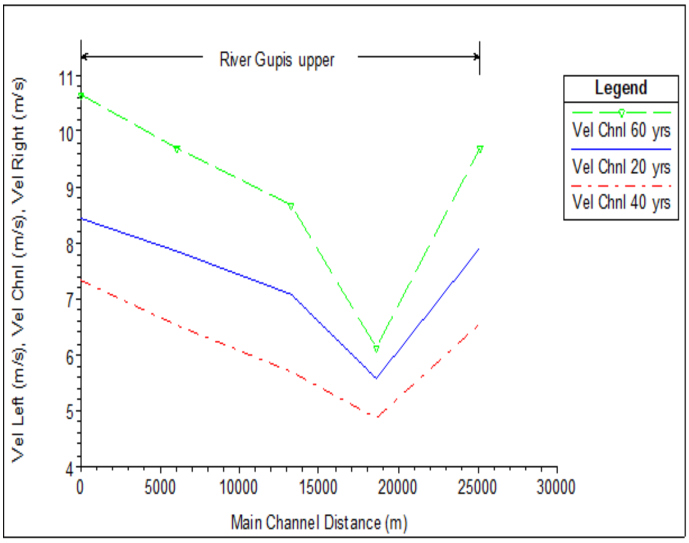

Figure 10. Graphical results of velocity profile for sub-river, Gupis.

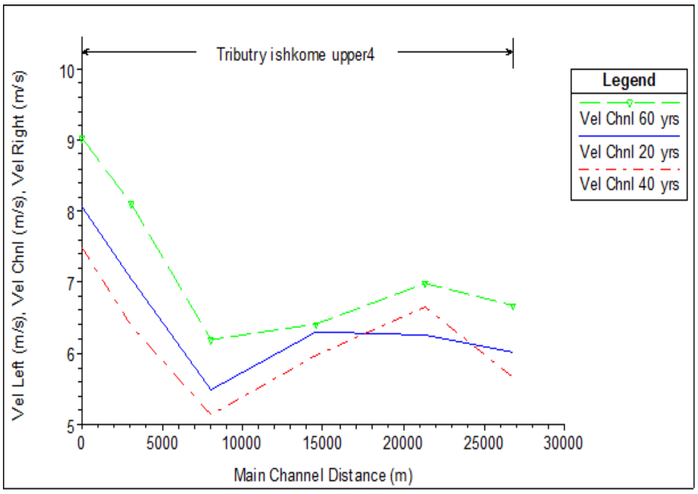

Figure 11. Graphical results of velocity profile for sub-river, Ishkome.

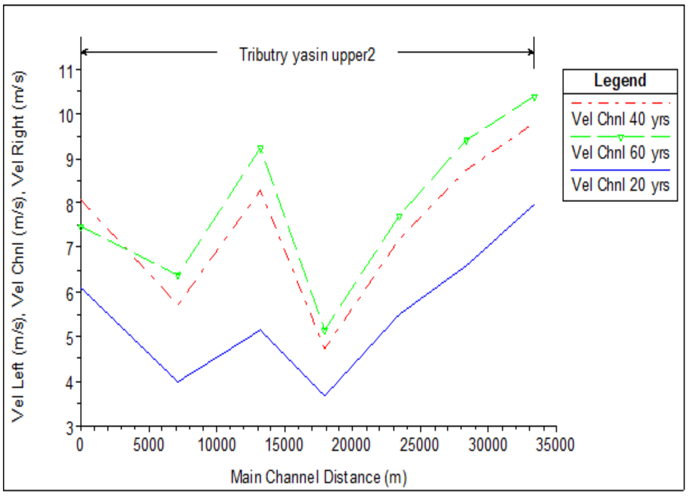

Figure 12. Graphical results of velocity profile for sub-river, Yasin.

