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Household flood resilience in the Nowshera district, Pakistan: A multidimensional analysis

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ABSTRACT

In response to the limitations of conventional flood control measures, modern flood risk management is evolving towards a more community-centred approach, emphasizing household flood resilience. In line with this shift, a multidimensional framework encompassing physical, social, economic, and institutional aspects of flood resilience was developed and applied to Akbar Pura, Mohib Banda, Aman Kot, Khaishki Bala, and Pir Piai union councils in the Nowshera district in Pakistan. An indicator-based approach was used to collect data through questionnaire-based surveys from 210 households in the five union councils. A standardized index-creation procedure was used to create indices for flood resilience and its four key dimensions. The results revealed significant variations in household flood resilience across the union councils, Pir Piai showing the highest resilience (0.45) and Khaishki Bala the lowest (0.38). Access to communication tools, basic utilities, and social networks were factors that improved resilience while low participation in flood preparedness activities, lack of flood emergency plans, limited skills, inadequate financial preparedness, and low trust in government disaster risk reduction programs weakened resilience. We contribute to a growing body of knowledge on flood resilience by demonstrating the critical role of household-level dynamics, integrating often-neglected human and resource dimensions, and providing insights for targeted resilience-building in flood-prone communities.

1. Introduction

Floods pose a significant threat to human lives and property. Between 2000 and 2020, the EM-DAT database recorded 4623 climate-related disaster events, impacting over 3.39 billion people—44 % of the global population in 2020—and causing more than 472,000 deaths. Floods accounted for 55 % of these events, affecting 1.38 billion people and resulting in 89,462 deaths, making them one of the most critical global hazards [1]. According to a World Bank report [2], 2.2 billion people worldwide face some level of flood risk, with East Asia and the Pacific (595.3 million people) and South Asia (370 million people) being particularly vulnerable. As climate science predicts more frequent and extreme precipitation [3], floods are projected to increase in frequency and severity, exacerbating the already large losses they cause globally [4]. The conventional approach to address floods has relied on traditional hard control infrastructure, such as embankments and protection walls [5,6], which has proven inadequate in the face of climate change, urbanization, and compounding factors [5,7,8]. Consequently, a focus on resilience is increasingly considered critical to flood mitigation and recovery [9–11].

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Resilience, a widely-discussed concept across disciplines [12], has over 70 definitions which causes ambiguity about it [13]. The definitions range from viewing resilience as the capacity of a system, groups or communities to recover after a shock or stress to understanding it as their ability to navigate external pressures [14]. Engineering resilience is associated with stability, a system's ability to return to its pre-disrupted state [15]. This view assumes a single ideal state, applicable to many technical systems but less so to ecological ones. As our understanding of social and ecological systems has evolved, resilience concept has expanded to include system flexibility [16], innovation and learning [14], adaptability and self-organization [17], and development [18]. This dynamic understanding acknowledges that resilience is more than bouncing back, encompassing the ability to learn, adapt, and transform in the face of change and uncertainty [19]. Resilience is also aligned with sustainable development and environmental justice theories and is considered community-centred. In this context, societal systems have not yet reached desired sustainable or equitable states, and disruptions demonstrate this deficit. Hence, "community resilience" requires ongoing adaptation and transformation to achieve these goals [20]. The key difference in these varied definitions lies in the interpretation of the "desired functionality or state" of the system, i.e. whether resilience requires returning to the previous state, recognition that multiple suitable states may exists, or a transformation towards an ideal state that has not yet been attained [21].

In flood risk management, there is a shift in focus from physical infrastructure stability to a more comprehensive approach encompassing socio-ecological factors within complex adaptive systems. This shift emphasizes adaptability, transformation, and change, with a focus on human, ecological, and technical system facets [22]. However, this shift presents challenges for policymakers and practitioners in designing strategies that emphasize adaptability to evolving flood scenarios [19,23]. Central to this shift is the recognition that resilience operates at multiple scales, from ecosystems to communities and households. While community and broad city-level resilience indices has garnered considerable attention, its foundation—household resilience—remains underexplored [24]. Household resilience, which reflects the ability of individuals and families to withstand, adapt, and recover from floods, is influenced by physical conditions, social networks, economic resources, and institutional support, making it a critical yet often overlooked component of broader resilience frameworks. Understanding and strengthening resilience at household level is essential for translating broader socio-ecological resilience principles into actionable outcomes at the community level [25]. Household-level resilience analysis integrates household and individual social subjective factors (e.g., beliefs and perceptions) and considers environment and governance settings, offering a holistic perspective and insights into how individual capacities aggregate to shape broader community resilience. However, current research lacks comprehensive theoretical exploration and offers limited guidance for measuring these processes and resilience building outcomes [24]. Additionally, there is a lack of empirical case studies demonstrating the relevance of resilience principles in flood risk management [22].

This study sought to quantitatively assess household-level flood resilience in the Nowshera district, Pakistan, to understand the factors influencing flood resilience. Pakistan ranks 35th most vulnerable to and 27th least prepared in coping with the effects of climate change [26, p.18]. This vulnerability was manifested during the floods of 2022, which resulted in extensive loss of life, livelihoods, and properties: economic losses exceeded $30 billion and $16 billion was needed for reconstruction [27]. Traditional flood management strategies, centred on walls, embankments, and warning systems, proved insufficient during the 2022 floods [28]. In response, authorities are shifting towards proactive approaches [29], which presents an opportunity not only to address immediate challenges but also to learn and derive insights for effective flood risk management strategies. Effective flood risk management requires an understanding of existing flood vulnerabilities and resilience. However, in Pakistan research has mainly focused on flood vulnerabilities [30–34] with limited attention to household-level flood resilience. We attempted to assess household flood resilience in the Nowshera district, Pakistan, and identify indicators influencing it. While the household is the unit of study, the aggregation of household units within a geographic boundary around a flood risk or 'shared fate' can be conceptualized as a 'community' and accordingly we refer to community resilience as the collective resilience of households.

In what follows, section 2 presents frameworks and measurement of flood resilience. Section 3 outlines the conceptual framework and indicators. Section 4 presents material and methods, including study area, research design, sampling techniques, and data collection and analysis methods. Section 5 presents the results and section 6 discusses them.

2. Frameworks and measurement of flood resilience

2.1. Frameworks of resilience

Engineering resilience, ecological resilience, and socio-ecological or adaptive resilience are the three main resilience approaches [22] that offer somewhat different insights. Engineering resilience focuses on the functionality and stability of a system and its physical and technical aspects [35,36]. For it, a priority is enhancement of the robustness and capacity of engineered systems, such as levees and other flood control measures, to withstand disturbances and maintain functionality [37]. The concept of "return time" is central, as it measures how quickly a system can recover and regain its equilibrium after a disturbance.

Ecological resilience in turn focuses on the dynamics of complex ecological systems and their ability to cope with, resist, and bounce forth from disruptions. It recognizes multiple equilibrium states, the interconnectedness of ecological processes, and the need for self-organization and adaptation to maintain ecosystem functions [36]. This framework acknowledges that ecosystems may not return to their original state after a disturbance, but instead may undergo a transformation into a new equilibrium. In flood risk management, ecological resilience highlights the capacity to resist or absorb disturbances while maintaining functionality, which includes withstanding floods and recovering with minimal impact. Here, resilience is based on technical and social factors such as risk avoidance, robustness, redundancy, resourcefulness, and the rapid recovery or restoration of the system [5,38,39]. McClymont and colleagues [37] emphasize that the difference between ecological and engineering resilience lies in their core assumptions about dynamic stability domains, multiple equilibrium states, and the time required to restore equilibrium. While engineering resilience measures the time it takes for a system to return to its equilibrium state, often referred to as "return time," ecological resilience recognizes the potential for unsteady system conditions to trigger transformation or adaptation to new behavioural regimes [36].

Socio-ecological resilience takes an even broader perspective by acknowledging the interdependencies and interactions between social and ecological systems. This framework emphasizes the need for systems to not only resist and recover from disturbances but also to adapt, persist, and transform in the face of disturbances, such as floods, through human intervention [40]. Socio-ecological resilience recognizes that natural or human-made systems operate within dynamic and evolving contexts, emphasizing the temporal dimension of resilience [22]. It highlights nonlinear dynamics, thresholds, and the interplay between gradual and rapid change, while addressing uncertainties associated with slow drivers like climate change, population growth, and resource depletion [18]. In this approach, human intervention, such as flood governance, is a choice between stabilization to prevent the system from moving to a less desirable system state or the transformation towards a more desirable system state, often referred to as "bouncing forward" [41].

In flood risk management and governance, there is increasing recognition that resilience cannot be understood solely in terms of technical infrastructure (engineering resilience). Instead it is essential to integrate robustness and adaptability, emphasizing human, ecological, and technical components [22]. Socio-ecological resilience has emerged as a guiding concept which emphasizes the intricate interplay between social and ecological systems. It highlights the importance of incorporating dimensions such as social cohesion, adaptive governance, ecosystem services, and effective communication in flood risk management [18,42]. However, transitioning to a resilient approach has challenged policymakers and practitioners in designing strategies that emphasize adaptability to evolving flood scenarios [19,23].

2.2. Measuring flood resilience

One challenge of measuring flood resilience arises from the absence of its universally shared definition. At the core of flood resilience lies an interplay between individuals and their environment, where many factors such as past experiences, income levels, health status, flood protection measures and infrastructure decisions come into play, shaping the capacity to withstand and recover from floods [22]. While some indicators are straightforward to assess, others such as flood impacts, introduce uncertainties into the measurement [43]. Systematic metrics for the measurement and operationalization of flood resilience are being developed [44]. However, its multidimensional nature [45,46] complicates the development of measurement tools [47]. Several frameworks have been proposed to conceptualize resilience: they span different scales and contexts, cover phases from pre- to post-disaster situations, and address single shocks or multiple hazards [48]. However, these frameworks are still evolving and undergoing testing and refinement [49].

While there is no universally applicable framework or approach to resilience measurement, researchers have highlighted scorecards, models, toolkits, and indices in their reviews [50–53], with indices being most commonly employed [48,52] to assess resilience across diverse contexts. Notably, indices are applied across fields such as disaster risk [54], vulnerability [55,56], public health [57], urban development and environmental sustainability [58,59]. Indices provide a transparent and understandable way for assessing and comparing resilience [60], making them useful for different types of resilience assessments, including flood resilience. Indices typically integrate multiple indicators across resilience dimensions, allowing for a standardized approach to resilience measurement [44,61]. By quantifying and aggregating indicators, they facilitate comparisons and evidence-based planning. They also encourage consistent data collection, thus bridging data gaps and enabling resilience-building efforts over time [44].

