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ARTICLE

Multidimensional Model for Vulnerability Assessment of Urban Flooding: An Empirical Study in Pakistan

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Abstract Urban flooding has become a regular phenomenon in many towns and cities in the Asia Pacific region over the past years. Professionals associated with disaster management and climate change are at the forefront of addressing urban flooding. To reduce flood risks, vulnerability and its components must be understood. Vulnerability assessment methods are diverse and complex, with a varied nature of understanding the key terms used in various contexts, and this diversity ultimately reflects on the interpretation of results in research settings. Diverse interpretations and definitions exist in the disaster risk and climate change literature, complicating the process of astute and comprehensive vulnerability assessment. The main purpose of this study was to quantify vulnerability indicators and develop a multidimensional model for vulnerability assessment. Vulnerability is explored through the lens of five dimensions: social, economic, physical/infrastructural, institutional, and attitudinal. This methodology is applied to urban flooding in Pakistan, to verify the proposed model. Three study sites in urban areas with different population sizes, situated in high-risk flood zones in the Punjab Province of Pakistan were selected for empirical investigation. A household survey was conducted, and indices were developed for each dimension based on well-defined indicators. The proposed methodology for vulnerability assessment was tested and found operational. This method can be replicated irrespective of spatial scales and can be modified for other disasters by streamlining hazard specific indicators.

Keywords Pakistan · Punjab · Urban flooding · Vulnerability assessment

1 Introduction

Vulnerability assessment is an essential part of both disaster risk reduction and sustainability science (Turner et al. 2003; Zhou et al. 2015). Vulnerability has emerged as a widely used concept in global environmental change, disaster risk management, and climate change adaptation (Schröter et al. 2005; Adger 2006; Polsky et al. 2007; Gain et al. 2015). Vulnerability assessment entails both the identification and the reduction of the susceptibilities of the exposed elements. It is deemed a crucial step towards reducing the consequences of natural hazards and disaster risks (Fuchs et al. 2012). Vulnerability is often exacerbated by socioeconomic inequalities, poverty, high population density, lack of awareness, weak institutions, and poor infrastructure (Cutter et al. 2003; Rana and Routray 2016). To minimize the potential harm associated with disasters, communities' vulnerabilities and factors need to be measured (Schröter et al. 2005; Armaş 2012). Recently, interest has been focused on working out vulnerability assessment methodologies (Balica et al. 2012), but these methodologies still require proper refining before they can be included in policies. Vulnerability is multifaceted and includes diverse components, but there is a lack of an integrated

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methodology that fuses all the components together. This study tries to quantify multidimensional vulnerability using social, economic, physical/infrastructural, institutional, and attitudinal dimensions. This multidimensional vulnerability assessment would greatly help in identifying a relevant course of action for disaster risk reduction in exposed communities.

Disasters are occurring with increasing intensity and frequency (Balica et al. 2009). Vulnerability to disasters is one of the most underestimated issues in sustainable urban development. Rapid urbanization has dramatically increased the vulnerabilities and risks of urban inhabitants in already exposed areas (Phung et al. 2016). Under severe threat of climate change, the frequency of flooding is expected to rise in urban areas (IPCC 2012). Urban flooding is putting large populations at risk and is now being thoroughly studied in disaster risk science (Gain et al. 2015; WMO 2015; Rana and Routray 2018).

Ineffective coping mechanisms, rapid urbanization, terrorism, political instabilities, weak disaster initiatives, and lack of awareness are plaguing poor disaster risk management in Pakistan (Rana and Routray 2016; Saqib et al. 2016). Socioeconomic and infrastructure inequalities are also rampant among urban areas (Rana et al. 2017), further worsening the situation. Disaster risk management systems are still reactive, and local institutions are managing disasters on an ad hoc basis (Rana and Routray 2016). In Pakistan, floods are the most widely occurring type of disaster. Out of 145 districts in the country (as of 2010 administrative boundaries), 113 were classified as located in medium to very high flood risk zones (NDMA 2012).

