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ORIGINAL PAPER

Beyond the banks and deluge: understanding riverscape, flood vulnerability, and responses in kashmir

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Abstract

Flooding in Kashmir results from a complex interplay of physical, sociopolitical, and economic factors, which presents a severe environmental challenge. The intricate interplay between the Jhelum's riverscape, social interactions, and economic factors is profoundly shaped by the persistent problem of flooding and its associated vulnerabilities. In this study, we examine the vulnerability of Kashmir to flooding and provide a comprehensive assessment of the recent floods. The purpose of this vulnerability assessment is to delve into these intricacies and offer deeper understanding of flood vulnerability in Kashmir. We explore the concept of riverscape in the context of the Jhelum River to encompass a holistic view of the river, understanding its physical features and socio-economic aspects, and examining the spatial and temporal dynamics of river ecosystems. This study analyses the spatial distribution of the inundated population, rainfall and hydrological analysis, flood gauge analysis of the Jhelum River, hydrological trends, and annual peak discharge at key discharge stations from 2003 to 2023. We analyse the policy landscape, social capital, and responses to recent flooding and provide a historical analysis of these policies. Using a mixed methods approach of qualitative as well as remote sensing methods to analyse recent flooding in Kashmir, we assessed the impact of flooding on population and LULC. We analyse how marginalised communities, lacking essential services and resources, disproportionately bear the brunt of these floods.

Keywords Vulnerability · Riverscape · Kashmir · Marginalisation · Flood · Disaster · Climate change

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1 Introduction

Vulnerability to floods is influenced by physical and social factors, such as proximity to floodplains and poor socio-economic conditions (Mavhura 2019; Nur and Shrestha 2017). In the last two decades, the examination of floods has transitioned from a narrow focus on physical attributes to a more inclusive approach that considers socioeconomic factors (Bogdan et al. 2020; Schuster-Wallace et al. 2018). This approach recognises that disasters are impacted by social factors, necessitating the examination of social as well as physical dynamics. This shift in perspective has resulted in a greater emphasis on understanding and addressing the susceptibility of communities to floods, as well as the need for integrated, anticipatory policies and strategies, which are essential for climate change adaptation (Malik and Ford 2024; Malik 2024). A flood is an overflowing of the usual boundaries of a stream or other water body or the accumulation of water in regions that are typically not submerged (IPCC 2012) and is characterised as the elevation or level of water surpassing a specific reference, often the edges of a riverbed.

The North-western Himalayas are highly susceptible to floods, glacial lake outburst floods (GLOFs), and alterations in river patterns due to geological instability, glacial melting, monsoonal rainfall, rapid urbanisation, and population growth (Sultan et al. 2022; Roy et al. 2021; Pandey and Prasad 2018). These vulnerabilities are exacerbated by climate change, increasing the flood risk in the region (Panwar 2020). Among the hotspots of the North-western Himalayas that are highly vulnerable to floods, affecting communities and their livelihoods, and having a myriad of socioeconomic and environmental impacts, is the Kashmir Valley (Malik 2022a). Historical and tree-ring records indicate a long history of high-impact floods in the region (Ballesteros-Cánovas et al. 2020). The recent floods, including the 2014 flood, the worst in the last hundred years, had a significant impact on the environment, economy, and society, highlighting the region's vulnerability to floods (Malik and Hashmi 2021). The geomorphic configuration of the valley, particularly the Jhelum basin, played a role in the recent flooding, exacerbated by anthropogenic factors such as urbanisation and the loss of wetlands (Romshoo et al. 2018a). Watershed characteristics, including terrain and land cover, also influence flood vulnerability in the region (Meraj et al. 2015).

A range of studies have discussed the flood vulnerability in the Kashmir Valley (Alam et al. 2018; Romshoo et al. 2018a; Meraj et al. 2015). However, most of these studies focus on physical vulnerability, examining factors such as topography, hydrology, and land use patterns, and some focus on anthropogenic causes that influence flood risk. A few ethnographic studies have provided understanding of the human experiences and responses to these floods, shedding light on the politics of relief and rescue (Malik and Hashmi 2022; Malik 2022b; Malik 2022c). There is a dearth of studies, however, that focus on the concept of *riverscape*, which encompasses rivers, floodplains, and interconnected habitats, their cultural significance, historical and aesthetic value, and the dynamic relationship between rivers and their surroundings (Stanford et al. 2017; Pietz and Zeisler-Vralsted 2021).

In Kashmir, flood vulnerability research lacks studies that evaluate the effectiveness of current policy frameworks in reducing flood risks and a comprehensive approach that combines ethnographic methods with remote sensing and the Geographic Information System (GIS), i.e., a combination of methods that consider both natural and social dimensions to understand the complex interplay between these factors. Addressing this gap requires a holistic approach that considers both natural and social dimensions of vulnerability. Our study—underpinned by the concept of the riverscape—adopts a mixed-methods approach to include both human and physical sciences approaches to examine recent flooding, with a special focus on the 2014 floods. It incorporates ethnographic research with the help of semi-structured interviews and focus group discussions, remote sensing, and Geographic Information Systems (GIS) to understand the complexity and dynamics of flood vulnerability. Ethnography provides qualitative insights into community experiences, perceptions, responses, and adaptive practices, while remote sensing and GIS offer spatial analysis of flood inundation and impact on Land Use and Land Cover (LULC). By integrating these methods, it is possible to develop a nuanced understanding of vulnerability within the riverscape, cross-reference spatial data with community perspectives, and inform effective flood management strategies.

2 Methodology

2.1 Study area

Kashmir Valley lies in the north-western part of the Himalayas (Fig. 1). Lying between the Pir Panjal Range in the south and the Greater Himalayas in the north (33° 55′–340° 50′N and 74° 30′–75° 35′E), it is an oval-shaped valley that spans 15,853 km^2 (Malik 2022b). The climate of the Kashmir Valley, influenced by the southwest monsoon and extratropi-