Indices have been used to gauge city or community characteristics, revealing relative positions, magnitudes, and trends in resilience. For example, the City Resilience Index, developed by Arup International Development [62], employs four dimensions of resilience (health and well-being, economy and society, infrastructure and environment, and leadership and strategy) along with 12 goals and 52 indicators. These indicators identify critical city level factors that contribute to the set goals for each city. Miguez and Veról [63] proposed a Flood Resilience Index (FResI) of seven indicators encompassing flooded properties and social factors such as population size, income, and inadequate sanitation. The FResI facilitates decision-making by comparing value differences between present and future scenarios. Batica and Gourbesville [64] developed a city Flood Resilience Index (FRI) featuring five dimensions (social, economic, institutional, physical, and natural) and a set of 91 indicators to describe the urban system characteristics.

A common aspect in the earlier studies is that the resilience indices are not time-dependent and are evaluated on a city-wide basis. Most frameworks and indicators are not applicable at the household level [65], as they prioritize systems, institutions, and policies, overlooking the role of households and their capacities [66]. Also, while many frameworks consider past, present and future time horizons [53], event-based analyses are less common [67]. To address this gap, we attempted to evaluate flood resilience at the household level, using 2022 floods in Pakistan as a case.

3. Conceptual framework

Measuring flood resilience at the household level presents challenges that existing frameworks often overlook, as discussed above. This oversight is significant, as household-level capacities and resources are pivotal for both preparing for and recovering from flood events. Communities exhibit multifunctional characteristics by embracing a range of capacities, emphasizing the importance of interactions between different functionalities that enhance resilience. This concept is highlighted in Wilson's [68] multifunctionality approach, which asserts that communities display diverse capacities that contribute to their overall resilience. Our conceptual framework for assessing household flood resilience adapts and builds on insights from previous frameworks discussed above, especially the works of Wilson [68] and Batica and Gourbesville [64], and focuses on social, physical, economic, and institutional dimensions (see Fig. 1). In our household-focused framework, the social dimension covers community cohesion, family support, and engagement, emphasizing social networks and individual capacities in flood response and recovery. The physical dimension covers communication infrastructure, utility access, and durability of housing, evaluating structural elements crucial for resilience. Economic resilience refers to economic diversification, insurance, and finances for recovery. The institutional dimension covers flood governance, community participation, personalized emergency plans, and trust in government's disaster risk reduction (DRR) efforts.

Unlike approaches such as the City Resilience Index, which primarily focus on systems and policies, our framework considers individuals and household-level capacities and the resources available within communities. Resilience, in this context, is built through local resources and community structures that enhance both individual and collective abilities to cope with flood risk. It highlights that households benefit from well-established systems in these dimensions (social, physical, economic, and institutional) in their community. If these systems create a supportive environment where resources, information, and assistance are readily available, they enable households to effectively prepare for, cope with, and respond to flood events. For instance, strong social networks can facilitate knowledge sharing and encourage community members to participate in resilience-building initiatives, such as flood preparedness training and resource pooling. The framework also acknowledges time and scalability, and recognizes the interplay between society, hazard exposure, resilience strategies, and governance in flooding context. By establishing a resilience-improvement feedback loop, the framework facilitates continuous assessment and iterative improvements. It is also sensitive to site-specific attributes of resilience: indicators related to technology access, literacy rates, and social support networks are context-specific and play a role in influencing resilience outcomes. This ensures that the analysis is grounded in site-specific attributes and offers insights about the unique challenges faced by households in different communities.

3.1. Indicator selection

We used a deductive approach to identify relevant indicators in scoping, selection, design and implementation phases (Fig. 2). The process led to the choice of 41 indicators (Table 1). For the social resilience dimension, literacy of the household head, family composition, presence of dependent individuals, long-term illness or disability, participation in community flood activities, first aid

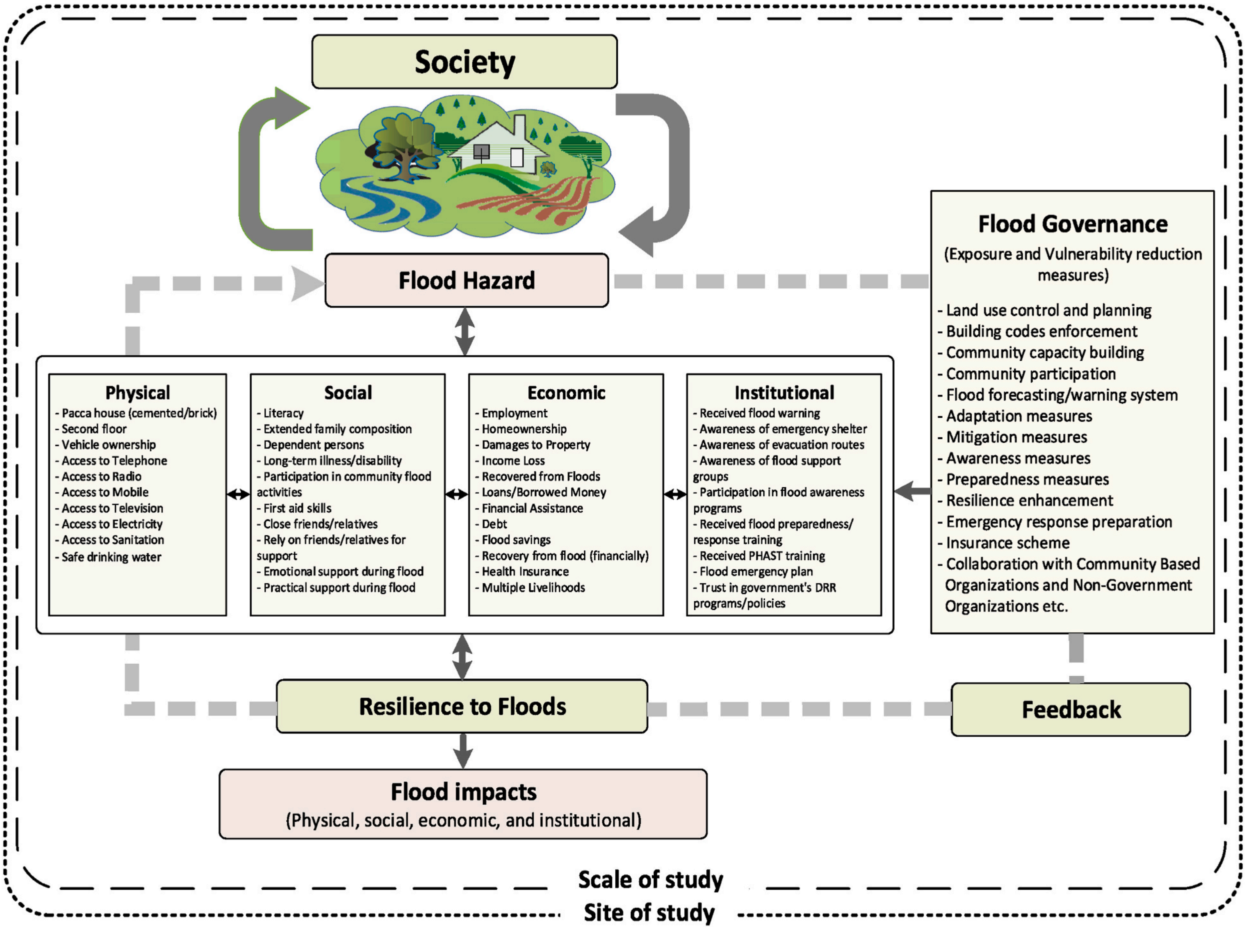

Fig. 1. Conceptual framework.

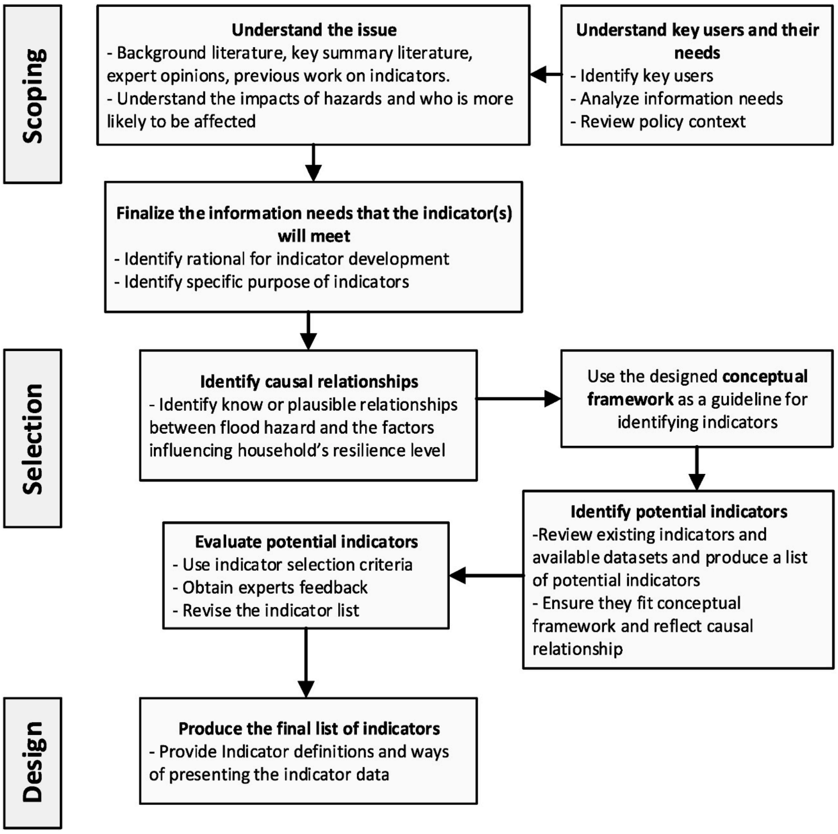

Fig. 2. Indicator development process (adapted from Mason et al. [69]).

skills, presence of friends/relatives in the community, reliance on social support, and reception of emotional and practical support during floods were selected as indicators. The economic resilience dimension is captured through indicators of employment status, property ownership, property damages, loss of income, recovery capability, financial assistance, debt, flood savings, financial recovery, and access to health insurance. For the institutional resilience dimension, flood warning availability, awareness of emergency shelters and evacuation routes, familiarity with flood support groups, participation in awareness programs and training, possession of flood emergency plans, and trust in government disaster risk reduction programs/policies were considered as indicators. The physical resilience dimension encompasses indicators such as housing type (cemented, brick), multi-storey housing, access to communication tools (telephone, radio, mobile, television), electricity, improved sanitation, and safe drinking water.