Urban centers are continuously facing an increase in riverine, flash, and pluvial flooding, causing widespread infrastructural damages. Damages of USD 10 billion were estimated by the government as a result of the 2010 floods (Federal Flood Commission 2012) that paralyzed almost half of Pakistan. Economic losses of USD 39 billion as a result of flooding have been estimated for the period from 1950 to 2012 (Federal Flood Commission 2012). This huge flood impact calls for assessing the vulnerabilities of flood-prone communities for developing effective disaster risk reduction strategies. Some research has been done on flood vulnerabilities in Pakistan (Rana and Routray 2016; Sadia et al. 2016; Jamshed et al. 2017; Shah et al. 2018), but a multidimensional vulnerability assessment is lacking, particularly for urban communities. This study proposes a methodology for assessing multidimensional vulnerability, and its application to flood-prone urban communities in Pakistan.

2 Theoretical Background

This study identifies vulnerability as a multifaceted and multidimensional phenomenon. Diverse definitions and interpretations of vulnerability exist in the scientific literature (Adger 2006; Fuchs et al. 2012; Birkmann et al. 2013). This has led to confusion (Janssen and Ostrom 2006). Numerous models have been developed to explain relationships, causes, and dependencies of vulnerability. Despite the existence of these models for vulnerability assessment, which have evolved over time, no consensus has been achieved on what method works best (Armaş 2012). This study sets itself apart from similar vulnerability assessment studies by incorporating various dimensions that are known to determine vulnerability from the perspective of climate change adaptation and disaster risk science.

2.1 The Concept of Vulnerability

In disaster risk science and climate change adaptation, vulnerability is increasingly acknowledged to be a human-induced phenomenon and has been recognized as the root cause of severe disaster impacts (UNISDR 2004; Wisner et al. 2004; Adger 2006; IPCC 2012). Vulnerability is considered an integral and defining part of disaster risk in many interpretations of disaster risk concepts (Wisner et al. 2004; Birkmann 2006; Birkmann et al. 2013). The operational definition of vulnerability, as conceptualized in this study, is stated by the United Nations International Strategy for Disaster Reduction (UNISDR), which defines vulnerability as “the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard” (UNISDR 2009). Vulnerability can also be seen as the gaps and weaknesses in the coping strategies that are adopted by a community. Vulnerability also overlaps with other concepts in disaster risk science and climate change, like adaptation, capacities, and resilience (Balica et al. 2009).

2.2 Models of Vulnerability

Vulnerability has been viewed through the lens of multiple contexts, dimensions, and spatiotemporal scales, and there is no universal theory or model (Jamshed et al. 2017). Vulnerability models/frameworks are part of climate change adaptation and disaster risk science and general enough to incorporate the urban flooding problem. The hazards-of-place vulnerability model contends that vulnerability is specific to spatial scale and an amalgamation of both biophysical and social dimensions (Cutter et al. 2000). Bohle’s (2001) double structure of vulnerability tried to explain internal and external aspects of vulnerability. The pressure and release model explains the progression of vulnerability (Wisner et al. 2004). Turner et al.'s (2003) vulnerability framework argued that global environmental change can be seen through the lens of sensitivity, exposure, and resilience. The Bogardi, Birkmann and Cardona Framework (BBC) contended that vulnerabilities must be seen as dynamic phenomena that can be measured within the environmental, social, and economic spheres (Bogardi and Birkmann 2004; Birkmann 2006). An eight-step approach was also suggested for measuring vulnerability (Schröter et al. 2005). Birkmann (2006) broadened the theory of vulnerability by suggesting five spheres, including multidimensional features such as physical, social, economic, institutional, and environmental features. A vulnerability scoping diagram was also proposed (Polsky et al. 2007). The Intergovernmental Panel on Climate Change (IPCC) Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) framework described vulnerability as a subsequent part of disaster risk and its impact on development in the light of disaster risk management and climate change adaptation (IPCC 2012). Recently, methods for the improvement of vulnerability assessment in Europe with the MOVE (Methods for the Improvement of Vulnerability Assessment in Europe) framework were put forth (Birkmann et al. 2013). All these models have provided confirmation of the multidimensional characteristics of vulnerability and its assessment.