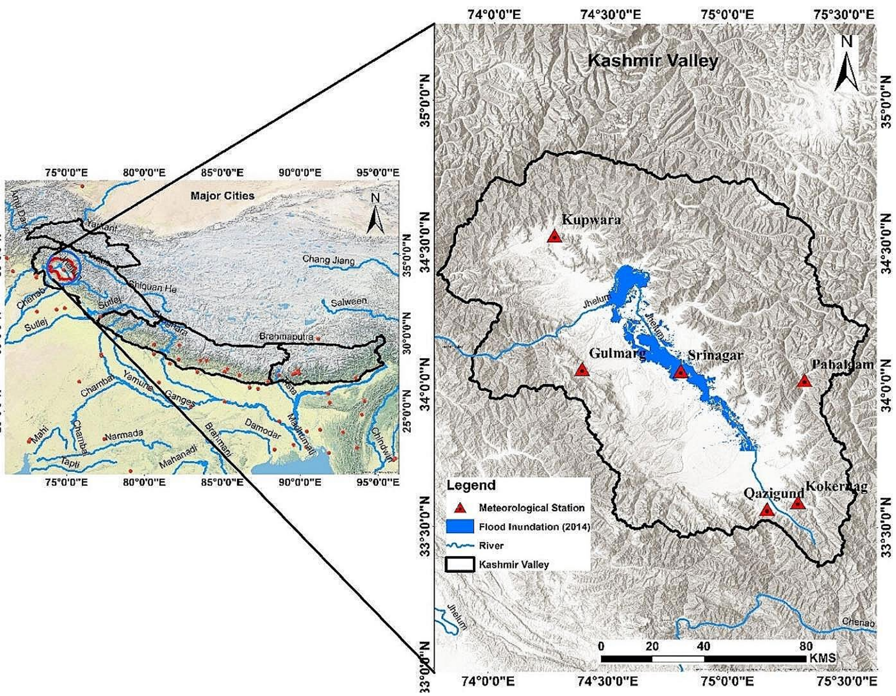

Fig. 1 Study area map

cal cyclones, has experienced a decrease in stream flows and precipitation and an increase in temperature (Romshoo et al. 2018a; Shafiq et al. 2020). This has led to adverse impacts on water-dependent sectors such as agriculture, horticulture, and tourism (Romshoo et al. 2018b). The valley's main river, the Jhelum River, rich biodiversity, and diverse habitats support a predominantly agricultural economy, mainly farming and mixed crops (Zargar et al. 2021; Bhat et al. 2019). It's Geological and climatic history, dating back to the Plio-Pleistocene era, provides a valuable context for understanding these changes (Agrawal et al. 1989). The valley's unique landscape, including the Karewa deposits and freshwater lakes, is a result of tectonic activities (Ganjoo 2014).

2.2 Methods, data collection, and conceptual base

We use a mixed methods approach to include qualitative as well as remote sensing methods to analyse flood vulnerability in Kashmir. The qualitative methods include semi-structured interviews, focus group discussions, and ethnographic approaches.

2.2.1 Semi-structured interviews

A total of 65 semi-structured interviews were conducted in 2014 ($n=20$), 2017 ($n=30$), and 2023 ($n=15$) with community members and key informants, including community leaders, government officials, disaster management experts, and NGO representatives. These interviews aimed to gain perspectives and perceptions of flood vulnerability, coping strategies, and opinions on policies, as well as to explore individual experiences and understand the nuances of local contexts. The purposive sampling took place across three time periods to monitor flood dynamics and response.

2.2.2 Focus group discussions (FGDs)

Nine FGDs were conducted (three each year), involving a group of participants from the community and experts to discuss issues related to flood vulnerability and policy.

2.2.3 Ethnographic studies

Ethnography involves conducting extensive and immersive fieldwork in a particular community or environment to get insights into its culture, practices, and social systems. This method involved the researcher immersing himself in the community related to flood management in Kashmir, which allowed him to observe and document social interactions, stories, narratives, and practices in real-time. The researcher spent several weeks in flood-affected areas of Kashmir, engaging with local communities and organisations, participating in daily activities alongside community members, attending meetings, and contributing to relief efforts. The process included conducting formal and informal interviews, focus groups, and participant observations. The fieldwork was conducted by the lead researcher, who is from the region, while based at AMU, India, and continued the work at UoL, UK. Throughout the study, ethical considerations such as informed consent, and confidentiality were prioritised.

This study also analysed historical documents and policies for managing floods in the Kashmir Valley, assessing various initiatives and their effectiveness. It draws from archival records, including key reports and publications that shed light on the area's flood control measures. The materials include the Harris Report (1929), the Uppal Report (1956), the Master Plan (1959), and the High-Level Flood Committee Report (1977). Additionally, the state's yearly administrative reports, such as Ghulam Hassan Khan's 1961 study on irrigation and flood issues, Jarnail Singh Dev's 1983 examination of disasters, and Hakim and Tramboo's 2016 analysis of floods, contributed to the understanding of flood management. These archival materials were subjected to a qualitative analysis to evaluate the policy framework.

2.2.4 Assessing population impact of flooding using WorldPop data

To examine the population distribution affected by the 2014 Kashmir floods, we used WorldPop data (https://www.worldpop.org/), which gives population distribution estimates at several spatial resolutions. We determined the spatial distribution of the affected population by overlaying flood-affected zones on the WorldPop population distribution dataset. We assessed the entire population affected by the floods using this technique, which provided insight into the flood's intensity in terms of human impact. Visual representations, such as maps, were created to show the geographic breadth of the flooding impact. This methodology enabled a thorough assessment of the population effect, assisting with informed decision-making and disaster response operations.

2.2.5 LULC map for the flood inundated area

To analyse the spatial impact of the 2014 Kashmir Flood on LULC categories, Landsat imagery captured before the flood event was utilised. Landsat data were downloaded from the United States Geological Survey (USGS) Earth Explorer website (https://earthexplorer.usgs.gov/), a reliable source for satellite imagery. The Landsat imagery had a spatial resolution of 30 m and included spectral bands such as visible, near infrared, and thermal bands. The imagery underwent preprocessing steps to enhance quality, including atmospheric and geometric correction. Using maximum likelihood classification in the ArcGIS environment, a LULC map was generated, categorising the region into built-up areas, cropland, vegetation, water bodies, and barren land. By comparing pre-flood and post-flood imagery or ground observations, the impact of the flood on each LULC category was assessed. Landsat data was used for LULC analysis due to its availability, spectral resolution, and historical archive, making it a suitable choice for this analysis. This methodology facilitated a comprehensive understanding of the flood's spatial extent and severity across various land use types.

2.2.6 Hydrometeorological data analysis

The Irrigation and Flood Control Department of the Government of Jammu and Kashmir provided us with data on peak discharge rates measured in cubic feet per second (Cusec) at three different sites (Asham, Sangam, and Ram Munshi Bagh) between 2003 and 2023. The dataset contained daily discharge measurements from each station, which we used to determine annual peak discharge rates. These yearly peak discharge numbers represent the highest discharge observed at each station each year, offering a complete picture of hydrological extremes. We examined these annual peak discharge rates to discover trends and fluctuations over the research period, using statistical techniques such as linear regression and time series analysis to determine the direction and degree of trends. In addition, we examined the yearly peak discharge rates spatially among the three sites to identify differences in hydrological conditions. Discharge rate differences between stations suggest variances in catchment characteristics, land use, or proximity to major watercourses.

This study uses vulnerability assessment, and the concept of riverscape, as explored by Wang et al. (2014), Stanford et al. (2017), and Carbonneau et al. (2012), which emphasises the spatial and temporal dynamics of river ecosystems, including their connectivity, heterogeneity, and disturbance. This concept has practical applications in river restoration and management (Torgersen et al. 2022), considering the cultural and historical aspects of riverscapes in their design and preservation (Chías and Abad 2019). The "Truths of the Riverscape" advocate sustainable river management through diversity, respect, understanding natural processes, and river condition assessment, enabling proactive catchment plans to address biodiversity loss and climate adaptation (Brierley and Fryirs 2022). The philosophy of 'working with nature' and 'working with the river' gains global traction to call for collective action to foster diverse, inclusive communities of practice (Fryirs and Brierley 2021), underscoring the concept of 'hydro-resilience' in managing consequences (Beattie and Morgan 2017). Human disturbances pose significant challenges to the sustainable management of rivers. Traditional water harvesting techniques, rooted in traditional knowledge, aligned with natural processes, but colonial command-and-control methods imposed external values, asserting human authority over rivers, underscoring the need for a holistic, transdisciplinary approach integrating traditional and scientific knowledge to support proactive and precautionary river management (Brierley et al. 2023).