4. Material and methods

4.1. Study area

Khyber Pakhtunkhwa (KP) province of Pakistan has an area of 74,521 km^2 and a population of 30 million. Agriculture is the primary livelihood for 70 % of the population. The province experiences mild winters and hot summers and has an intricate river system. The major rivers crossing the region are Zhob, Gomal, Kurram, Swat and Kabul Rivers and they cause floods almost every year [27]. Fig. 3 shows the reference map of the study area.

Nowshera district in KP province is highly flood-prone. The district covers 1748 km^2 and has a population of 1.5 million (51.5 % male, 48.5 % female). Average household size is 7.7 persons, literacy rate is 58 %, and 91 % of households have access to electricity. About 17 % of the population is in wage employment and 21 % rely on agriculture. Other livelihoods include private, government, and business endeavours [70]. The district consists of 53.3 % built-up area, 38 % agricultural land, and the rest is range land and water bodies. The yearly average temperature is 24.4 °C although temperature often exceeds 40 °C in the summer. The average annual rainfall is 532 mm, rain occurring in 145 days yearly, most of it in February, March, April, July and August [71].

The Kabul and Bara rivers frequently flood during the rainy season. Jindai, Adazai, and Swat, Naguman, Shah Alam, and Bara Rivers converge into the Kabul River within a 5 km area, leading to floods in the union councils of Akbar Pura, Mohib Banda, Aman Kot, Khaishki Bala, and Pir Piai. Floods disrupt communities, submerging mud-brick homes, crops, and transforming streets, markets, and fields into torrents [71]. Flood vulnerability is exacerbated by the lack of flood risk awareness, absence of building codes, weak institutional frameworks, inadequate land planning, and illegal settlements [72].

Table 1
List of resilience indicators.

Resilience dimension	I#	Indicator	Effect on resilience	Data description
Social resilience	S1	Literacy of household head	+	1 = Literate 0 = Illiterate
	S2	Family composition	+	1 = Extended 0 = Nuclear
	S3	Dependent persons (<15 years and >60 years)	–	1 = No 0 = Yes
	S4	Long-term illness or disability	–	1 = No 0 = Yes
	S5	Participation in community flood activities	+	1 = Yes 0 = No
	S6	First aid skills	+	1 = Yes 0 = No
	S7	Friends/relatives in community	+	1 = Yes 0 = No
	S8	Reliance on friends/relatives for support	+	1 = Yes 0 = No
	S9	Received emotional support during flood	+	1 = Yes 0 = No
	S10	Received practical support during flood	+	1 = Yes 0 = No
Economic resilience	E1	Employment status of household head	+	1 = Employed 0 = Unemployed
	E2	House ownership	+	1 = Yes 0 = No
	E3	Damages to property	–	1 = No 0 = Yes
	E4	Loss of income	–	1 = No 0 = Yes
	E5	Recovery from flood	+	1 = Yes 0 = No
	E6	Loan/borrowed money	–	1 = No 0 = Yes
	E7	Financial assistance for flood losses	–	1 = No 0 = Yes
	E8	Debt	–	1 = No 0 = Yes
	E9	Flood savings	+	1 = Yes 0 = No
	E10	Financial recovery from flood	+	1 = Yes 0 = No
	E11	Health insurance	+	1 = Yes 0 = No
	E12	Multiple livelihoods	+	1 = Yes 0 = No
Institutional resilience	I1	Flood warning	+	1 = Yes 0 = No
	I2	Awareness of emergency shelter	+	1 = Yes 0 = No
	I3	Awareness of evacuation routes	+	1 = Yes 0 = No
	I4	Awareness of flood support groups	+	1 = Yes 0 = No
	I5	Participation in flood awareness programs	+	1 = Yes 0 = No
	I6	Received flood preparedness/response training	+	1 = Yes 0 = No
	I7	Received PHAST training	+	1 = Yes 0 = No
	I8	Flood emergency plan	+	1 = Yes 0 = No
	I9	Trust in government's DRR programs/policies	+	1 = Yes 0 = No
Physical resilience	P1	Pacca house (cemented, brick)	+	1 = Yes 0 = No
	P2	Housing unit with second floor	+	1 = Yes 0 = No
	P3	Own vehicle	+	1 = Yes 0 = No

(*continued on next page*)

Table 1 (*continued*)

Resilience dimension	I#	Indicator	Effect on resilience	Data description
	P4	Access to telephone	+	1 = Yes 0 = No
	P5	Access to radio	+	1 = Yes 0 = No
	P6	Access to mobile	+	1 = Yes 0 = No
	P7	Access to television	+	1 = Yes 0 = No
	P8	Access to electricity	+	1 = Yes 0 = No
	P9	Access to improved sanitation	+	1 = Yes 0 = No
	P10	Access to safe drinking water	+	1 = Yes 0 = No

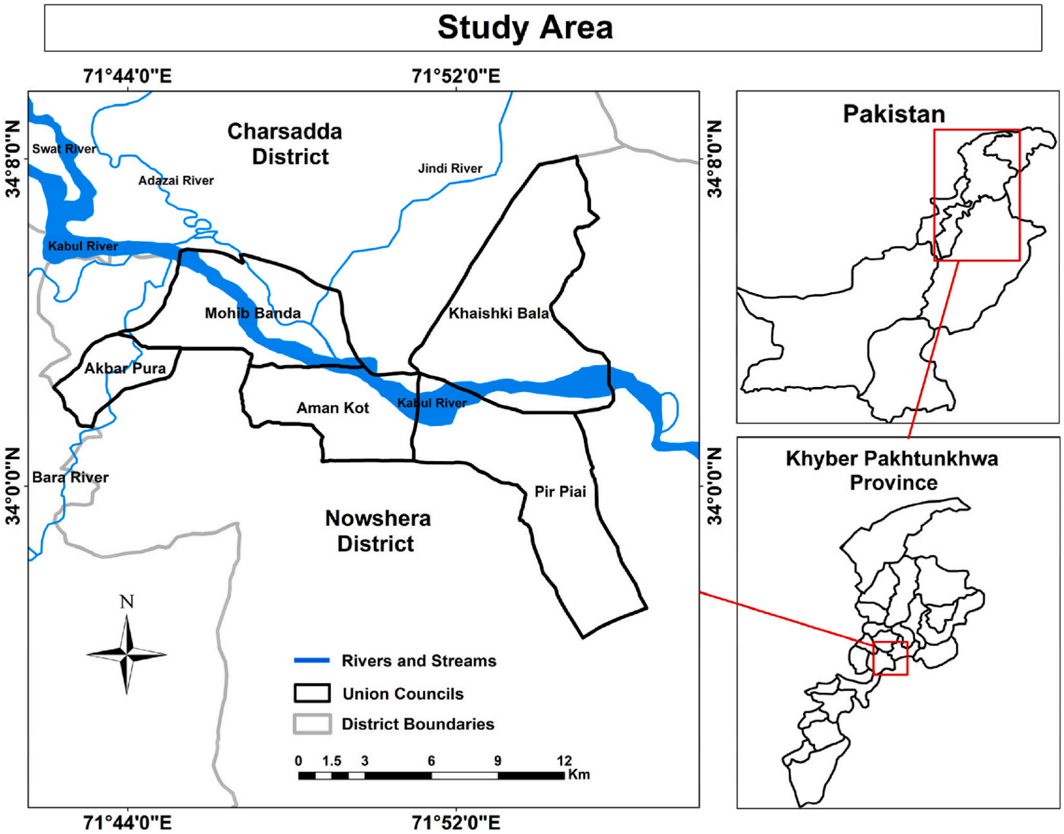

Fig. 3. Study area.

4.2. Sampling approach

Multi-stage sampling approach was used to ensure a comprehensive and valid representation of the flood-affected population. Below, each step of the sampling process is explained:

- **Phase 1:** The choice of focus on the KP province was made due to its history of severe floods. By selecting a province with a significant flood history, the study can shed light on critical issues related to flood impacts and resilience.
- **Phase 2:** Initially the districts of Charsadda, Nowshera, and Peshawar were identified as potential case study sites due to their high flood vulnerability. In the end, Nowshera district was chosen as study area for risk and logistical reasons.
- **Phase 3:** The most affected Union Councils (UCs) of the Nowshera district were identified by superimposing the assessment reports of the Provincial Disaster Management Authority [73] and the flood extent maps from 2010 [74] and 2022 [75].

- **Phase 4:** A purposive sampling method was employed to select UCs located close to rivers and affected by floods. The UCs Akbar Pura, Mohib Banda, Aman Kot, Khaishki Bala, and Pir Piai were selected as areas within the flood-affected region.
- **Phase 5:** The formula $n = \frac{N}{1+N(e)^2}$ proposed by Israel (2013) was used to determine the target sample size. The formula considers the population size, desired confidence level, and margin of error. The sample size of 204 households was determined for a 7 % margin of error. This guarantees that the sample is sufficiently representative of the population.
- **Phase 6:** A total of 210 households were randomly selected from flooded areas within the five chosen UCs to minimize bias and enhance the generalizability of the findings.

4.3. Data collection and analysis

A descriptive cross-sectional survey based on quantitative research design was employed. A questionnaire was designed and refined following a pilot study, and survey was carried out with 210 household heads during April 2023. Prior to data collection, research plan was approved by the University of Leeds ethics committee (ethical approval reference AREA 20–070). Informed consent was obtained from all respondents, ensuring they understood the study's purpose and their right to withdraw at any time. Respondents were assured that their responses would remain confidential and would only be used for research purposes. Data were anonymized and any identifiable information was removed from the dataset. Before analysis, data cleaning was conducted to address incomplete questionnaires and missing values, resulting in 193 complete questionnaires. The collected data were then input into SPSS and Microsoft Excel for further analysis.