The changes in velocities over time in the region of Ghizer will cause greater destruction to human and natural environments in the affected areas. It is observe form these maps that the downstream of the river will experience a greater velocity of flood in the coming years because the volume and capacity increase as the river moves from upstream to downstream. The downstream area is densely populated, and their settlements near the river area are at greater risk than other zones of the river. It is also predicted by the map that the velocity of the river incoming years will increase from an average of 0 to 9 m/s, which indicates that nearby settlements to downstream are more in danger. Moreover, the velocity in the next20-year return period would increase from 0 to 7 m/s. Similarly, the velocity is predicted from 0 to 8 m/s in the next 40-years, and from 0 to 9 m/s in the next 60-years of the return period. Two zones are selected as case studies to provide prediction data. It is important to note that the darker the brown, the higher the likelihood of a flood event occurring; conversely, the denser the color, the greater the probability of a flood event (Figure 13).

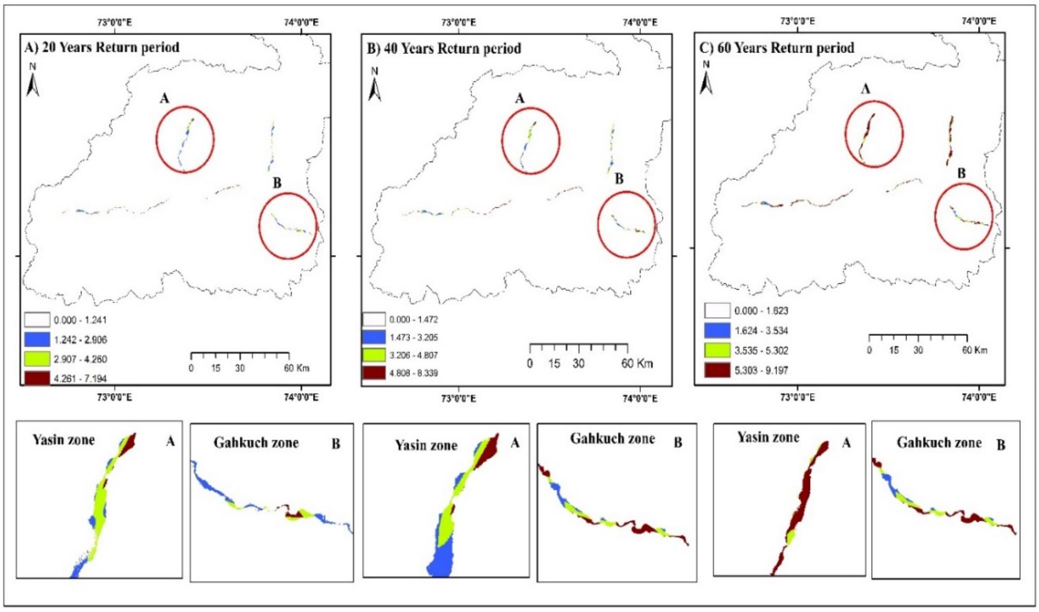

Figure 13. Plot of spatial extent and velocity profiles of Ghizer River.

3.3. Water surface Elevation (WSE) profiles in Return Period

Dash et al. (2022) studied the flood simulation of River Pilli using steady flow to assess the river's surface extent due to flooding. They computed water surface elevation (WSE) for each tributary, presenting results through rating curves that show average WSE increases during return periods. The graph visually represents the WSE for downstream zones, predicting significant inundation in agricultural and settlements. Specifically, (a) shows WSE for Ghizer River, (b) for Gupis, (c) for

Iskhomen, and (d) for Yasin (Figure 14). It visualizes the water surface extent for specific return periods of the Ghizer river belt, highlighting changes in a certain section of the river region.