2.3 Vulnerability Assessment

Vulnerability assessment is an integral part of the research on climate change adaptation and disaster risk science (Wisner et al. 2004; Adger 2006; Birkmann 2006; IPCC 2012; Birkmann et al. 2013). Researchers have assessed vulnerability from many aspects, such as social vulnerability (Cutter et al. 2003; Wisner et al. 2004; Yoon 2012), physical vulnerability (Thouret et al. 2014; Papathoma-Köhle et al. 2017), economic vulnerability (Briguglio 1995; Willroth et al. 2011), institutional vulnerability (López-Martínez et al. 2017), and livelihood vulnerability (Hahn et al. 2009). Under the IPCC approach, exposure, sensitivity, and capacity are also used by researchers to measure vulnerability (Balica et al. 2009; Hahn et al. 2009; Birkmann et al. 2013; Zhou et al. 2015; Phung et al. 2016). Some researchers have inferred vulnerability due to past economic damage trends and potential future losses (Hallegatte et al. 2013). However, the main challenge of vulnerability assessment lies in integrating components, dimensions, and methodologies within different disciplines (Schröter et al. 2005; Polsky et al. 2007; Fuchs et al. 2012). There has been no clear-cut and standardized methodology available for measuring the multidimensional aspects of vulnerability (Mazumdar and Paul 2016). This study tries to accommodate various aspects of vulnerability and focuses on proposing a methodology for multidimensional vulnerability assessment, and testing the methodology in flood-prone urban areas of Pakistan.

While the disaster risk literature has identified and researchers have explored various dimensions of vulnerability, an integrated framework of multidimensional vulnerability has been lacking, especially with respect to including the dimension of attitudinal vulnerability. The most important dimensions are the social and economic vulnerabilities, which is supported by a plethora of literature (Cutter et al. 2003; IPCC 2012). For the risk assessment of large cities, understanding the physical vulnerability of buildings and infrastructure is an essential step towards disaster risk reduction (Armaş 2012; Thouret et al. 2014). Institutional vulnerability is also an important dimension, because it amplifies hazards due to the inefficiency of the different authorities responsible for hazard management (Birkmann et al. 2013). But a proper methodology for assessing institutional vulnerability is still lacking (López-Martínez et al. 2017). Attitudinal vulnerability, with roots in risk perception, incorporates fatalistic beliefs and attitudes that can influence vulnerability (Rana and Routray 2016). A detailed analysis of each vulnerability dimension is needed for effective disaster risk reduction (Fuchs et al. 2012; López-Martínez et al. 2017).

Assessing vulnerability based on indices has recently appeared as a widely used quantitative measure (Tate 2012). A composite index would be appropriate for taking into account various dynamic characteristics of vulnerability, because an index summarizes complex data in a simpler way for any nontechnical person to understand (Birkmann 2006). Steps to develop a composite index include developing a conceptual framework for the composite, identifying relevant indicators, standardizing data for comparative analysis, weighing and aggregating indicators, and conducting uncertainty measures to gauge the robustness of indicators (Adger 2004). These kinds of indices have been criticized by many researchers for overgeneralizing and undermining important factors of vulnerability (Yoon 2012). This study develops a comprehensive multidimensional model for vulnerability assessment using a composite index method.

3 Application of the Proposed Model

In the disaster risk and climate change literature, vulnerability has clearly been established as multidimensional (Cutter et al. 2003; Polsky et al. 2007; Yoon 2012), and various qualitative and quantitative methods have been defined to explain vulnerability (Fuchs et al. 2012; Birkmann et al. 2013). This study presents a model for assessing the multidimensional vulnerability of urban communities in Pakistan to flooding. Flood-prone zones and three urban centers were identified in Punjab Province using secondary sources. Primary data were collected through questionnaires from households of three urban communities in June and July 2015. An index-based approach was employed for the assessment of the multidimensional vulnerabilities of the households. The equal class interval technique was used to classify household vulnerability into very low, low, moderate, and high levels for comparative analysis with respect to each dimension. Due to the comparative analysis among more than two cities, ANOVA (analysis of variance) was utilized to determine difference, where p value shows the level of significance.