We used a standardized index-creation procedure to develop a flood resilience index, producing measurable data that is crucial for evaluating flood resilience [60]. We followed the index-creation methodology of 5 stages proposed by Asadzadeh et al. [50]: i) framework selection/design, ii) indicator selection, iii) data transformation and aggregation, iv) result visualization, and v) index validation. The index creation workflow is presented in Fig. 4, with conceptual framework and indicators discussed in Section 3, while the remaining stages are presented below.

a. Data normalization and aggregation

Data normalization, weighting, and aggregation are needed to prepare the data for aggregation into composite indices. A normalization process is required to adapt the indicator values into a comparable range [76]. For this purpose, Min-Max normalization (Equation (1)) was used to transform the indicators values (in percentages) into a standardized format ranging between 0 and 1.

$$N_{ij} = \frac{X_{ij} - \text{Min}\left(X_{ij}\right)}{\text{Max}\left(X_{ij}\right) - \text{Min}\left(X_{ij}\right)} \tag{1}$$

Equation (1): Minimum-Maximum normalization method

Where Nij denotes the normalized value of each indicator of resilience components for a study unit j, Xij denotes the actual value of indicator for the respective component. Min (Xij) and Max (Xij) are the minimum and maximum values of the indicators for the study unit j. After normalization, equal weighting was used. Cutter and colleagues [60] support equally weighted indices due to their transparency and intuitiveness to end-users. Finally, the normalized and weighted indicator data is aggregated to create composite indices. For data aggregation, average index approach (Equation (2)) was adopted, as it is widely used in composite indicator studies [55,77,78]. For each resilience dimension average indices are calculated and presented as physical resilience index (PRI), social resilience index (SRI), economic resilience index (ERI), and institutional resilience index (IRI).

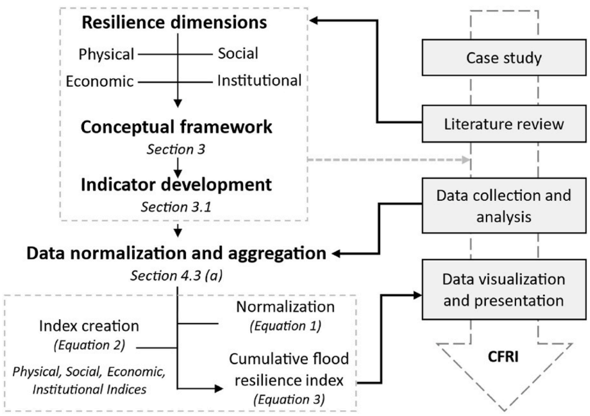

Fig. 4. Methodological approach and workflow of the index creation system.

$$I = \frac{\sum_{i=1}^{n} N_{ij}}{n} \tag{2}$$

Equation (2): Average index method.

Where I is the averaged index for the resilience, Nij is the normalized value of the indicator for the study unit j, and n is the number of indicators. Finally, the composite flood resilience index (CFRI) is computed by inserting the averaged indices of each dimension (PRI, SRI, ERI, and IRI) into Equation (3).

$$\text{CFRI} = \frac{PRI + SRI + ERI + IRI}{4} \tag{3}$$

Equation (3): Additive aggregation method.

The results are presented through tabulated forms and ArcGIS-generated maps, offering both quantitative and visual data representations. Maps use colour classification to illustrate spatial distribution of resilience across the study areas. Tables showcase individual indicator scores expressed as percentages and normalized values (NV), capturing variations in resilience. This combined approach enhanced data representation and understanding of resilience dynamics within study area.

5. Results

5.1. Demographic and socioeconomic characteristics of the respondents

The sample consists of only male participants because of the local norms that prevent women from coming forward to engage with a male researcher [79]. Obtaining data from female participants would have necessitated female research assistants, which was not feasible due to resource constraints. The rationale for a male-only sample was twofold. Firstly, it addressed the practical resource limitations. Secondly, male members of households in the study area typically make the key household decisions so they are the relevant participants. While the followed approach has limitations in terms of generalizability, it underscores the importance of navigating cultural nuances and resource constraints in the design and implementation of research studies.

The largest age group of participants is the 18–29 olds (45.8 %), followed by the 50–59 age group (19.8 %; see also Table 2). Most respondents are married (71.4 %) but some are single (17.7 %) or widowed (10.9 %). A good proportion (42.2 %) of respondents have resided in their homes for 11–15 years. A total of 31.8 % have no education, 40.6 % have completed matriculation, and 8.9 % had a master's degree or higher. The majority (59.4 %) of household heads are unemployed and 40.6 % are employed. Most (60.9 %) respondents had PKR 20,000–40,000 income, a quarter (26.6 %) had an income of less than PKR 20,000, and a minority (12.5 %) earned PKR 40,001–60,000.

5.2. Household flood resilience

Household flood resilience was determined with the Composite Flood Resilience Index (CFRI) (see Fig. 5 and Table 3). The findings indicate that Pir Piai has the highest CFRI value (0.45), while Khaishki Bala has the lowest CFRI value (0.38).

Table 2
Demographic and socioeconomic characteristics of the respondents.

		Frequency	Percent
Gender	Male	192	100
Age	18–29	88	45.80
	30–39	32	16.70
	40–49	34	17.70
	50–59	38	19.80
Marital status	Single	34	17.7
	Married	137	71.4
	Widowed	21	10.9
Duration living in current home	1 to 5	57	29.7
	6 to 10	36	18.8
	11 to 15	81	42.2
	16 or more	18	9.4
Education level of household head	Primary	20	10.4
	Matric	78	40.6
	Intermediate	16	8.3
	Master's and above	17	8.9
	No education	61	31.8
Employment status of household head	Employed	78	40.6
	Unemployed	114	59.4
Monthly income	< PKR 20,000	51	26.6
	PKR 20,000–40,000	117	60.9
	PKR 40,001–60,000	24	12.5

CFRI is a comprehensive measure that considers the physical, social, economic, and institutional dimensions of flood resilience. Pir Piai achieved the highest PRI score at 0.67 for the highest physical resilience. Khaishki Bala in turn had the lowest PRI score (0.55) for lower physical resilience. All UCs have moderate scores for social resilience with Pir Piai attaining the highest SRI score (0.56). The ERI and IRI scores are low in all UCs, highlighting weaker economic and institutional resilience. Khaishki Bala obtained lowest ERI score (0.30). In terms of IRI, Pir Piai had comparatively the highest score (0.23) while Mohib Banda had the lowest (0.14).

Overall, Pir Piai's comparatively higher resilience is due to its better PRI, SRI, and IRI scores. Conversely, Khaishki Bala's lowest resilience is attributed to its low PRI, SRI, and ERI scores. The differences between Pir Piai and Khaishki Bala is due to variations in their indicator values. Next, we present comprehensive analysis of the indicators and their influence on physical, social, economic, and institutional dimensions.

a. Physical resilience

The findings (Fig. 6) indicate that Pir Piai has the highest physical resilience (PRI = 0.67), while Khaishki Bala has the lowest (PRI = 0.55). Pir Piai's higher PRI score is due better access to telephone and radio, improved sanitation, and safe drinking water (see Table 4). Conversely, Khaishki Bala's low PRI score is due its lower scores for all indicators (P1 to P10).

Presence of a second floor is very low in all UCs, ranging from 11 % to 17 %. Vehicle ownership is also low, ranging from 8 % to 12 %, highlighting mobility challenges during floods and in accessing relief. While telephone access (19 %–31 %) is low, good access to mobiles (90 %–95 %) and TVs (76 %–92 %) facilitates communication and provides real-time information.

Most households have access to electricity (92 %–98 %). Access to sanitation (68 %–92 %) is also good, the majority of households have toilet and waste management. Safe drinking water access is also common (62 %–87 %), which is key for hygiene and disease prevention during floods when water contamination risk increases. Access to these utilities strengthens households' capacity to endure floods while safeguarding their health and well-being.

b. Social resilience

Pir Piai had the highest social resilience (SRI = 0.56), while Aman Kot had the lowest (SRI = 0.47) (see Fig. 7 and Table 5). Pir Piai's strong SRI score is due to its high percentage of literate household heads (64 %), extended families (67 %), absence of long-term illness/disability (82 %), comparatively higher participation in community flood activities (23 %), and reception of practical support during flood (46 %). Most households did not have members with long-term illness or disability, ranging from 61 % in Aman Kot to 82 % in Pir Piai. The absence of dependents (children and elderly) ranged from 16 % to 32 %. Participation in community flood activities was very limited (12 %–23 %) and first aid skills were scarce (3 %–8 %) across all UCs.

Most households (82 %–93 %) have close friends or relatives, and reliance on them for flood support varied from 43 % to 62 %.

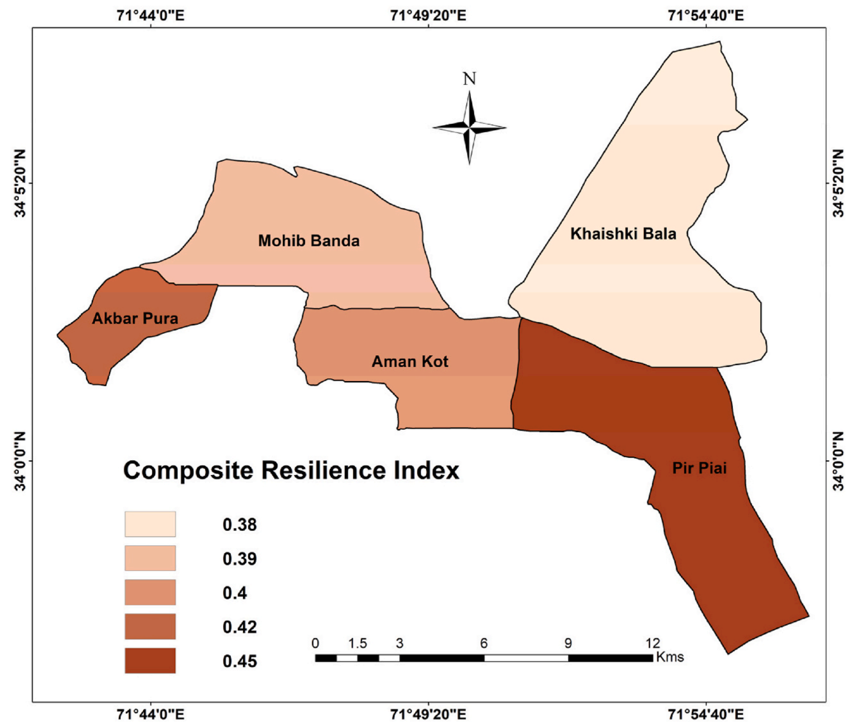

Fig. 5. Composite resilience of households.

Table 3
Composite resilience indices.