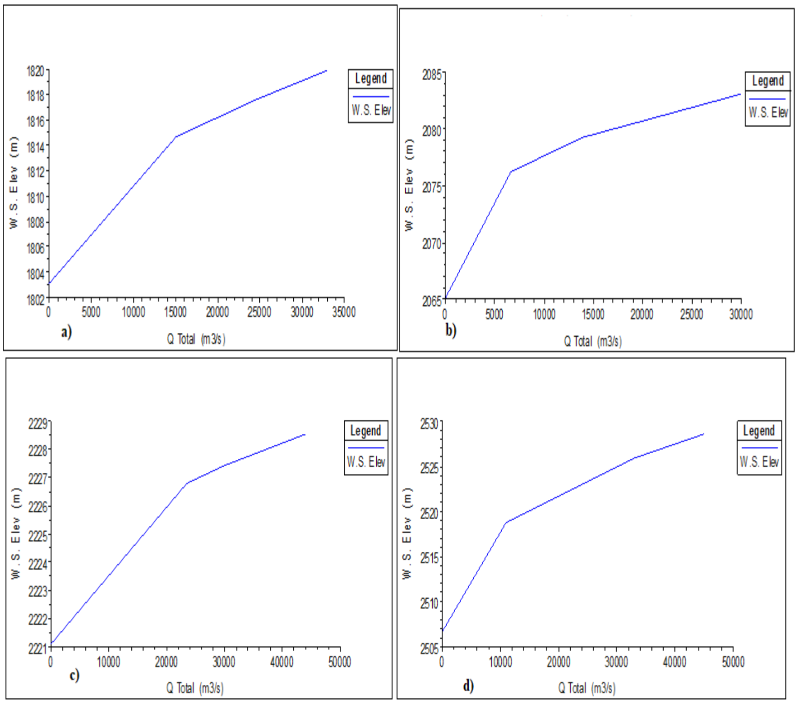

Figure 14. Graphical results of Water surface elevation of Ghizer river (**a**) WSE of sub-river Gahkuch (**b**) WSE of sub river-Gupis (**c**) WSE of sub-river Ishkomen (**d**) WSE of sub-river Yasin.

It is predicted from Figure 15 that the average rise of WSE in predicted years (20-year,40-year,60-year) would be 1695 to 3285 m. The denser color, the higher the chances of a flood event in that zone in the study area. The zones Yasin and Gahkuch are pointed out as case studies to show the change in water surface elevation in return periods, and the results show that the denser color indicates increases in the WSE in these zones.

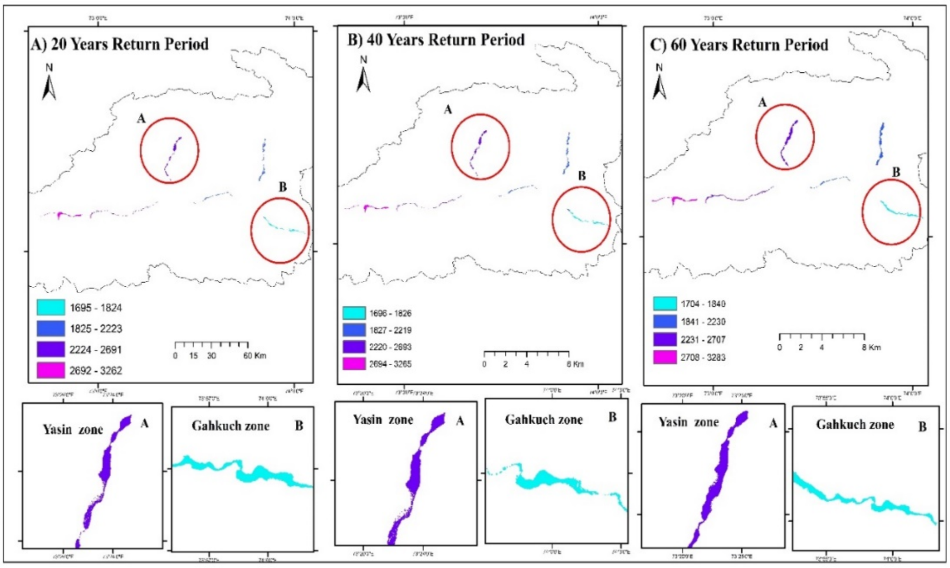

Figure 15. Vertical profile of Water surface elevation of Ghizer River.

3.4. River Patterns Dynamics by Using Automate Water Extraction Index (AWEI)

AWEI is a crucial hydrology tool for detecting changes in river patterns over time. It quantitatively measures surface water dynamics, enabling analysis of morphological changes by comparing images from different years. This helps to reveal fluctuations in water levels, flow paths, and channel expansions or contractions.

Researchers believe that AWEI is the best method for monitoring floods in rivers by detecting increases in water volume. Figures 16 and 17 illustrate the changes in the Ghizer River from 1994 to 2023, highlighting that river morphology changes take time. Floods significantly contribute to these changes. This method effectively tracks river pattern alterations over two decades and helps identify erosion caused by flooding, revealing changes in vegetation patterns in the affected areas. Currently, loss of huge tracts of agricultural land.