3 Results and discussion

3.1 Historical analysis of flood events and hydrological trends

Kashmir has a long history of flooding, with devastating events recorded over the years. Historical documents indicate that Kashmir has experienced significant human and property losses due to persistent flooding events (Ali et al. 2022). Kashmir experienced flooding in the years 1893, 1928, 1950, 1959, 1992, 2010, 2014, 2015, 2017, 2019, and the latest in 2022 and 2023 (Wani and Malik 2023; Malik and Hashmi 2021), and 2024. Before 1880, flood knowledge in Kashmir was scant. Ancient period measures included Suyya's scheme under Awantivarman (Kalhana 2013). Medieval period efforts were limited, with no significant long-term strategies, funds, or alternative channels (Kaw, 1984). Embankments were sporadically constructed using stones. Mughal and Afghan rulers initiated limited embankment projects. By the 19th century, flood knowledge increased, leading to structural (channelization, levees) and non-structural (warnings, evacuation) measures (Khuihami 2015). European experts initially focused on flood management in Srinagar, with early efforts led by British engineers like Captain Capper (Harris 1929; Uppal 1956). Walter Lawrence laid groundwork for understanding flood patterns and proposed using embankments. Post-1893 flood, Srinagar's defences were reinforced, leading to projects like the Flood Spill Channel (completed 1903–04) (Lawrence 1895). After 1909, broader flood management efforts began, triggered by consultations with external experts. Focus initially cantered on Srinagar, expanding to Sangam by 1928 and South Kashmir post-1950, coinciding with the advent of democratic governance in Kashmir (Uppal 1956). Despite efforts, achieving complete flood immunity was deemed unattainable and undesirable, with emphasis on preserving agricultural land and reclaiming swamps.

The history of floods in Kashmir stands as evidence of the region's susceptibility to flooding, leaving lasting marks on its landscape and communities. From the early 20th century to recent times, recurrent floods have caused extensive devastation, posing significant developmental challenges. In 1950, a catastrophic flood struck Kashmir, wreaking havoc on homes and livelihoods. Reflecting on the impact, a participant remarked, "The floods of 1950 were a nightmare, sweeping away everything in their path." The flood of 1959 further burdened Kashmiri communities, leaving some homeless and struggling to rebuild. Recalling the devastation, a survivor shared, "The floods of 1959 left us homeless and destitute, struggling to rebuild our lives. Our house was totally damaged, we then had to construct a new house." This event highlighted the vulnerability of the region and the imperative for coordinated response efforts to address the aftermath of flooding. In 1992, another deluge exposed the inadequacies of existing disaster preparedness. Residents were unprepared for the scale of devastation, emphasising the need for proactive planning and resilient infrastructure. "The floods of 1992 took us by surprise, leaving us unprepared for the scale of devastation. All my sheep died, which were my main source of income," noted one resident. The floods of 2010 acted as a wake-up call, revealing the impacts of climate change experienced by the communities, prompting them for renewed efforts to enhance resilience and adaptation measures against evolving environmental challenges. Reflecting on the experience, a community member observed, "The floods of 2010 forced us to confront the reality of changing weather patterns and their implications for our future. We have seen dramatic changes in weather conditions lately." In 2014, Kashmir witnessed unprecedented flooding, submerging a lot of places, and stretching relief efforts to their limits. A participant narrated, "The floods of 2014 were unlike anything we had ever seen, overwhelming our capacity to respond." "I have never seen such a flood in my seventy years of life. It was so devastating; we had to leave our homes and stay in a shelter camp for a week" shared an elder. This event underscored the urgent need for comprehensive disaster risk reduction strategies and investment in sustainable development to mitigate future flood risks. Traditionally, proactive measures to mitigate or reduce flood damage have been largely overlooked. This is attributed to the perception of floods as acts of divine wrath or challenges too great to confront, coupled with the infrequent nature of these disasters, which led to a collective amnesia regarding their enduring historical consequences.

Figure 2 depicts peak discharge rates measured in cubic feet per second (cusec) at three stations: Asham, Sangam, and Ram Munshi Bagh, from 2003 to 2023. Discharge rates have fluctuated over the years, reflecting the variety of hydrological conditions. Significant changes can be seen between stations and over time. For example, Asham typically has lower discharge rates than Sangam and Ram Munshi Bagh, indicating possible variances in catchment area characteristics or local precipitation patterns. In contrast, Sangam and Ram Munshi Bagh have higher discharge rates, most likely due to their closeness to major watercourses or changes in terrain and land use.

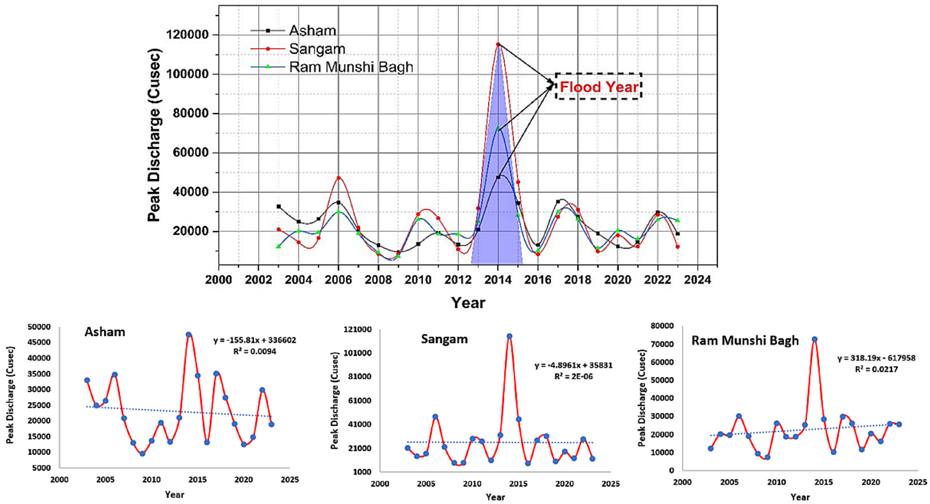

Fig. 2 Annual Peak Discharge (Cusec) at Asham, Sangam, and Ram Munshi Bagh from 2003 to 2023

The year 2014 stands out prominently across all locations with significantly higher peak discharge rates than previous years. Ram Munshi Bagh saw a peak discharge of 115,218 cusec, while Asham and Sangam saw much higher rates of 47,600 cusec and 72,585 cusecs, respectively. This increase in discharge rates coincides with the onset of a flood year, indicating a significant influx of water into the region's water bodies. This increase in discharge rates coincides with larger climatic events or significant precipitation episodes, highlighting the region's vulnerability to hydrological extremes. The ensuing years indicate a progressive reduction in discharge rates, showing a return to more normal hydrological conditions after the abnormal flood year. Overall, the trends in Peak discharge at all the three stations is showing a decreasing trend as depicted in Table 1; Fig. 2.

The peak in discharge rates in 2014 is particularly notable, and it calls for additional investigation into the meteorological and hydrological causes that caused such an event. Intense rainfall, snowmelt, land use changes, or changes in watershed dynamics are all possible causes of the 2014 flood event. Analysing these characteristics in conjunction with historical discharge data can provide significant insights into the region's vulnerability to extreme hydrological events, allowing for more informed decision-making on flood risk management and adaptation methods. Furthermore, examining long-term discharge rate trends might help us understand the larger effects of climate change on hydrological processes and advise proactive steps to reduce future flood and water resource hazards.