Dimensions^	Akbar Pura	Mohib Banda	Aman Kot	Pir Piai	Khaishki Bala
PRI	0.63	0.61	0.64	0.67	0.55
SRI	0.51	0.50	0.47	0.56	0.50
ERI	0.37	0.31	0.34	0.35	0.30
IRI	0.17	0.14	0.15	0.23	0.18
CFRI	**0.42**	**0.39**	**0.40**	**0.45**	**0.38**

^Note: PRI, Physical resilience index; **SRI**, Social resilience index; **ERI**, Economic resilience index; **IRI**, Institutional resilience index; **CFRI**, Composite flood resilience index.

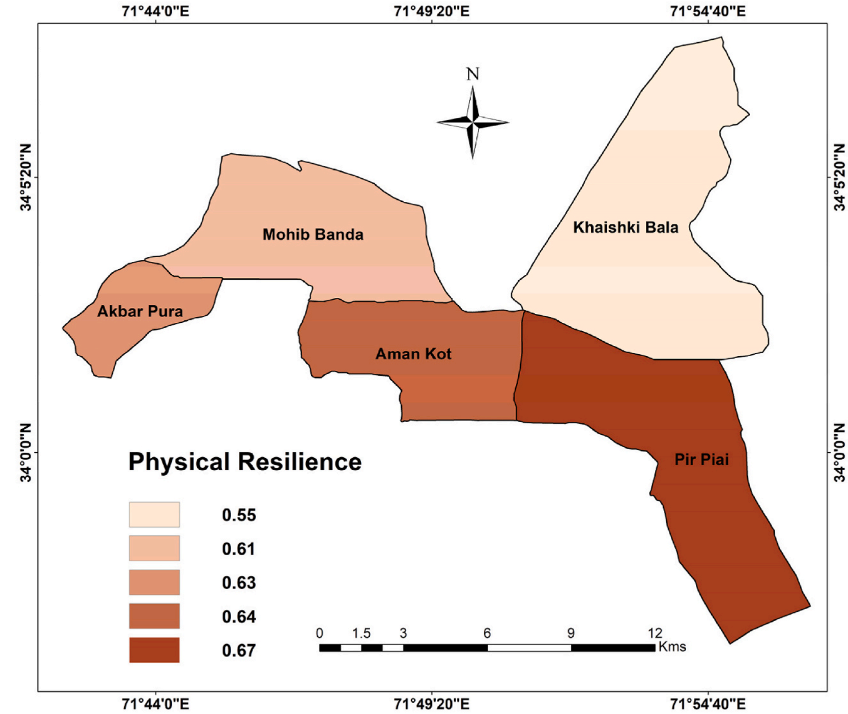

Fig. 6. Physical resilience of households.

Table 4
Physical resilience indicators.

Indicators^	Akbar Pura %	NV*	Mohib Banda %	NV	Aman Kot %	NV	Pir Piai %	NV	Khaishki Bala %	NV
P1	58	0.57	43	0.44	61	0.62	54	0.55	38	0.39
P2	16	0.11	14	0.12	17	0.15	15	0.14	11	0.09
P3	11	0.06	8	0.06	12	0.10	10	0.08	8	0.06
P4	29	0.26	27	0.26	22	0.21	31	0.31	19	0.18
P5	82	0.83	76	0.79	80	0.82	82	0.86	51	0.55
P6	95	0.97	92	0.97	95	0.97	90	0.94	92	1.00
P7	87	0.88	76	0.79	85	0.87	92	0.97	76	0.82
P8	97	1.00	95	1.00	98	1.00	95	1.00	92	1.00
P9	79	0.80	84	0.88	88	0.90	92	0.97	68	0.73
P10	82	0.83	78	0.82	78	0.79	87	0.92	62	0.67
PRI		**0.63**		**0.61**		**0.64**		**0.67**		**0.55**

^Note: P1, Pacca houses (cemented, brick); **P2**, Household with second floor; **P3**, Vehicle ownership; **P4** Access to telephone; **P5**, Access to radio; **P6**, Access to mobile; **P7**, Access to television; **P8**, Access to electricity; **P9**, Access to improved sanitation; **P10**, Access to safe drinking water; **PRI**, Physical resilience index.
*__Note: NV__, Normalized values.

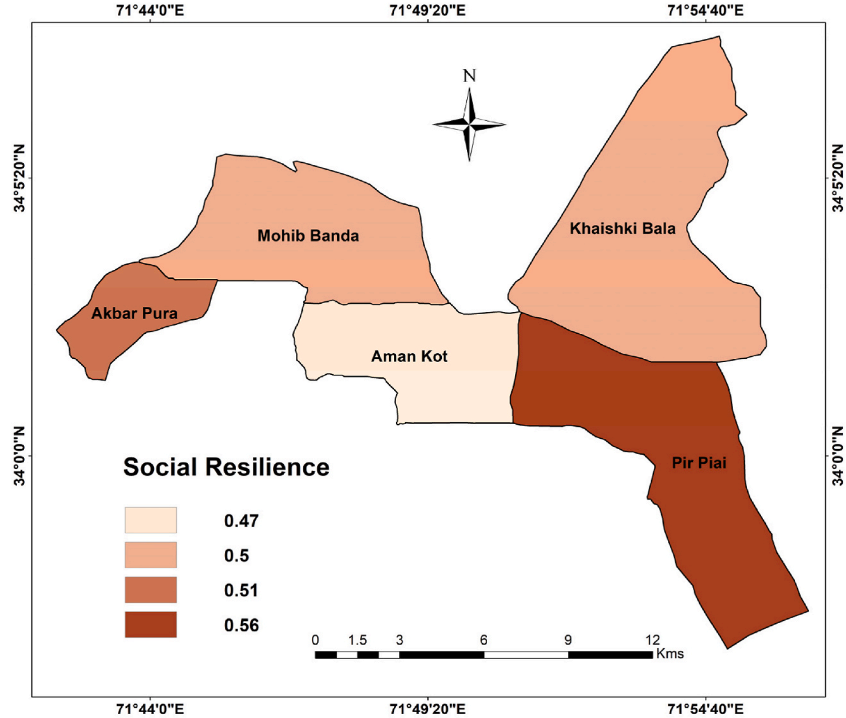

Fig. 7. Social resilience of households.

Table 5
Social resilience indicators.

Indicatorsˆ	Akbar Pura %	NV*	Mohib Banda %	NV	Aman Kot %	NV	Pir Piai %	NV	Khaishki Bala %	NV
S1	55	0.54	43	0.44	51	0.51	64	0.67	49	0.51
S2	66	0.66	51	0.53	59	0.59	67	0.69	57	0.61
S3	32	0.29	30	0.29	20	0.18	26	0.25	16	0.15
S4	66	0.66	73	0.76	61	0.62	82	0.86	78	0.85
S5	16	0.11	14	0.12	12	0.10	23	0.22	19	0.18
S6	8	0.03	5	0.03	5	0.03	3	0.00	5	0.03
S7	87	0.88	84	0.88	93	0.95	82	0.86	89	0.97
S8	58	0.57	62	0.65	46	0.46	59	0.61	43	0.45
S9	95	0.97	89	0.94	90	0.92	87	0.92	81	0.88
S10	42	0.40	32	0.32	37	0.36	46	0.47	38	0.39
SRI		**0.51**		**0.50**		**0.47**		**0.56**		**0.50**

ˆNote: S1, Literacy of household head; **S2**, Extended family composition; **S3**, No dependent persons; **S4**, No long-term illness/disability; **S5**, Participation in community flood activities; **S6**, First aid skills; **S7**, Close friends/relatives; **S8**, Rely on friends/relatives for support; **S9**, Received emotional support during flood; **S10**, Received practical support during flood; **SRI**, Social resilience index.
Note: NV, Normalized values.

Most households (81 %–95 %) received emotional support from their social networks during floods. However, practical support was less common, ranging from 32 % in Mohib Banda to 46 % in Pir Piai. Overall, Pir Piai had the highest social resilience and Aman Kot the lowest. Pir Piai benefits from higher literacy, extended families, fewer dependents, absence of long-term illness/disability, and robust community participation. In contrast, Aman Kot is disadvantaged in terms of literacy, community participation and first aid skills.

c. Economic resilience

All UCs have low economic resilience (Fig. 8). Akbar Pura is the most economically resilient (ERI = 0.37), while Khaishki Bala is the least resilient (ERI = 0.3; see Table 6). Akbar Pura's high ERI score is due to its higher percentage of households with no flood-related income loss (24 %), no loans/borrowed money (71 %), no debt (71 %), health insurance (17 %), and financially recovered from flood (11 %). Khaishki Bala in turn has lower percentage of households with no flood-related loans/borrowed money (54 %), no financial assistance for flood losses (27 %), no debt (46 %), health insurance (8 %), and financially recovered from flood (3 %).

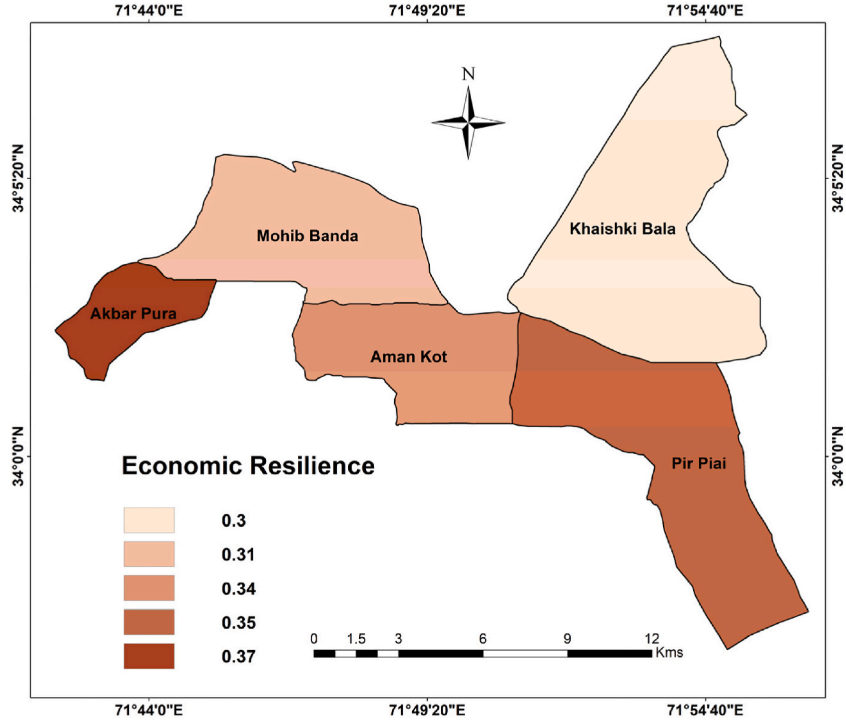

Fig. 8. Economic resilience of households.