Figure 16 illustrates the Ghizer River channel changes from 1990 to 2014. Morphological shifts were observed in 56 locations due to consecutive major and minor flash floods and Glacial Lake Outburst Floods (GLOFs) affecting the river's patterns during this period. Table 2 below shows the measurements of the movement of the river in certain positions during the time period between 1990 and 2014, as well as its changes in the left bank or right bank at specific zones. In these zones or areas, several floods caused inundation to nearby areas and resulted in the flooding of a large agricultural land area.

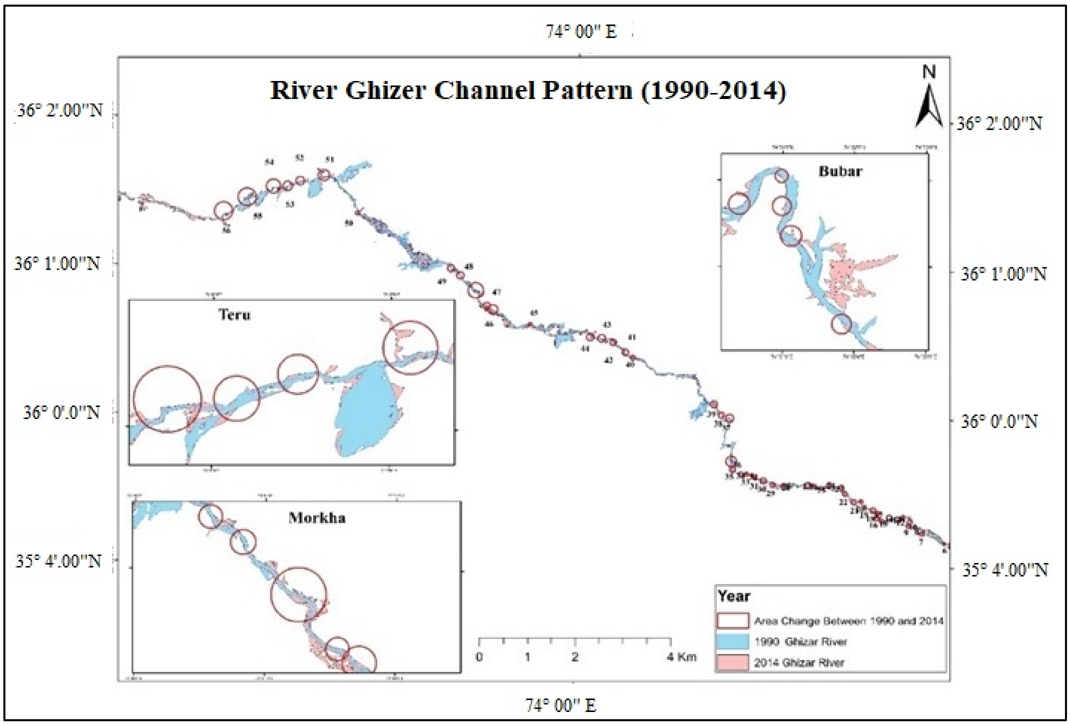

Figure 16. Morphological pattern of Ghizer River from 1990-2014.

Table 2. Results of Ghizer River movement from 1994-2014.

S. No	**River Move Km**	**Left/Right**
1	0.08	Left side
2	0.02	Right side
3	0.08	Left side
4	0.04	Left side
5	0.03	Right Side
6	0.03	Left side
7	0.2	Left side
8	0.03	Right Side
9	0.04	Right Side
10	0.08	Left side
11	0.05	Left side
12	0.03	Right Side
13	0.04	Right Side
14	0.03	Right Side
15	0.03	Right Side
16	0.06	Left side
17	0.06	Left side

18	0.04	Left side
19	0.02	Left side
20	0.06	Right side
21	0.08	Left side
22	0.1	Left side
23	0.03	Right Side
24	0.02	Right Side
25	0.06	Right Side
26	0.02	Right Side
27	0.04	Right Side
28	0.06	Left side
29	0.07	Left side
30	0.06	Right Side
31	0.07	Left side
32	0.03	Right Side
33	0.1	Right Side
34	0.04	Right side
35	0.04	Left side
36	0.2	Left side
37	0.03	Right Side
38	0.09	Left side
39	0.2	Left side
40	0.2	right side
41	0.03	Left side
42	0.13	Left side
43	0.08	Left side
44	0.2	Right side
45	0.11	Left side
46	0.2	Right side
47	0.14	Left side
48	0.2	Left side
49	0.04	Left side
50	0.03	Left side
51	0.04	Left side
52	0.1	Right side
53	0.05	Right Side
54	0.08	Right Side
55	0.09	Right Side
56	0.1	right side