3.2 Vulnerability assessment

Kashmir Valley is highly vulnerable to floods, with the recent flooding event being particularly devastating (Malik and Hashmi 2021; Ballesteros-Cánovas et al. 2020). The region's topography, characterised by its intricate network of rivers, lakes, and wetlands, renders it susceptible to floods and riverine inundations (Ballesteros-Cánovas et al. 2020; Romshoo et al. 2018a). Urban growth of 75% in the last two decades, particularly in the central and southern parts of Srinagar, has exacerbated this vulnerability (Ahmad et al. 2019, 2024).

Table 1 Peak discharge at key discharge stations

Peak Discharge (Cusec)			
Year	Asham	Sangam	Ram munshi bagh
2003	32,881	21,065	12,320
2004	25,000	14,500	20,240
2005	26,400	16,593	19,600
2006	34,800	47,300	30,000
2007	20,793	21,952	19,000
2008	12,980	8540	9250
2009	9567	8610	7350
2010	13,575	28,812	26,185
2011	19,300	26,717	18,812
2012	13,349	10,989	18,637
2013	20,933	31,831	25,241
2014	47,600	115,218	72,585
2015	34,440	45,154	28,372
2016	13,154	8414	10,268
2017	35,156	27,493	29,881
2018	27,400	31,100	26,231
2019	18,996	9847	11,539
2020	12,500	18,120	20,460
2021	14,740	12,434	16,265
2022	29,784	28,549	25,895
2023	18,822	12,236	25,519

Data *source* Irrigation and Flood Control Department, Govt. of J&K

The recent floods caused significant damage to natural vegetation and built-up areas, particularly in Bandipore, Baramula, Pulwama, and Srinagar (Kumar and Acharya 2016). The Jhelum floodplain is particularly vulnerable due to its high population density (Meraj et al. 2015). However, the public perception of flood vulnerability in the region is not well understood and lacks a thorough analysis. This study documents the public perception of flood vulnerability, identifying narratives and themes that people experience.

Due to the dependence of socio-economic activities on agriculture and horticulture, this amplifies the impact of floods, disrupts livelihoods, and exacerbates poverty (Table 2). "We are dependent on agriculture and horticulture for everything, so we are not just dealing with floods; we are dealing with loss and threat of our socioeconomic activities," says a resident, summarising the prevalent sentiment felt throughout vulnerable areas. The study highlights the unpleasant reality of flooded areas with high population densities, particularly in urban and peri-urban communities. Another community member notes, "Our neighbourhoods are densely packed, with barely any breathing space, and when floods occur everything is submerged," underscoring the dearth of open space in their areas that is made worse by the impending threat of flooding. Many people in these areas view them as more than just places to live; they are the centre of their livelihoods and are closely linked to the dangers posed by flooding. This dual reality is expressed by a local shopkeeper, who says, "Our businesses flourish here, but at the same time our anxiety due to flooding." This feeling is shared by many small business owners, whose financial situation is under threat during flooding. The study emphasises the fundamental socioeconomic interconnectedness within these communities, where the daily ebb and flow are inextricably linked with the Jhelum river's rhythms.

Table 2 Profiling of quotes describing flood vulnerability

Quote	Year
"We lack the basic infrastructure that is needed to survive, which exacerbates the flood situation here. Every time it rains heavily, the streets start to flood in no time, and we fear for our lives and properties."	2014
"It seems that floods target the poor specifically. We have suffered so much loss, particularly from the 2014 floods, that it brought misery and poverty to a lot of people in our locality."	2014
"Our drainage system and embankments are outdated and poorly maintained and cannot accommodate flood waters. We need significant improvements in infrastructure to enhance flood resilience."	2017
"Our communities lack critical infrastructure like flood shelters, ambulances, and evacuation facilities. Vulnerable populations are left stranded during floods with no one to help them."	2017
"Community involvement is lacking in decision-making processes for effective flood management, which often results in the mismanagement of resources, creating issues during floods. The community needs should be met to tackle flooding."	2023
"We have seen recent floods devastating our homes and livelihoods every time they occur. Our susceptibility to floods has not changed. They result in death and destruction."	2023

The study examines the structural inequities that are created by long-standing socioeconomic inequality. " We are left to fight for our survival, while the wealthy people remain unaffected by the floods. They have houses in different parts of the world," expresses a community leader, highlighting the stark divide between the classes in the face of disaster. The marginalised groups are disproportionately affected, with their limited access to resources and opportunities exacerbating their exposure to flood risks. "We are always the last ones to receive the flood relief, if we receive it at all," laments a community member, underscoring the systemic inequities that compound the challenges of resilience and recovery.

The assessment highlights the plight of those residing in informal settlements, where inadequate infrastructure exacerbates vulnerability. "The recent floods, especially the 2014 flood, affected our community a lot. We incurred a great financial loss. Our homes are at the mercy of the waters, and so are we," remarks a member of such a community, expressing the profound sense of insecurity wrought by living in structures ill-equipped to withstand flooding. The lack of critical services such as healthcare, clean water, and sanitation exacerbates the challenges encountered by these vulnerable communities during floods. Essentially, the socioeconomic components of vulnerability show a striking picture of inequity.

Community members express concern about the encroachment on floodplains and uncontrolled urban expansion. "We have experienced the consequences of shortsighted development firsthand. The development in urban areas is so haphazard and unplanned. It doesn't make any sense," narrates a participant, emphasising the issue of favouring short-term advantages over long-term resilience. The assessment emphasises how rampant urbanisation reduces the region's ability to absorb floodwaters naturally, leaving vulnerable communities more exposed to floods. as a community member mentioned, "Earlier, we used to have a very less urbanised area; now it seems like a concrete landscape, making water accumulate within half an hour in our lanes."

The assessment explores the broader ecological shifts that make people vulnerable to flooding. An environmental activist points out that “we have seen the degradation of our natural defences against flooding over the years,” highlighting the encroachment onto important wetlands and floodplains. The region’s ability to endure floods is weakened by the loss of these natural buffers and unchecked urban growth, making populations more vulnerable to the disastrous effects of rising waters. “Our natural green surroundings are disappearing, replaced by concrete buildings and jungles ill-equipped to absorb excess rainfall,” says a conservationist, emphasising the far-reaching impact of unregulated growth on environmental resilience.

The 2014 floods devastated a large part of the Kashmir Valley, submerging several places for more than a month. The Jhelum basin inundated 912 km^2 of its 1760 km^2 of floodplains, affecting nearly two million people. The districts severely affected included Anantnag, Kulgam, Pulwama, and Srinagar in Kashmir (Fig. 3).