3.1 Study Area Selection

Through multistage sampling, three cities of different population sizes (more than 1 million, 0.5 to 1 million, and less than 0.5 million) in highly flood-prone areas were selected in Punjab Province (Fig. 1), the most populous province in Pakistan (2017 estimated population 110 million), home to more than half of Pakistan's population and frequently prone to flooding. Rawalpindi (2017 population 2.1 million) is the fourth most populous metropolitan city of Pakistan. The city is characterized by mixed functions and is exposed to regular pluvial flooding in the monsoon season due to Nullah[1] Lai. Sialkot (2017 population 656 thousand) is a predominantly industrial city that also experiences pluvial flooding in the rainy season due to Nullah Aik and Nullah Degh. Muzaffargarh (2012 population 226 thousand) specializes in agro-industrial activities. The town is a *doab*, which is "land between two rivers," between the Indus River in the west and the Chenab River in the east, making it highly prone to riverine flooding. A comparative analysis of these urban areas would help in understanding the vulnerability dynamics and their dimensions in the three different tiers of urban settlement.

3.2 Sampling

One community from each of the selected cities—Rawalpindi, Sialkot, and Muzaffargarh—was further chosen for in-depth study based on interviews with the respective city administration, and identified based on proximity to flood hazard sources, frequent severe flooding, and past heavy flood damages. A total of 12,867 households lived in the three selected communities in 2014 (Punjab Bureau of Statistics 2014). Using the Cochran principle of sampling (Cochran 1977), a minimum of 194 samples were estimated, the confidence level was kept at 95%, with a precision value of 0.07. A minimum of 64, 69, and 61 samples was required from each flood-prone community of Rawalpindi, Sialkot, and Muzaffargarh, respectively. However, 70 samples from each urban community were taken for comparative analysis, bringing the total to 210 sample households. Using 30 questionnaires, pretesting was done in the field in June 2015 to streamline the questionnaire. After finalizing the questionnaire, attempts were made continuously until 210 valid and necessary samples had been collected. The locations of the three selected study sites—Dhok Ratta in Rawalpindi, Hajipura in Sialkot, and Khangarh City of Muzaffargarh—are shown in Fig. 1.

3.3 Formulation of a Multidimensional Vulnerability Index

Urban flooding problems fall under both climate change and disaster risk science, and involve various professionals, such as urban planners, engineers, architects, economists, and ecologists. The vast and intricate dynamics of flooding need comprehensive vulnerability assessment, which should incorporate the multifarious factors that affect the complexities in urban areas. The index-based approach of this study was developed for assessing five dimensions of vulnerability—social, economic, physical/infrastructural, institutional, and attitudinal vulnerability. Indicators were chosen through extensive literature review for each dimension of vulnerability. These indicators were chosen from empirical studies from the disaster risk science and climate change fields. Indicators were scrutinized with a view to local conditions and adjusted accordingly. Seven indicators each were used for social, institutional, and attitudinal vulnerability; 10 indicators for economic vulnerability; and 13 indicators for physical/infrastructural vulnerability. The five dimensions are given equal importance, as all three cities experience flood hazards primarily because of *nullahs* and rivers. Therefore, an average was calculated for all dimensions, which helped in devising the multidimensional vulnerability index.

The original primary datasets were standardized using respective weights for the computation of the composite index as used in other studies of urban flooding (Thouret et al. 2014; Gain et al. 2015; Rana and Routray 2016). This study also uses a subjective weighting technique to allocate values to classes of phenomena for each indicator and formulates indices based on Eq. 1.

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[1] Drainage channel fed by seasonal rains.