There are several positions of the River that provide fluctuations in its left and right banks of about 17 positions of the main river due to flooding in these decades. Figure 17 manifests the changing pattern during 2014 to 2023, and Table 3 shows the measurement of the movement of river Ghizer in certain positions during the time period from 2014 to 2023. It also visualizes the changes in the right or left bank at specific zones. Several floods occurred in these zones or locations, causing inundation in neighboring communities and the loss of huge tracts of agricultural land.

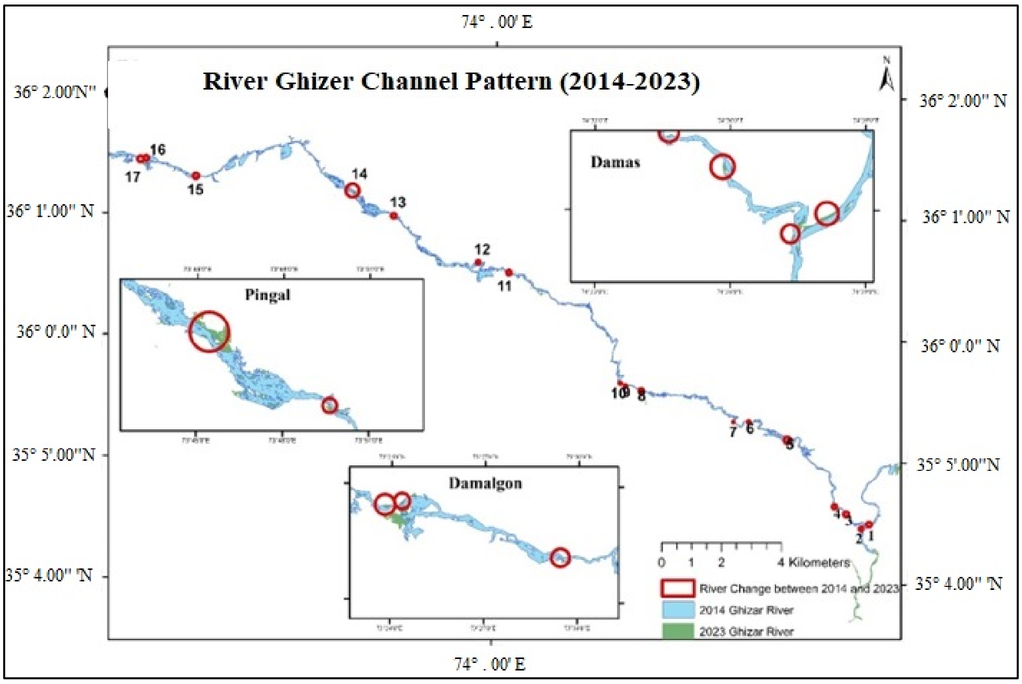

Figure 17. Morphological pattern of Ghizer River from the year 2014–2023.

Table 3. Results of Ghizer River movement from 2014–2023.

Serial Number	River Move (Km)	Left or Right Side
1	0.1	Right Side
2	0.07	Left Side
3	0.14	Left Side
4	0.04	Right Side
5	0.12	Right Side
6	0.06	Right Side
7	0.09	Left Side
8	0.4	Left Side
9	0.04	Right Side
10	0.13	Left Side
11	0.15	Right Side
12	0.26	Right Side
13	0.06	Left Side
14	0.7	Right Side
15	0.07	Left Side
16	0.14	Right Side
17	0.19	Right Side

Similarly, the erosion and accretion processes, crucial after river flooding, shape geological features by removing and depositing sediments. An example is Khalti lake beach along Ghizer river's backlines, formed through accretion in 1999. Figure 18 illustrates erosion and accretion from 1990-2023. Over two decades, erosion along Ghizer river banks increased due to floods and natural factors. From 1990-2014, erosion totaled 10 km and accretion 40 km, influenced by floods and GLOFs depositing minerals into the river. Predictions for 2024-2023 suggest erosion of 18 km and reduced accretion to 14 km, indicating ongoing environmental changes impacting the region's river dynamics.