3.3 Riverscape

The riverscape concept in this study is examined in the context of the Jhelum River in Kashmir, which encompasses a holistic view of the river and its surrounding landscape. It involves understanding its ecosystem, including physical features, vegetation, and socio-economic aspects. The Jhelum River, a transboundary river flowing through Kashmir to Pakistan, holds immense significance in terms of social, environmental, economic, geomorphological, and ecological aspects. Its cultural and religious importance is intertwined with

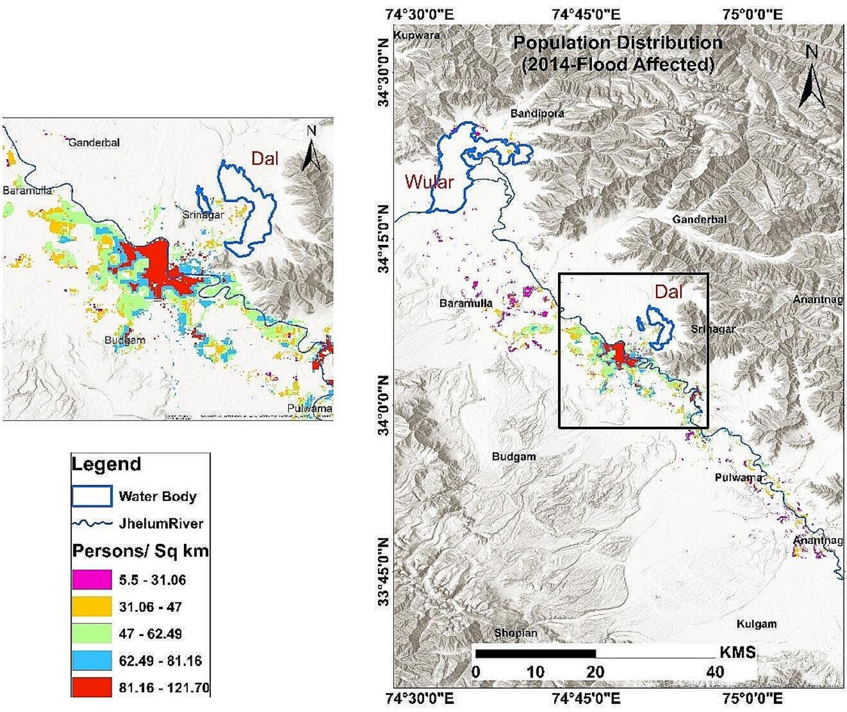

Fig. 3 Spatial distribution of inundated population due to Kashmir Floods of 2014

its role as a vital water resource. The Jhelum River, originating from a deep spring at Verinag (locally called Vernag) in the South Kashmir district of Anantnag, flows north-westward through the Valley of Kashmir to Wular Lake in North Kashmir. The river is an important source of irrigation and hydroelectric power generation.

The Jhelum River is a key component of the valley's river system, and is a vital resource for the local population, providing economic value and livelihoods (Wani et al. 2019). However, it faces significant challenges, including pollution and encroachment (Dar et al. 2021), urban sprawl (Kumar et al. 2020), land system changes (Rather et al. 2016), and decreasing stream flows due to the influence of seasonal precipitation and rising temperatures (Romshoo et al. 2018b; Shafiq et al. 2020). These factors have led to a decline in water quality and increased vulnerability to flooding (Dar et al. 2019; Romshoo, 2018a).

This study reveals that Jhelum River holds immense importance in both the social and economic fabric of Kashmir. Culturally and historically, it is inextricably linked to Kashmir's identity. The river's influence extends beyond its banks, and has shaped settlement patterns, providing offering arable land for farming and acting as a critical supply of water for daily needs such as drinking and irrigation. The river has been a centre for recreational activities and cultural practices, with communities gathering along its shores for festivals, ceremonies, and leisure activities such as boating and fishing. It also holds religious significance for communities, with several temples, shrines, and mosques situated along its course. The river also facilitates tourism and hydroelectric production.

"Jhelum is not a river now; it is a big drain," asserted a community leader in 2014. The community members believe that the reason for flooding in the Jhelum River is its diminished flow capacity caused by the accumulation of waste materials and high levels of silt over an extended period. A resident in 2017 mentioned, "People have extracted only sand from the river and no other materials." Another community member mentioned, "Encroachment on the Jhelum River, like planting trees and houses, has reduced the capacity of the river, which results in flooding." These experiences show that the riverscape of the Jhelum River has been greatly changed to increase the flood vulnerability in Kashmir. These experiences were echoed by other residents at different places, as a community member mentioned, "The 2014 flood showed the earlier actual roots and paths of the river," while another member recollected, "People used to drink the water of the Jhelum River, but now we can't even wash our faces with it at some places. The waste material from house boats is dumped in the river," showing how pollution has affected the riverscape of Jhelum. "A lot of waste material like polythene, bottles, wastage from drainage in upper areas like Srinagar, branches of trees, and soil from mountains and upper areas is accumulated in the Jhelum River per year. This is a continuous process," laments a community leader in 2023. The drainage system of Srinagar city and other places along the Jhelum River is connected with the river, making it highly polluting and reducing the carrying capacity of the river, further exacerbating its vulnerability to flooding.

Community members frequently voice their concerns regarding the recurring floods and their far-reaching consequences for their lives and livelihoods. For instance, a resident of Srinagar, the capital city of Kashmir, lamented in 2023, "During every major flood, when the Jhelum overflows its banks, we lose everything. Our homes, our crops, our memories—all washed away by the relentless floodwaters. It is the mostly the community members that come to the rescue." This poignant statement underscores the profound impact of flooding on the social fabric and economic stability of communities in the region. Moreover, vulnerability to flooding is not evenly distributed among the population. Marginalised communities living along the banks of the river, including low-income households and marginalised ethnic groups, often bear the brunt of the devastation caused by floods. A community member in a flood-prone area expressed frustration in 2014, saying, “We are the ones who suffer the most whenever the river floods. We need to protect the river from degradation and encroachment.”

LULC is important to examine the land use dynamics (Jamal et al. 2022). A LULC map was generated using the pre-flood satellite image to identify flood-affected areas along the Jhelum River floodplain. This map divided the region into built-up areas, cropland, vegetation, water bodies, and barren land. The Kashmir Flood of 2014 had a significant impact on different LULC categories. Water bodies, which comprise 15% of the total area, experienced substantial overflow and inundation (Fig. 4). Vegetation, which covered 8%, faced damage to plant life and soil erosion. Barren lands, which make up 20%, were affected by sediment deposition and changes in soil structure. Croplands, the largest category (41%), suffered significant crop damage, soil erosion, and waterlogging, affecting agricultural productivity. Built-up areas, accounting for 16%, experienced infrastructure damage, property loss, and service interruptions. As a result, the flood devastated all LULC categories, with agricultural and built-up areas impacted most severely.

The lack of infrastructure in the Jhelum River has accounted for several accidents, resulting in the deaths of several people over the years. While the flood threat loomed over the valley in April and May 2024, a boat capsized in the Jhelum River on April 16, 2024, near Batwara, Gandbal, Srinagar, carrying 26 passengers, including schoolchildren and their families. Six fatalities are confirmed, with five rescued and hospitalized. The remaining passengers are still missing. In 2006, another incident occurred in the Bandipora district of North Kashmir, where a boat carrying at least 35 schoolchildren capsized in Wular Lake, claiming the lives of ten children (Gillani 2024). Several residents rely on boats for transportation, establishing a routine due to the absence of bridges for connectivity. When development prioritises tourism over essential infrastructure, tragedies like the recent boat accident in Srinagar are bound to occur. Despite a footbridge in the vicinity of the Srinagar incident awaiting completion for a decade, attention is diverted to cosmetic enhancements such as paintings and lighting throughout the city. The Gandbal Boat Tragedy exposes the disregard for critical infrastructure in Kashmir. The bridges in areas like Rajbagh, Srinagar are transformed into tourist attractions, essential bridge connections are overlooked, resulting in tragic deaths. While the marginalised locals continue to suffer, the prolonged delay in completing critical infrastructure projects, such as bridges, highlights the failure of development initiatives, exacerbating the vulnerability along the Jhelum River.