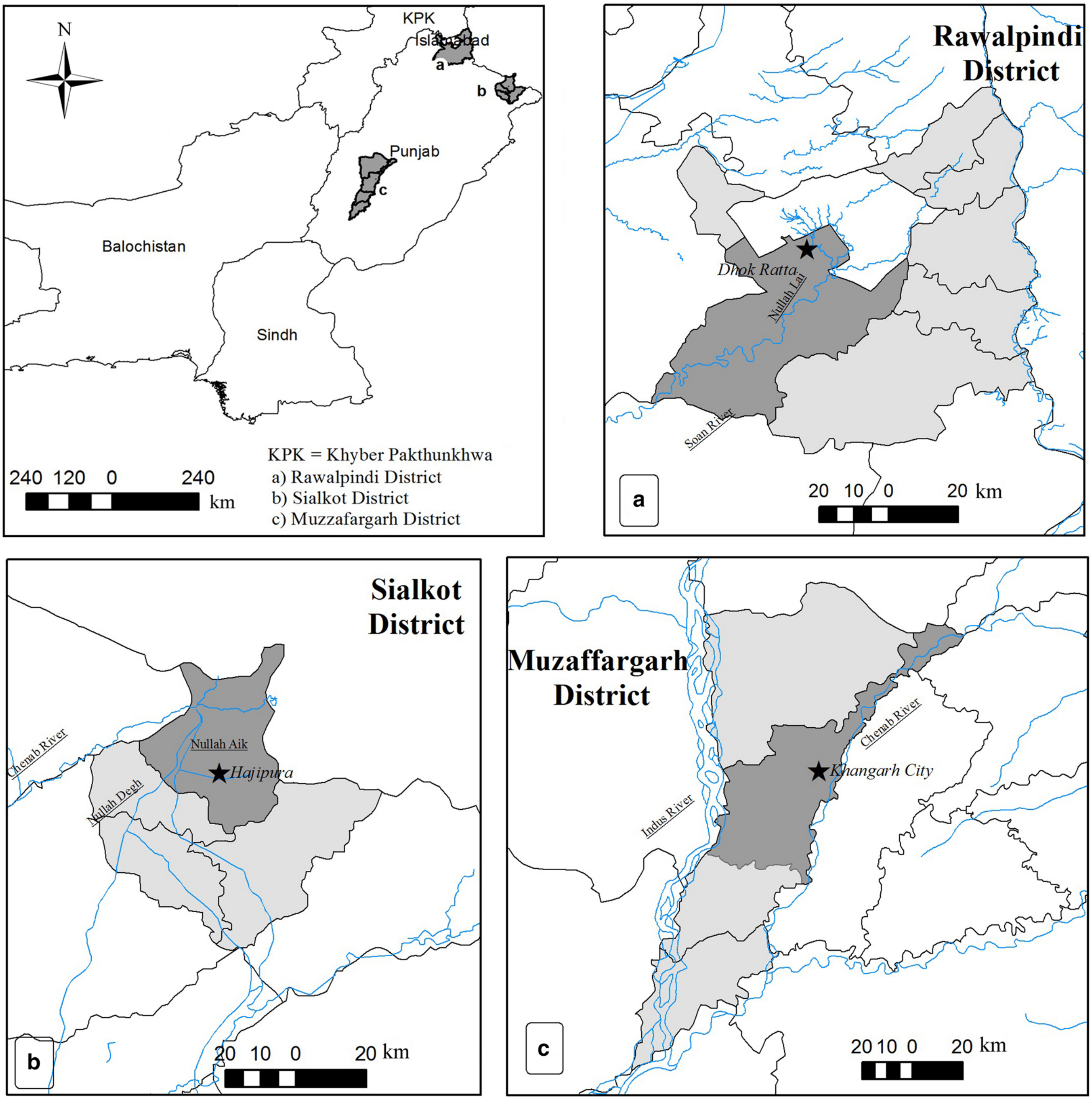

Fig. 1 Map of the study areas in Punjab Province, Pakistan, showing the location of the three selected study sites in **a** Rawalpindi, **b** Sialkot, and **c** Muzaffargarh districts

$$\mathrm{CI} = (W_1 + W_2 + W_3 + \cdots W_n)/n = \sum_{i=1}^{n} Wi/n \qquad (1)$$

where, CI is the composite index, W_1 to W_n are respective transformed values assigned to indicators, and n is the number of indicators used for computing the composite index.