Table 6
Economic resilience indicators.

Indicators^	Akbar Pura %	NV*	Mohib Banda %	NV	Aman Kot %	NV	Pir Piai %	NV	Khaishki Bala %	NV
E1	40	0.37	41	0.41	34	0.33	49	0.50	41	0.42
E2	61	0.60	68	0.71	46	0.46	51	0.53	57	0.61
E3	24	0.20	11	0.09	22	0.21	18	0.17	19	0.18
E4	37	0.34	22	0.21	34	0.33	33	0.33	38	0.39
E5	13	0.09	8	0.06	22	0.21	10	0.08	14	0.12
E6	71	0.71	62	0.65	56	0.56	64	0.67	54	0.58
E7	79	0.80	60	0.62	85	0.87	69	0.72	27	0.27
E8	71	0.71	54	0.56	56	0.56	62	0.64	46	0.48
E9	5	0.00	3	0.00	2	0.00	3	0.00	3	0.00
E10	11	0.06	3	0.00	5	0.03	8	0.06	3	0.00
E11	17	0.12	8	0.06	15	0.13	10	0.08	8	0.06
E12	42	0.40	35	0.35	39	0.38	46	0.47	49	0.51
ERI		**0.37**		**0.31**		**0.34**		**0.35**		**0.30**

*__Note: E1__, Employment; **E2**, Homeownership; **E3**, Undamaged house; **E4**, No income loss; **E5**, Recovered from flood; **E6**, No flood-related loans/ borrowed money; **E7**, No financial assistance for flood losses; **E8**, No debt; **E9**, Flood savings; **E10**, Financially recovered from flood; **E11**, Health insurance; **E12**, Multiple livelihoods; **ERI**, Economic resilience index.
*__Note: NV__, Normalized values.

From 34 % to 49 % household heads were in employment and homeownerships ranged from 46 % to 68 %. No income losses were experienced by 22 %–38 % of households, and 11 %–17 % of them did not experience damage to their houses. Only 8 %–22 % of households had recovered from floods. Very few households had flood savings (2 %–5 %) or health insurance (8 %–17 %), and few of them had financially recovered from flood (3 %–11 %).

On the other hand, the findings indicate that most households did not take out a loan or borrow money (54 %–71 %) and are not in debt (46 %–71 %). The percentage of households that didn't apply for or receive financial assistance ranged from 60 % to 79 %, except in Khaishki Bala (27 %). The percentage of households with multiple livelihoods ranged from 35 % to 49 %.

The results indicate limited but varied economic resilience, with Akbar Pura having the highest and Khaishki Bala the lowest resilience. Akbar Pura's high ERI score stems from many households with no flood-related income loss, no loans, no debt, health insurance, and post-flood financial recovery. Conversely, Khaishki Bala's lower score stems from fewer households without flood-related loans and debt with minimal health insurance and post-flood financial recovery.

d. Institutional resilience

All UCs have very low institutional resilience (IRI) (Fig. 9). Pir Piai had the highest institutional resilience (IRI = 0.23), while Mohib Banda had the lowest (IRI = 0.14). Pir Piai's higher IRI score is due to higher percentage of its households receiving flood warnings (69 %), being aware of evacuation routes (39 %), emergency shelter (33 %), and flood support groups (28 %) (see Table 7). Mohib Banda's low IRI score is in turn due to its low percentage of households who received flood warning (49 %), were aware of emergency shelter (19 %) and evacuation routes (16 %), participated in flood awareness programs (14 %), and received flood preparedness/response training (8 %).

High proportion (from 49 % to 68 %) of households received flood warnings. In contrast, there was lower awareness of emergency shelters (19 %–33 %), evacuation routes (16 %–39 %), and flood support groups (15 %–28 %). There was also very limited participation in flood awareness programs (14 %–19 %), reception of flood preparedness/response training (8 %–12 %) and PHAST training (2 %–8 %), as well as the availability of flood emergency plans (2 %–5 %). The results also highlight limited trust (3 %–8 %) in government's DRR programs and policies, which undermines effective cooperation and collaboration during emergencies.

5.3. Correlation analysis

Correlation analysis examines associations between resilience indicators through correlation coefficients (r) ranging from −1.0 to 1.0. Key correlations are presented in a chord diagram (Fig. 10). Other correlations do exist, but they are not presented due to their limited relevance to the objectives of the analysis. A comprehensive correlation matrix heatmap is in Appendix A. It is important to note that the correlation coefficients reveal relationships between variables but do not imply causation.

No correlations emerged between physical and institutional dimensions of resilince. But significant positive correlations exist between cement/brick housing and having a second floor (r = 0.32), improved sanitation (r = 0.34), and access to safe water (r = 0.52). Improved sanitation is also correlated with access to safe water (r = 0.44). Cement/brick housing also correlated positively with reliance on friends/relatives for support (r = 0.3) and receiving practical support during floods (r = 0.38). However, negative correlations exist between cement/brick houses and no house damages (r = −0.49), flood recovery (r = −0.40), and no income loss (r = −0.62). That is, while such construction offers protection against physical damage, households remain vulnerable to flood-related damages and income losses from damaged household items, furniture, and productive assets like crops, livestock, or small businesses. The analysis also revealed positive correlation between access to mobile phones and literacy (r = 0.3), as well as flood warnings (r = 0.22), suggesting that households with mobile phones might have higher literacy rates and access to flood-related information and warnings.

Among social resilience indicators (S1 to S10), literacy correlated positively with employment (r = 0.47), receiving flood warnings (r = 0.62), and awareness of flood support groups (r = 0.23). Extended family structures have positive correlations with emotional

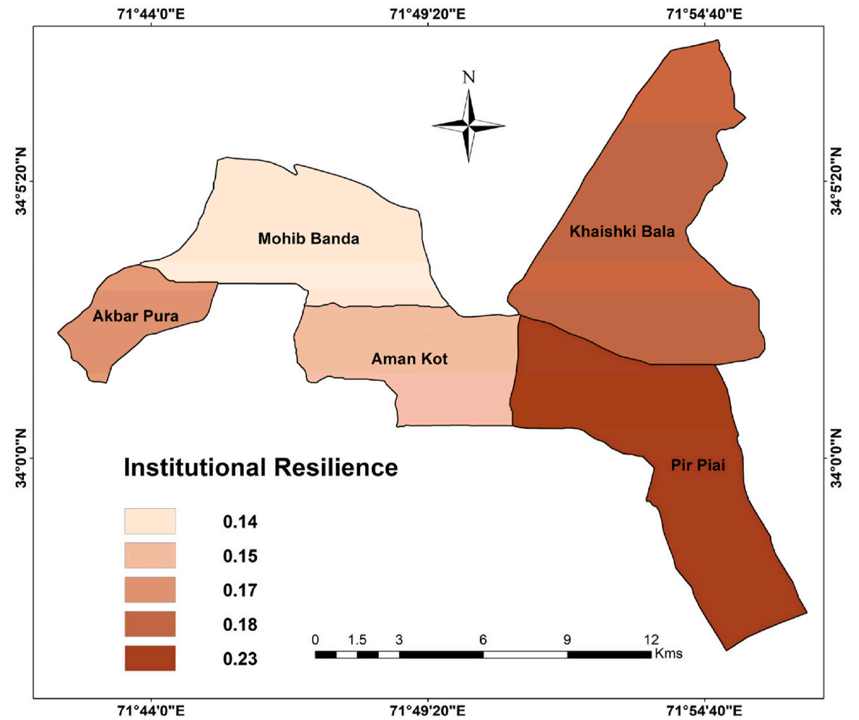

Fig. 9. Institutional resilience of households.

Table 7
Institutional resilience indicators.

Indicators^	Akbar Pura %	NV*	Mohib Banda %	NV	Aman Kot %	NV	Pir Piai %	NV	Khaishki Bala %	NV
I1	68	0.69	49	0.50	54	0.54	69	0.72	62	0.67
I2	32	0.29	19	0.18	27	0.26	33	0.33	30	0.30
I3	21	0.17	16	0.15	17	0.15	39	0.39	22	0.21
I4	18	0.14	19	0.18	15	0.13	28	0.27	16	0.15
I5	18	0.14	14	0.12	15	0.13	18	0.16	19	0.18
I6	11	0.06	8	0.06	12	0.10	10	0.08	11	0.09
I7	8	0.03	3	0.00	2	0.00	8	0.05	5	0.03
I8	5	0.00	5	0.03	2	0.00	5	0.02	3	0.00
I9	8	0.03	5	0.03	7	0.05	5	0.02	3	0.00
IRI		**0.17**		**0.14**		**0.15**		**0.23**		**0.18**

^Note: I1, Received flood warning; **I2**, Awareness of emergency shelter; **I3**, Awareness of evacuation routes; **I4**, Awareness of flood support groups; **I5**, Participation in flood awareness programs; **I6**, Received flood preparedness/response training; **I7**, Received PHAST training; **I8**, Flood emergency plan; **I9**, Trust in government's DRR programs/policies; **IRI**, Institutional resilience index.
*__Note: NV__, Normalized values.