3.4 Rainfall and hydrological analysis

The rainfall analysis revealed that the region received a high amount of rainfall from September 2 to 6, 2014. Srinagar, which has an average rainfall of 26.6 mm in September, received over 173 mm in the first week alone, setting a record. Southern Kashmir experienced more than 200 mm of rainfall, resulting in massive surface runoff and flooding. Hydrological stations recorded a considerable increase in water levels in the Jhelum River. On September 3, 2014, water levels at Sangam station surged from 5.7 m to more than 10 m the next day. By September 6, the river had spilled over, resulting in several breaches. The

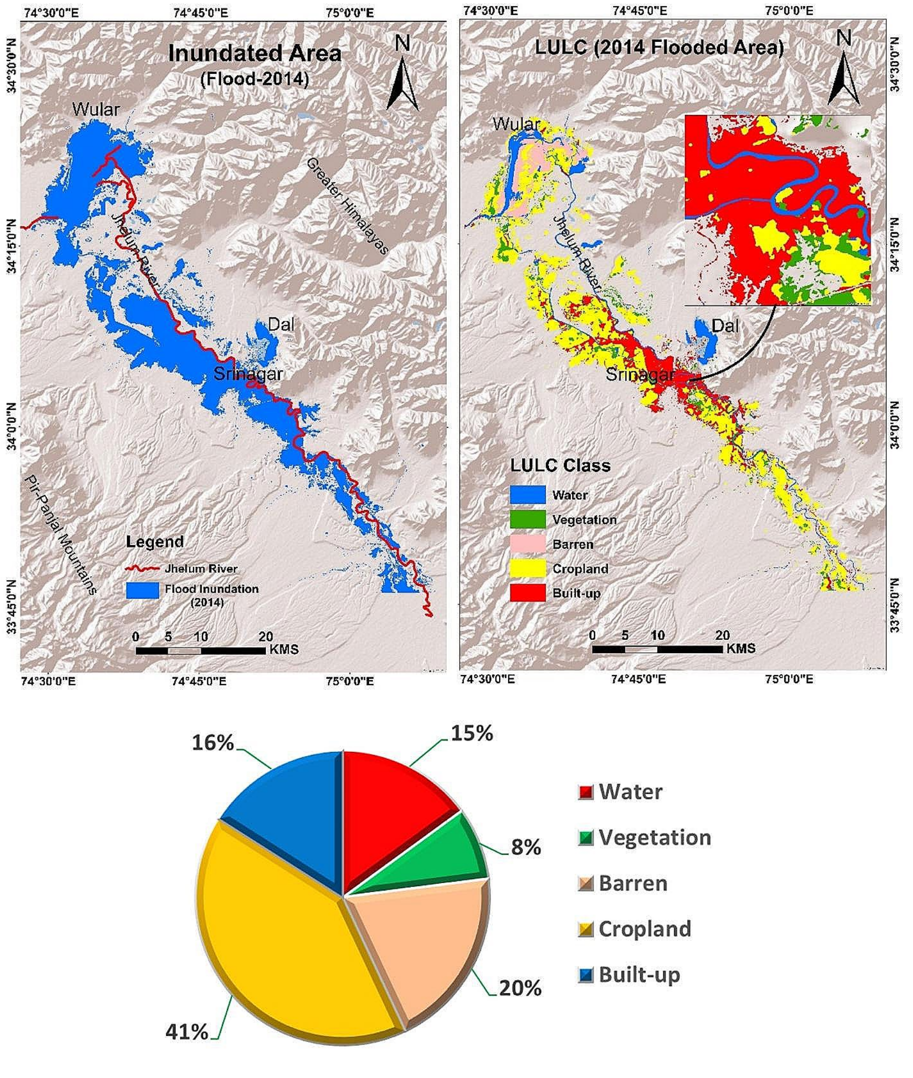

Fig. 4 Spatial analysis of flood inundation along the Jhelum River

flow rate at Sangam was around 135,000 cusecs (cubic feet per second), significantly above the river's limit of 35,000 cusecs in Srinagar, causing severe flooding.

Table 3 shows the maximum flood gauges and associated discharge rates recorded at three flood monitoring locations along the Jhelum River, comparing historical records to measurements made during the September 2014 floods. This comparison shows the unprecedented nature of the 2014 flooding. Prior to September 2014, the highest recorded water level at the Sangam monitoring site was 32.60 feet (5232.08 ft above mean sea level) in September 1992, with a discharge rate of 65,305 cubic feet per second. However, during the September 2014 floods, the water level increased to 34.70 feet (5234.18 ft above mean sea level), and the discharge rate nearly doubled to 115,218 cusecs. This abrupt increase implies

Table 3 Comparison of Highest Recorded Water Levels and Discharge at key flood monitoring sites along the Jhelum River prior to and during the September 2014 Flood

Flood Monitoring Site	Highest Flood Gauges/ level recorded along with discharge prior to and during the September 2014 flood.				
	Month/ Year	Gauges/ Water level	Discharge in cusecs	Gauges/ Water level (2014)	Discharge in cusecs (2014)
River Jhelum at Sangam	09/1992	32.60 Ft 5232.08 Ft	65,305	34.70 Ft 5234.18	1,15,218
River Jhelum at Munshibagh	07/1959	24.70 Ft 5209.14 Ft	46,000 24.00 Ft	**29.50 Ft** 5213.94	72,585
River Jhelum at Asham	06/1996	19.35 Ft 5190.99 Ft	52,750	18.33Ft 5189.97 Ft	47,600

Data *source* Irrigation and Flood Control Department, Govt. of J&K

a significant increase in both water volume and flow, emphasising the devastating impact of the 2014 floods in the area. At the Munshibagh monitoring site, the highest recorded water level prior to the 2014 floods was 24.70 feet (5209.14 feet above mean sea level) in July 1959, with a discharge rate of 46,000 cusecs. During the September 2014 floods, the water level increased to 29.50 feet (5213.94 feet above mean sea level), and the discharge rate rose to 72,585 cusecs. This significant rise in both water level and discharge rate highlights the extreme conditions experienced during the 2014 floods, indicating a much greater severity compared to past events.

In contrast, at the Asham monitoring site, the highest water level prior to the 2014 floods was 19.35 feet (5190.99 feet above mean sea level) in June 1996, with a discharge rate of 52,750 cusecs. During the September 2014 floods, the water level was slightly lower at 18.33 feet (5189.97 feet above mean sea level), with a discharge rate of 47,600 cusecs. This data suggests that the impact of the 2014 floods at Asham was less severe compared to the previous highest recorded levels, indicating variability in the flood's impact across different locations along the river.

3.5 Flood gauge analysis of jhelum river and associated nallahs during september 2014 flooding

Figure 4 depicts a complete overview of the maximum gauge levels recorded during the September 2014 floods at several monitoring stations along the River Jhelum (R.J.) and its adjacent Nallahs (channel/ravine/riverbed/depression). At Awantipora, the gauge level of the River Jhelum was 7.62 m, with the left embankment reaching 6.09 m and the right embankment reaching 7.16 m, both exceeding the danger level of 5.18 m. Similarly, in Pampore, the maximum gauge level was 7.65 m, with left and right embankment levels of 5.85 and 6.50 m, respectively, above the danger level of 4.85 m. The Sempora location recorded a gauge level of 9.43 m, which exceeded the legal embankment level of 6.85 m and the danger threshold of 4.85 m.