Following this general principle, the Social Vulnerability Index (SI), Economic Vulnerability Index (EI), Physical/Infrastructural Vulnerability Index (PI), Institutional Vulnerability Index (II), and Attitudinal Vulnerability Index (AI) were calculated. The Multidimensional Vulnerability Index (MVI) for each household in the study area was calculated using Eq. 2.

$$\text{Social Vulnerability Index (SI)} = \sum_{i=1}^{7} \text{SW}_i/n \quad (n = 7)$$

$$\text{Economic Vulnerability Index (EI)} = \sum_{i=1}^{10} \text{EW}_i/n \quad (n = 10)$$

$$\text{Physical/Infrastructural Vulnerability Index (PI)} = \sum_{i=1}^{13} \text{PW}_i/n \quad (n = 13)$$

$$\text{Institutional Vulnerability Index (II)} = \sum_{i=1}^{7} \text{IW}_i/n \quad (n = 7)$$

$$\text{Attitudinal Vulnerability Index (AI)} = \sum_{i=1}^{7} \text{AW}_i/n \quad (n = 7)$$

$$\text{Multidimensional Vulnerability Index (MVI)} = \frac{\text{SI} + \text{EI} + \text{PI} + \text{II} + \text{AI}}{5} \tag{2}$$

The original values of the indicators have been transformed to 0–1 based on the vulnerability level, for the purpose of computing the indices. The values closer to 0 signify low vulnerability, whereas values closer to 1 denote high vulnerability. Each variable was further divided into classes depending on its characteristics: for example, nature of response was divided into two classes (yes or no response), three classes, four classes, and five classes, as required. With literature support, these classes were framed to demonstrate the degree of variation, as much as possible, in that particular variable. In dual classes, the values were 0 and 1. The indicators with three classes were assigned the values 0.33, 0.67, and 1; for four classes, the values were 0.25, 0.50, 0.75, and 1; and for five classes, the values were 0.2, 0.4, 0.6, 0.8, and 1. Thus, the composite index for each component fell between 0 and 1. Table 1 lists the indicators used for the different dimensions, the classes and values, and the empirical studies that have used these indicators.

4 Results and Discussion

Indices for each dimension were calculated using the methodology described in the previous section. Statistical tests were performed to understand the level of difference in each dimension. The results for each dimension are separately described, followed by an overall explanation of multidimensional vulnerability.

4.1 Social Vulnerability

The surveyed households in all three communities mostly had 5–10 members (61%). Most of the households were nuclear families (87%). About 22% of households included members who were suffering from a chronic illness or a physical/mental disability, or were pregnant, increasing vulnerability. A significant variation ($\chi^2 = 16.34$, p value = 0.03) was observed among the three communities with respect to education level of household head. Around 21% of household heads were illiterate, but most household heads were primary or secondary schooled. This lack of extended education increases vulnerability. It can critically endanger a household because of poor understanding of early warnings and emergency protocols. Most of the households (77%) had been living in the hazard-prone areas for over 10 years, making them aware of possible evacuation routes and safe areas in their community, reducing vulnerability. Around 79% of households had experienced floods, which would help them in foreseeing potential flood damages and mitigation measures. But in Rawalpindi many of the surveyed households had no past experience with floods, possibly because they were fresh migrants, which increased their vulnerability.

The social vulnerability index of households varied from 0.28 to 0.71 in Rawalpindi community, 0.22–0.62 in Sialkot community, and 0.25–0.70 in Muzaffargarh community, with an average value of 0.48, 0.41, and 0.44 in the three study sites, respectively. In terms of overall social vulnerability, a significant difference ($F = 9.988$, p value = 0.001) was observed among the three communities (Table 2). Around 21, 13, and 14% of the surveyed households were highly vulnerable in Rawalpindi, Sialkot, and Muzaffargarh, respectively. Higher vulnerability in Rawalpindi community can be attributed to limited past experiences of households, and due to the fact that most families had relatively recently moved into houses constructed in the flood-prone area. With respect to overall social vulnerability, around 16% of the surveyed households were classified as highly vulnerable.