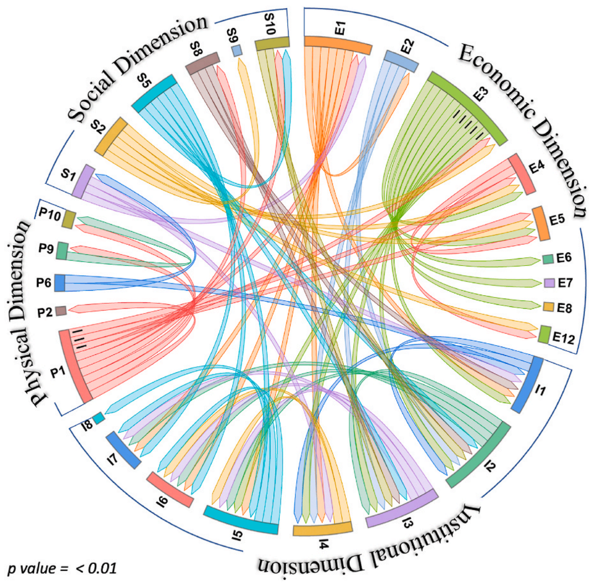

Fig. 10. Correlation chord diagram.
Note: The "–" sign showing negative correlations while the rest showing positive correlations.

support (r = 0.31), no house damage (r = 0.37), no income loss (r = 0.41), multiple livelihoods (r = 0.61), and flood recovery (r = 0.29). Participation in community flood activities positively correlated with awareness of emergency shelter (r = 0.59) and evacuation routes (r = 0.49), participation in flood awareness programs (r = 0.47), preparedness/response training (r = 0.40), PHAST training (r = 0.40), and practical flood support (r = 0.50). This underscores the importance of community involvement in enhancing awareness, emergency resources access, and supportive networks for effective response. Additionally, reliance on friends/family for support correlated positively with receiving flood warnings (r = 0.32) and awareness of emergency shelter (r = 0.40) and evacuation routes (r = 0.41). Receiving practical flood support correlated positively with awareness of emergency shelter (r = 0.59) and evacuation routes (r = 0.48).

Among economic resilience indicators (E1 to E12), employment correlated positively with house ownership (r = 0.28), receiving flood warnings (r = 0.24), awareness of flood support groups (r = 0.21), participation in flood awareness programs (r = 0.37), preparedness/response training (r = 0.20), and PHAST training (r = 0.24): employed households likely access resources, engage in community networks, and prepare for floods. Home ownership correlated positively with awareness of emergency shelter (r = 0.27), evacuation routes (r = 0.21), and flood support groups (r = 0.22). Undamaged houses displayed positive correlations with no income loss (r = 0.63), no loan/borrowed money (r = 0.38), no financial assistance (r = 0.30), no debt (r = 0.30), and flood recovery (r = 0.82). However, undamaged houses were negatively correlated with receiving flood warning (r = −0.51), awareness of emergency shelter (r = −0.3), evacuation routes (r = −0.24), flood support groups (r = −0.23), and participation in flood awareness programs (r = −0.21): flood impacts play a role in influencing household behaviour and decision-making regarding flood resilience. Furthermore, no income loss correlated positively with multiple livelihoods (r = 0.82) and flood recovery (r = 0.53), indicating that diverse income sources contribute to lesser financial impact during floods and better recovery.

Among the institutional resilience indicators (I1 to I9), flood warnings correlated with awareness of emergency shelters (r = 0.15) and flood support groups (r = 0.29). Awareness of emergency shelters also correlated with awareness of evacuation routes (r = 0.79), participation in flood awareness programs (r = 0.34), flood preparedness and response training (r = 0.36), and PHAST training (r = 0.37). Awareness of evacuation routes correlated positively with participation in flood awareness programs (r = 0.35), received flood preparedness and response training (r = 0.38), and PHAST training (r = 0.32). Awareness of flood support groups had a positive correlation with participation in flood awareness programs (r = 0.28) and flood preparedness/response training (r = 0.40). These correlations indicate that households are aware of evacuation routes and that flood support groups more likely engage in flood awareness and preparedness training for improved readiness and response to floods. Participation in flood awareness programs is also positively correlated with receiving flood preparedness and response training (r = 0.63), PHAST training (r = 0.40) and with the existence of flood emergency plans (r = 0.26).

6. Discussion

In response to the limitations of conventional flood control measures [5,7,8], modern flood risk management is evolving towards a more community-centred approach, emphasizing the importance of building community flood resilience [48]. In line with this shift, we assessed flood resilience at the household level in a developing country context, encompassing the physical, social, economic, and institutional dimensions (see Fig. 1). Our study focused on the union councils of Akbar Pura, Mohib Banda, Aman Kot, Khaishki Bala, and Pir Piai in the Nowshera district in Pakistan. We employed a standardized procedure (section 4.3) to create indices for flood resilience and its four key dimensions. This approach helped generate quantifiable and measurable data, which is crucial for evaluating complex concepts like flood resilience [60].

The findings indicate varying levels of household flood resilience, with Pir Piai exhibiting higher resilience and Khaishki Bala having the lowest resilience. Pir Piai's higher flood resilience is due to its better scores in the physical, social, and institutional dimensions, whereas Khaishki Bala's lower resilience arises from weaker scores in the physical, social, and economic dimensions. The findings highlight that the key indicators that increase physical resilience are pacca houses (cemented and durable structures), access to communication tools (telephone, radio, TVs), improved sanitation, and safe drinking water. Existing research underscores that physical resilience is linked to durable housing, which can better resist floods than mud houses [80]. Access to communication channels and utilities in turn enables households to receive real-time information, coordinate with family and community, and maintain key services, reinforcing their capacity to endure flood impacts and safeguard their health and well-being [81,82]. However, the scarcity of vehicle ownership and second-floor housing hinder household responses to flooding [83,84].

The study's exploration of social resilience identified larger extended families, absence of long-term illness/disability, good literacy rates among household heads, and strong social support networks as key variables. These factors are recognized to enhance resilience [81,85]. Literacy aids informed decision-making through improved information access, while extended families can provide support during floods [81]. Adger [86] and Murphy [87] argue that strong social networks correlate with heightened resilience, aiding post-disaster recovery and adaptation. While the study area's robust social networks highlight mutual aid during floods, they also reveal an over-reliance on informal networks rather than formal support systems. To ensure a more resilient response to floods, it is essential to strengthen both informal and formal community support, as advocated by Walker-Springett et al. [88]. The findings also indicate that most households have dependents. While larger households are assumed to have more resources and reduce their vulnerability through education and financial assistance [89], this may not be true for rural communities, as argued by Shah et al. [90] and Hamidi et al. [91]. Dependents, including children and the elderly, can strain resource sharing and complicate decision-making, evacuation planning, and support systems during floods. They are vulnerable groups, requiring attention for safe relocation and households with dependents often encounter challenges in timely evacuation during floods [90,91]. Additionally, minimal engagement in community flood activities and limited first-aid skills prevailed in all UCs.

Economic resilience, which encompasses e.g. employment, wealth, business continuity and finance, plays a critical role in disaster mitigation [92,93]. Our findings highlight low economic resilience across the five UCs. This is manifested by the relatively high percentage of damaged houses with income loss, lack of flood savings, and limited financial recovery post-floods: these factors increase vulnerability to economic shocks and impair financial preparedness for losses. Only few households have health insurance which is crucial for injury treatment and recovery [94]. However, despite these challenges, all UCs had a relatively high level of employment, homeownership, multiple livelihoods, and households without loans/debt. These factors have been identified as enabling investment in flood-resilient structures and adaptation measures [93,95–97]. For example, Ahmed's [98] study in the same region found that households with diverse livelihoods adopted e.g. elevated ground floors to cope with floods. To enhance economic resilience, priority should be given to promoting economic diversification, livelihood protection, financial readiness, and insurance options tailored to vulnerable households (see also [81,99]).

Institutional resilience is closely linked to social, economic, and political dimensions [100]. It is underpinned by factors such as disaster planning, public awareness, participation in campaigns, contingency plans, emergency services access, and early warnings [42]. The findings suggest somewhat weak institutional resilience across the UCs, due to households' low awareness of emergency shelters, evacuation routes, and flood support groups, as well as minimal participation in flood awareness programs and preparedness/response and PHAST trainings. There was also a lack of flood emergency plans and distrust in government's DRR programs and policies. The literature has emphasized the critical role of these factors for resilience [42,81,85,93,101]. Limited awareness and adoption of preparedness/response and PHAST training can leave households more susceptible to flood impacts and distrust in government's DRR programs/policies may hinder cooperation and collaboration during emergencies. Research has demonstrated that trust influences risk perception and affects engagement and compliance with recommended measures [102]. When trust is lacking, households may perceive government efforts insufficient, leading to reduced engagement, lower compliance, and obstacles to resilience-building initiatives [103]. To improve institutional resilience, interventions should promote community participation in awareness programs, provide accessible flood preparedness/response and PHAST training, encourage personalized flood emergency plans, and build trust through transparent and effective DRR programs/policies [81].

The findings indicate a complex interplay of factors of flood resilience. However, physical and institutional dimensions were not related, suggesting that formal measures and interventions may not be strongly associated with how people/households seek to avoid and mitigate risk. This resonates with Aftab et al.'s [104] research, which found that flood-affected communities in Pakistan receive limited short-term post-disaster government support, while comprehensive long-term strategic flood prevention and adaptive planning measures remain insufficient. Local institutions are often unprepared and lack resources, infrastructure and equipment, and suffer from coordination challenges [105], resulting in delayed responses and inadequate restoration of services after floods [98]. This lack of institutional support contributes to dissatisfaction with the current disaster management system [106] and distrust in institutional initiatives, which may explain the observed reliance on autonomous, community-driven adaptation measures. These findings echo those previous studies [81,98,104], which suggest that limited institutional support drives communities toward informal adaptive responses. Autonomous adaptation and bonding capital reflect the significance of community support networks in sharing burdens and strenthening resilience. Common adaptation measures include elevating building plinths, grain storage, communal flood preparation, and planting tree-lined shelterbelts for protection and resource use [104], as well as elevated ground floors and food stockpiling to cope with monsoon floods [98]. Ahmad's [98] research found that adaptation decisions mainly stem from past flood experiences, vulnerability, and communal learning, while Aftab and colleagues [104] identified factors such as flood duration, river proximity, communal flood preparation, and post-flooding support as key factors in influencing flood adaptations. These local practices are particularly important in rural and resource-constrained environments, where institutional reach is minimal. Such local community-driven adaptation efforts and traditional knowledge, such as memory on past events, highlight the need to incorporate local context and community-specific knowledge into flood resilience strategies for more effective and context-appropriate responses.