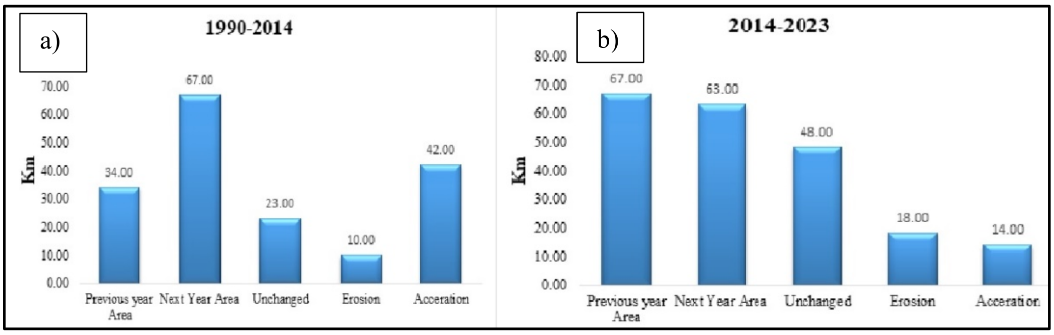

Figure 18. Erosion and Accretions of the Ghizer River (**a**) shows 1990-2014, Erosion and Accretions whereas, (**b**) shows 2014-2023, Erosion and Accretion.

These results have implications for climate science, suggesting that changing flood patterns may be linked to climate variability, such as glacier melt and altered precipitation. For policy, the study emphasizes the need for flood risk maps, early warning systems, and sustainable land management to reduce flood damage and support climate adaptation strategies. Overall, the study offers valuable insights for improving flood resilience and informing public policy on flood risk management.

4. Conclusion

The study highlights the dynamic morphological changes within the Ghizer River flood belt, utilizing the HEC-RAS model and AWEI to assess flood risks and predict return periods. The findings reveal that glacial melting significantly increases flood hazards, with projections indicating substantial inundation of the Ghizer Valley over the next 40–60 years. These results provide critical insights into river morphology and emphasize the necessity of developing adaptive flood management strategies to mitigate risks, protect vulnerable regions, and reduce long-term socioeconomic and environmental impacts. Main findings of this study are as under:

- The study identifies glacier melting is a primary driver of Ghizer River floods. Rising global temperatures accelerate the melting of compact water bodies, such as snow and glaciers, increasing water volumes in river catchments. To safeguard future water resources, reducing carbon footprints and preserving water reservoirs is imperative.
- Using HEC-RAS software, the study predicts the return periods of flood events and generates water surface profiles, highlighting changes in depth and velocity along the river channel. These profiles are crucial for understanding the river's behavior under various conditions and for effective flood management planning.
- The study also employs the GIS tool AWEI to analyses and predicts morphological changes in different regions of the Ghizer River. It recommends that policymakers integrate these patterns into hazard modeling and decision-making processes to enhance flood risk mitigation strategies.
- The research provides insights into erosion and accretion patterns along the river plain caused by floods and natural disasters. Between 1990 and 2014, erosion was estimated at 10 km, while accretion reached 40 km. However, projections for 2024–2023 estimate an increase in erosion to 18 km and a reduction in accretion to 14 km. These changes are influenced by flooding and glacial lake outburst floods (GLOFs), which transport heavy minerals that exacerbate erosion along the river.

Finally, future research should integrate high-resolution data, real-time flood forecasting, and AI-based predictive models to enhance early warning systems and flood mitigation strategies. Furthermore, hybrid modeling approaches that combine HEC-RAS with other hydrological and hydraulic models, including machine learning techniques, to improve flood risk predictions.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Approval
This article does not contain any studies with human participants or animals performed by any of the authors.

Informed Consent

Informed consent was obtained from all individual participants included in the study.

Data Availability Statement
Data sharing does not apply to this study as no new data were created or analyzed in this article.

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