4.2 Economic Vulnerability

The dependency ratio (dependents to total household size) was relatively low in all three communities. However, a significant difference ($\chi^2 = 49.27$, p value = 0.001) was observed in average monthly income among the three communities. Household heads were mostly the sole earning members of the household. In the Rawalpindi community, most of the households living in the flood-prone areas were middle income, working as government employees, traders, or daily wage earners. In Sialkot community, most of the surveyed households belonged to

Table 1 Indicators and transformed values for dimensions of vulnerability to urban flooding in Punjab Province, Pakistan

S. No.	Indicators	Classes	Transformed values	Explanation	Empirical studies
Social vulnerability					
1	Household size (in number)	< 5	0.33	The larger the household size, the higher might be the vulnerability	Cutter et al. (2003), Birkmann et al. (2013)
		5–10	0.67		
		> 10	1		
2	Family type	Extended	0.33	The extended family type will have more strength in number, and have more access to societal resources and support	Rana and Routray (2016)
		Nuclear	0.67		
		Single	1		
3	Female-male ratio	< 1	0.2	Males will be less vulnerable than females due to their mobility and physical strength	Armaş (2012), Phung et al. (2016)
		1–2	0.4		
		2–3	0.6		
		3–4	0.8		
		> 4	1		
4	Household that includes family members with chronic illness/pregnancy or disability	0	0	Household with special needs will be limited in its mobility in case of emergency	Hahn et al. (2009), Balica et al. (2012), Yoon (2012)
		1	0.33		
		2	0.67		
		> 2	1		
5	Household head's education level	No schooling	1	Low literacy will increase vulnerability of household's access to information and communication	Hahn et al. (2009), Pandey and Jha (2012), Armaş (2012)
		Primary	0.8		
		Middle	0.6		
		High	0.4		
		College/University	0.2		
6	Household living in community (in years)	> 40	0.2	Household residing for shorter time may not be aware of evacuation routes and emergency protocols	Rana and Routray (2018)
		30–40	0.4		
		20–30	0.6		
		10–20	0.8		
		< 10	1		
7	Household having past experiences with floods	No	1	People with previous encounters with floods can foresee issues and problems that could be faced	Birkmann et al. (2013), Rana and Routray (2018)
		Yes	0		
Economic vulnerability					
1	Dependency ratio (dependents to total household size)	< 0.25	0.2	Infants, children, and the elderly will be more vulnerable than young persons and adults, because of limited mobility and dependency	Pandey and Jha (2012), Gain et al. (2015), Zhou et al. (2015), Phung et al. (2016)
		0.25–0.50	0.4		
		0.50–0.75	0.6		
		0.75–1	0.8		
		> 1	1		
2	Average monthly household's income (in Pakistani rupees)[a]	< 10,000	1	Lower income results in higher vulnerability	Cutter et al. (2003), Balica et al. (2009), Phung et al. (2016)
		10,000–19,999	0.8		
		20,000–39,999	0.6		
		40,000–60,000	0.4		
		> 60,000	0.2		
3	Occupation of household head	Government service	0.2	Insecure sources of income will increase vulnerability	Armaş (2012), Pandey and Jha (2012), Yoon (2012), Mazumdar and Paul (2016), Phung et al. (2016)
		Trade and Commerce	0.4		
		Agriculture	0.6		
		Daily wagers	0.8		
		Unemployed	1		