In Sind Nallah, the Dodarhama site reported a gauge level of 4.43 m, with overflow levels on both embankments of 5.10 m (left) and 5.90 m (right), which exceeded the danger level of 5.40 m. At Narayan Bagh, the highest gauge level was 5.28 m, with the left and right embankments measuring 5.90 m and 4.80 m, respectively, above the danger limit of 4.30 m. Sukhnagh Nallah locations in Arizal and Kawoosa recorded gauge levels of 3.35 m and 4.60 m, respectively, with comparable embankment and danger levels suggesting a significant overflow and flood risk (Fig. 5).

Doodganga Nallah at Barzullah and Aloochi Bagh had maximum gauge levels of 4.25 m, significant overflow on both embankments, and danger levels of 4.85 m and 3.50 m, respectively. The Brenwar site reported a gauge level of 1.80 m, which matched the left embankment but exceeded the right embankment level of 1.60 m, with a danger level of 1.10 m. Kralpora and Raithan locations also revealed elevated gauge levels and embankment overflow, indicating extensive flooding. Tailbal Nallah had a gauge level of 3.80 m, with left and right embankments of 3.50 m and 2.50 m, respectively, which exceeded the danger level of 2.00 m.

The Spill Channel offtake measured a considerable overflow level of 6.20 m on the left embankment and 6.30 m on the right, which both exceeded the danger level of 5.20 m. The Bemina spill channel reported a gauge level of 3.80 m, with embankment overflows at 3.80 m (left) and 4.50 m (right), which exceeded the danger level of 2.80. Other important sites include Gogaldara Nallah in Aripanthan, Ferozpora Nallah in Magam, Romshi Nallah in Pahoo, and Rambi Ara Nallah in Nayina, all of which had considerable gauge levels and embankment overflows, indicating serious flooding concerns. Watal Ara Nallah in Chursoo and Hallmarg, as well as Aripal Nallah in Kadlabal and Batagund, both recorded significant gauge levels and embankment overflows, highlighting the extensive and severe impact of the September 2014 floods in these locations.

Table 4 presents the daily gauge readings and relative levels (R. Ls) of water surfaces at three critical points—Sangam, Munshibagh, and Wullar—during the floods of September 2014.

- **Sangam**: The water gauge levels ranged from a low of 3.20 feet (1689.85 m R.L.) on September 1st to a peak of 34.70 feet (1700.08 m R.L.) on September 6th. Following the peak, levels gradually declined, showing a steady decrease to 6.30 feet (1690.86 m

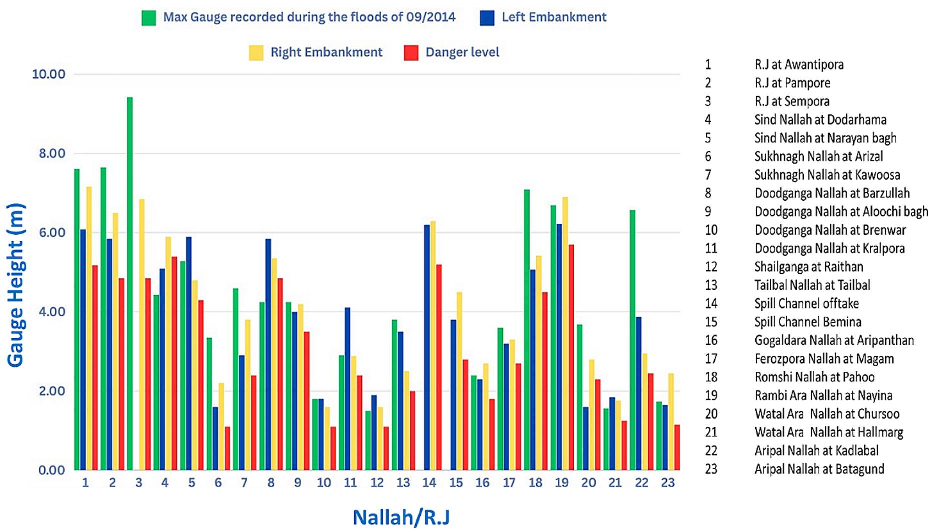

Fig. 5 Maximum Gauge Levels recorded during the September 2014 Floods at various sites along the River Jhelum and associated Nallahs, including overflow and danger levels

Table 4 Daily Gauges /R. Ls of Water Surface at Sangam, Munshibagh, Wullar during the Floods of September 2014

Daily Gauges/*R*.Ls of Water Surface at Sangam, Munshibagh, Wullar during the Floods of 09/2014									
Date	Sangam			Munshi bagh			Wullar		
	Gauge in Ft	*R*.L of water surface		Gauge in Ft	*R*.L of water surface		Gauge in Ft/Mt	*R*.L of water surface	
		Ft	***Mt***		***Ft***	***Mt***		***Ft***	***Mt***
01/09/2014	3.20	5202.68	1689.85	5.45	5189.89	1581.90	3.48/1.06	5168.01	1575.21
02/09/2014	5.40	5204.88	1690.57	7.80	5192.24	1582.62	5.77/1.76	5170.30	1575.91
03/09/2014	14.20	5213.68	1693.42	9.90	5194.34	1583.26	4.56/1.39	5169.10	1575.54
04/09/2014	30.80	5230.28	1698.82	21.80	5206.24	1586.88	4.62/1.41	5169.16	1575.56
05/09/2014	33.65	5233.13	1699.74	22.40	5206.84	1587.07	7.97/2.43	5172.50	1576.58
06/09/2014	34.70	5234.18	1700.08	25.00	5209.44	1587.86	11.81/3.60	5176.34	1577.75
07/09/2014	33.65	5233.13	1699.74	29.50	5213.94	1589.23	13.12/4.00	5177.66	1578.15
08/09/2014	30.50	5229.98	1698.72	26.30	5210.74	1588.25	14.27/4.35	5178.80	1578.50
09/09/2014	25.80	5225.28	1697.19	26.30	5210.74	1588.25	15.26/4.65	5179.80	1578.80
10/09/2014	21.75	5221.23	1695.88	24.25	5208.69	1587.63	15.91/4.85	5180.45	1579.00
11/09/2014	17.35	5216.83	1694.45	22.35	5206.79	1587.05	18.70/5.7	5183.23	1579.85
12/09/2014	14.60	5214.08	1693.55	20.60	5205.04	1586.52	18.47/5.63	5183.00	1579.78
13/09/2014	11.75	5211.23	1692.63	18.80	5203.24	1585.97	18.14/5.53	5182.68	1579.68
14/09/2014	10.30	5209.78	1692.16	17.00	5201.44	1585.42	17.71/5.40	5182.25	1579.55
15/09/2014	9.05	5208.53	1691.75	15.80	5200.24	1585.05	17.48/5.33	5182.02	1579.48
16/09/2014	8.00	5207.48	1691.41	14.75	5199.19	1584.73	17.06/5.2	5181.60	1579.35
17/09/2014	6.90	5206.38	1691.05	13.70	5198.14	1584.41	16.57/5.05	5181.10	1579.20
18/09/2014	6.30	5205.78	1690.86	12.90	5197.34	1584.17	15.91/4.85	5180.45	1579.00

Data *source* Irrigation and Flood Control Department, Govt. of J&K

R.L.) by September 18th.