This research makes a contribution to the literature on flood resilience assessment. First, it addresses a gap in the current methods of quantifying resilience by incorporating the often-neglected human and resource dimensions of resilience into the framework, which broader indices like the City Resilience Index omit [66]. Focusing on the household level allows for a nuanced examination of the complex interplay between floods, societal factors, resilience mechanisms, and governance. The framework's adaptability to the unique attributes of a study area makes it both practical and contextually relevant, enhancing its ability to offer tailored insights into resilience-building efforts. The selection of indicators aligned with the study area's specific challenges and strengths allows for the generation of more meaningful and actionable findings. This contextual alignment provides a deeper understanding of the factors that shape resilience outcomes and offers practical and actionable insights for policymakers and disaster management authorities. For example, learning from informal community responses to disasters can inform and strengthen formal response strategies. Additionally, establishing robust alert systems and effective communication channels can enhance preparedness and response efforts, ensuring that vulnerable populations receive timely information and support during crises. The framework's application in the Nowshera district demonstrates its potential as a tool for informing targeted resilience-enhancing interventions. Its household-focused approach, iterative nature, and sensitivity to local context makes it a valuable instrument for understanding and strengthening flood resilience at the community level. Second, earlier research has mainly relied on census data, which does not adequately capture/represent disaster resilience [107,108]. The use of household survey data to generate evidence improves understanding of key factors that contribute to household-level flood resilience.

The study has certain limitations, however. While the framework effectively quantified resilience in the Nowshera district, its applicability in other regions will depend on tailoring indicators to local contexts, as infrastructure, social dynamics, governance structures, and economic conditions may differ significantly. Additionally, the findings are based on a relatively small, exclusively male sample from 210 households, which limits the generalizability of the results. The choice to involve only males aligns with local cultural norms that restrict women from coming forward. Future research should involve trained female researchers to facilitate women's engagement, aligning with culturally considerate and inclusive disaster management practices [109–111]. Furthermore, the study relied on dichotomous variables as this allowed to capture a large range of variables without posing a large burden on the respondents. The use of straightforward yes/no questions ensured that respondents could easily engage with the questionnaire, reducing the risk of confusion or misinterpretation—particularly important in rural areas or among populations with lower literacy levels. In addition, this eases interpretation of the results. However, this may oversimplify experiences and perceptions regarding resilience. Future studies should incorporate ranked or ordinal variables (e.g., Likert scales) to capture a more nuanced understanding of resilience-related behaviours and perceptions. Qualitative methods, such as interviews and focus groups, would offer deeper insights into household resilience and provide a more comprehensive picture of how communities perceive and respond to floods. Expanding the sample size and including diverse communities will enhance the framework's applicability across different geographic, social, and economic contexts. Comparative studies across multiple regions and socio-economic strata can provide insights into the framework's scalability and the adaptability. Additionally, the framework could be modified for other hazards, such as earthquakes and droughts, as well as in urban settings with distinct governance and infrastructural characteristics. Integrating indicators on climate change impacts, hazard-specific exposure and vulnerability, long-term adaptive capacities, and autonomous adaptation strategies will be crucial for future research. Future studies could also explore adapting the framework using components-based approach, as proposed by Odunsi et al. [112]. This approach organises dimensions of resilience (e.g., physical, economic, social, and institutional etc.) under three components: absorptive, adaptive, and transformative capacities. While our study employs a multidimensional framework to measure resilience, structuring the dimensions within these components offers an alternative perspective that could provide additional insights. Further research could also examine how these conceptual approaches align or complement one another, contributing to the evolving body of knowledge on disaster resilience frameworks and their applications across diverse contexts.

7. Conclusion and recommendations

Flooding poses significant socioeconomic challenges in Pakistan and elsewhere. Traditionally, flood management strategies have centred on physical structures and warning systems. However, modern flood risk management is evolving towards a more community-centred approach, emphasizing household flood resilience. In line with this shift, this study aimed to quantitatively assess household flood resilience in the Nowshera district of Pakistan, focusing on Akbar Pura, Mohib Banda, Aman Kot, Khaishki Bala, and Pir Piai UCs. By applying a multidimensional framework encompassing physical, social, economic, and institutional aspects of flood resilience, we aimed to understand the factors influencing resilience at the household level. The findings reveal a moderate level of household flood resilience across the UCs, with notable variations among the different dimensions. Specifically, Pir Piai demonstrates the highest resilience, attributed to its robust scores in the physical, social, and institutional dimensions, whereas Khaishki Bala exhibits the lowest resilience, reflecting deficiencies in its physical, social, and economic dimensions. The main factors identified in the area that strengthen resilience include access to communication tools, strong social support networks, and reliable access to basic utilities. However, challenges remain, including low participation in community flood activities, flood awareness programs, and preparedness/response training, lack of flood emergency plans, limited possession of first aid skills, inadequate financial preparedness and awareness of critical resources, and low trust in government's DRR policies/programs. Based on these findings, several specific recommendations are proposed for the Nowshera district, which also yield general lessons for broader application:

- *Enhance community engagement:* Fostering active participation of households in community-based flood preparedness and response activities is critical. Designing tailored awareness campaigns, capacity building initiatives, and partnerships between communities and local authorities can drive engagement. Broadly, these strategies can be adapted to similar settings to promote community resilience in both rural and urban contexts.
- *Improve household preparedness:* First aid training and localized awareness campaigns should be prioritised to address low preparedness levels observed in the study areas. Reliable communication channels are vital for better awareness and resource access. Lessons from these efforts can inform the design of household preparedness programs in other regions, particularly those with limited literacy or resource access.
- *Strengthen institutional preparedness and response:* The study area underscores the need for effective flood awareness programs and the development of flood emergency plans. Enhance collaboration between local disaster management agencies and community-based organizations to strengthen institutional resilience.
- *Building trust in government programs and policies:* Addressing the low trust in DRR programs in the study area requires transparent communication and genuine community engagement. Trust is key for ensuring household participation in resilience-building efforts and compliance with government programs and policies.
- *Enhancing financial preparedness:* Financial resilience is crucial to cope with flood-related economic shocks. Improving financial awareness and promoting savings, such as community-based savings groups or initiatives, can enhance financial preparedness. Livelihood diversification programs can also provide alternative sources of income and reduce vulnerability.
- *Adopting inclusive approaches:* Address the needs of marginalized groups by ensuring equal resource access, participation in decision-making, and tailored support mechanisms. Integrate gender and vulnerability considerations into resilience strategies.
- *Supporting autonomous adaptation efforts:* Government support through targeted programs and interventions can empower local communities to uptake flood adaption measures. Encourage traditional knowledge, innovative practices, and local expertise, and provide resources, technical assistance, and funding for community-led adaptation initiatives.

By implementing targeted interventions, authorities and community members can work together to enhance household flood resilience. In the Nowshera district, and similar contexts, these efforts will contribute to reducing vulnerabilities, improve preparedness and response, and contribute to developing sustainable, and resilient communities in the face of flood events.

CRediT authorship contribution statement

Abdur Rahim Hamidi: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Paula Novo:** Writing – review & editing, Supervision. **Jouni Paavola:** Writing – review & editing, Supervision.

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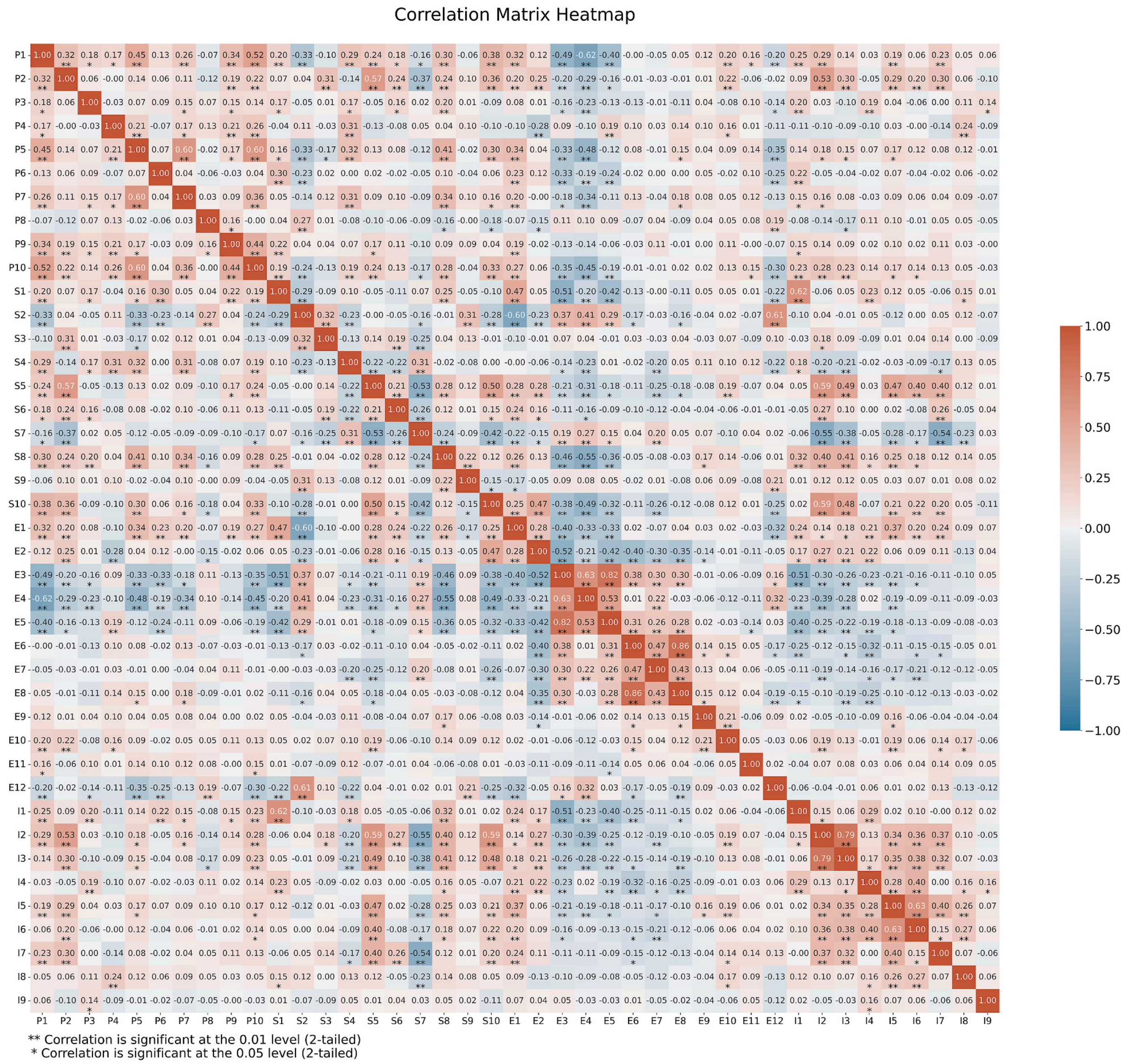
Declaration of competing interest

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.

Appendix A

Correlation Matrix Heatmap.



Data availability

Data not freely available because of signed data confidentiality.

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