- **Munshibagh**: This site recorded its highest gauge level of 29.50 feet (1589.23 m R.L.) on September 7th. The gauge readings started at 5.45 feet (1581.90 m R.L.) on September 1st, peaking on the 7th, and then gradually reducing to 12.90 feet (1584.17 m R.L.) by September 18th.
- **Wullar**: At Wullar, the highest gauge reading of 18.70 feet (5.7 m), corresponding to an R.L. of 5183.23 feet (1579.85 m), was recorded on September 11th. The initial reading was 3.48 feet (1.06 m) on September 1st. The levels showed fluctuations but gradually decreased to 15.91 feet (4.85 m) by September 18th.

The data demonstrates the peak and subsequent recession of water levels at these three sites during the flood event. It highlights the critical periods of the flood and provides a clear indication of the maximum water levels recorded each day, with notable peaks around September 6th to 7th and a significant level at Wullar on September 11th. This detailed monitoring is crucial for understanding the flood's dynamics and impacts, informing future flood management and mitigation strategies.

Table 5 Policies and proposals for flood management in Kashmir

Policies and Proposals	Highlights
Purves' recommendations (1915)	- Proposed improvements in outfall channel from Sopore to Khadanyar. - Recommended diversion of Pohru to Wular for maintaining supplies in upper Jhelum canal. - Emphasised need for further hydraulic data collection.
Harris's recommendations (1929)	- Proposed raising and strengthening of embankments along Jhelum. - Recommended construction of new outfall channels and cuts. - Suggested navigation lock near Dal gate and linking channel between Dal and Anchar lakes.
Uppal's recommendations (1956)	- Advocated maintenance of embankments to confine river within certain flood stages. - Proposed diversion of tributaries to prevent inflow of sediment into outfall channel. - Envisioned reclamation of swampy areas for cultivation.
Flood Protection Scheme	- Initiated measures to increase Jhelum River's capacity and limit discharge. - Strengthened embankments and constructed spillway channels.
Master Plan (1959)	- Emphasized dredging and diversion of tributaries for flood control. - Proposed establishment of absorption basins and development of outfall channel.
High Level Flood Committee (1975–1976)	- Recommended strengthening and raising of embankments along Jhelum. - Advocated diversion of excess water through supplementary channel. - Proposed prevention of encroachments and renewal of existing canals in city area. - Suggested measures for stabilization of hill torrents and dredging operations.

4 Policy landscape and response

The scrutiny of the policy landscape by this study highlighted several critical observations. It was found that the flood control strategies in Kashmir were predominantly reliant on physical constructs like dykes and drainage channels. Yet, these interventions proved insufficient for comprehensive flood control and diminishing susceptibilities. Proactive strategies such as alert mechanisms, zoning regulations, and community-driven efforts were noticeably deficient or underdeveloped. The policy structure suffered from a lack of cohesive strategy, with various departments and entities having separate flood control agendas. This disunity led to subpar coordination and cooperation among the involved parties, compromising the flood control initiatives' efficacy. The absence of explicit role definitions and responsibilities among the different entities exacerbated the execution challenges of flood control policies.

These policies and proposals for flood management in Kashmir (Table 5) represent a longstanding endeavour over numerous decades to alleviate the persistent flood threats in the area. Each subsequent policy development and proposal is an enhancement of the preceding ones, often refining tactics with updated information, technological progress, and insights from historical occurrences. Purves' (1915) strategies cantered on water engineering solutions, notably upgrading the main drainage route, and altering smaller streams to regulate water flow. However, the scarcity of extensive data impeded the full execution of this plan. Harris' (1929) strategies introduced the idea of fortifying the banks along the Jhelum River and constructing additional drainage routes and bypasses. His focus on defending the city of Srinagar underscored the necessity for targeted flood control strategies. Uppal's (1956) strategies signified a pivotal transition to inclusive flood management, covering not just levee upkeep but also transforming marshlands into arable land and rerouting tributaries to block sediment entry. This comprehensive strategy aimed to mitigate immediate flood dangers and address enduring agricultural and environmental issues.

Subsequent efforts, such as the Flood Protection Scheme and Master Plan (1959), concentrated on infrastructural enhancements, including overflow routes, absorption basins, and drainage route upgrades. These measures sought to strengthen the area's defences against flooding while also tackling issues like silt build-up and land reclamation. The formation of the High-Level Flood Committee in 1975–1976 indicated an ongoing dedication to evolving flood management approaches. The committee's recommendations stressed the reinforcement of embankments, the addition of auxiliary diversion routes, and pre-emptive actions to secure unstable mountain streams and oversee dredging activities. These initiatives and blueprints for flood control in the Kashmir Valley signify a developmental progression in flood mitigation tactics, transitioning from solitary water-centric solutions to holistic approaches that encompass ecological, societal, and fiscal elements. However, impediments like the dearth of data, lack of support, and limitations in resources have frequently obstructed their thorough realisation, underscoring the imperative for persistent cooperation and flexible management to confront the region's vulnerability to flooding.

In response to the persistent flooding, community members consistently emphasise the urgent need for improved infrastructure and disaster preparedness measures. A local activist advocating for flood-resilient infrastructure stated in 2017, "It's time for authorities to invest in robust flood management infrastructure that can address flooding along the Jhelum in the long term. We need sustainable solutions that prioritise the safety and well-being of our communities." During floods, it was mostly the community members that emerged as the rescuers and hope in the face of deluge and destruction. A community member, while recounting the memories of recent flooding, narrated, "When floods hit, the community relies on each other for support." Another community member mentioned, "Community solidarity is our greatest strength in times of crisis. It is part of our culture." While appreciating the communitarian efforts in times of floods, a participant mentioned, "When the 2014 floods hit us, we lost everything. The people from nearby villages emerged as saviours and distributed rice, vegetables, clothes, and money." Another participant mentioned, "It was the community themselves that saved each other. I am happy that helping each other is still part of our culture. I received a lot of help from people." These narratives depict that social capital and networking act as important factors for community resilience and facilitate mutual assistance and collective action in times of disaster.

5 Conclusion

Kashmir's history is marked by devastating floods, with recent floods serving as a stark reminder of the region's fragility and the necessity for robust flood management strategies. Insights from past experiences emphasise the urgency of proactive measures to mitigate future risks. Despite concerted efforts, challenges persist in implementing effective flood management policies. Inadequate infrastructure, bureaucratic obstacles, and financial limitations hinder the effectiveness of existing frameworks, necessitating a re-evaluation of strategies and priorities. The region grapples with infrastructure deficits, including poorly maintained embankments, inadequate drainage systems, and encroachments on floodplains, all of which exacerbate flood risks and impede disaster response. The intricate interplay between the Jhelum's riverscape, social interactions, and economic factors is profoundly shaped by the persistent problem of flooding and its associated vulnerabilities. The need for key strategies, including investing in early warning systems, integrating climate change adaptation into development planning, promoting community-based disaster preparedness initiatives, equity, and fostering transboundary cooperation for water management, is important in addressing flooding vulnerability in Kashmir.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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