Table 1 continued

S. No.	Indicators	Classes	Transformed values	Explanation	Empirical studies
4	Household that has taken out a loan in the last 10 years	Yes No	1 0	Household that has taken out a loan within the last 10 years shows that it could be economically challenged and could be more vulnerable in case of emergency	Hahn et al. (2009), Pandey and Jha (2012)
5	Household residing in rented houses	Yes No	1 0	Tenants on rent cannot repair, fortify their buildings against floods	Cutter et al. (2003), Tate (2012), Yoon (2012)
6	Livelihood options of the household	0 1 2 > 2	1 0.75 0.50 0.25	Multiple sources of livelihood will decrease vulnerability because even if one source is cut off, the household can survive on another	Hahn et al. (2009)
7	Number of earning members in the household	0 1 2 > 2	1 0.75 0.50 0.25	Higher number of earning household members can decrease vulnerability because even if one income source is cut off, the household can survive on another	Armaş (2012)
8	Household with family member employed outside flood-prone area	No Yes	1 0	Household with a family member employed outside the flood-prone area will sustain this family member's income	Hahn et al. (2009), Pandey and Jha (2012)
9	Household with land/house outside the flood-prone area	No Yes	1 0	Household with additional assets outside the flood-prone area can decrease vulnerability, as such households can settle outside the flooded area	Wisner et al. (2004)
10	Household with means of transportation	No Yes	1 0	Household with no means of transportation will be hindered in evacuation	Tate (2012), Yoon (2012); Mazumdar and Paul (2016)
Physical/infrastructural vulnerability					
1	Location of the house	Between Levee and riverbank Floodplain Upland	1 0.67 0.33	Low elevation and proximity to flood hazard source will increase vulnerability	Balica et al. (2009), Thouret et al. (2014)
2	Building type	Combined (row houses) Semidetached (common) Detached (Bungalow)	1 0.67 0.33	Household residing in house with limited open space and distance between neighboring houses will increase vulnerability	Birkmann et al. (2013), Thouret et al. (2014), Gain et al. (2015), Papathoma-Köhle et al. (2017)
3	Building height(number of stories)	Single Double Triple	1 0.67 0.33	Household living in single-story residence will increase vulnerability	Birkmann et al. (2013), Thouret et al. (2014), Papathoma-Köhle et al. (2017)
4	Building age of household residence (in years)	< 10 11–20 20–30 > 30	0.25 0.50 0.75 1	Old houses will be structurally weaker and make household more vulnerable	Birkmann et al. (2013), Gain et al. (2015), Papathoma-Köhle et al. (2017)
5	Construction materials of household residence	*Katcha* (Adobe, Mud) *Pacca* (Brick, Cement)	1 0	Type of materials used for construction would affect structure. *Katcha* and *Pacca* are local terminologies for describing strength of building materials used	Thouret et al. (2014), Gain et al. (2015), Mazumdar and Paul (2016), Papathoma-Köhle et al. (2017)

Table 1 continued

S. No.	Indicators	Classes	Transformed values	Explanation	Empirical studies
6	Distance to nearest medical facility (in km)	< 1 1–5 5–10 > 10	0.25 0.50 0.75 1	The longer the distance between nearest health facility and residence, the higher will be the vulnerability	Armaş (2012), Rana and Routray (2016)
7	Household access to drinking water	Yes No	0 1	Household with no access to safe drinking water will be more vulnerable	Hahn et al. (2009), Zhou et al. (2015), Mazumdar and Paul (2016), Phung et al. (2016)
8	Household access to improved sanitation	Yes No	0 1	Household with no access to improved sanitation will be more vulnerable	Balica et al. (2009), Mazumdar and Paul (2016), Phung et al. (2016)
9	Household access to electricity	Yes No	0 1	Household with no access to electricity will be more vulnerable	Mazumdar and Paul (2016)
10	Household means of communication (TV)	Yes No	0 1	Household with no access to means of communication will be more vulnerable	Yoon (2012), Mazumdar and Paul (2016)
11	Household means of communication (Radio)	Yes No	0 1		
12	Household means of communication (Telephone)	Yes No	0 1		
13	Household means of communication (Mobile)	Yes No	0 1		
Institutional vulnerability					
1	Warning about last floods received by the household	Yes No	0 1	Household that did not receive warning in last flood, indicates institution's inefficiency	Balica et al. (2009)
2	Household's level of understanding national warning system	Very high High Moderate Low Very low	0.2 0.4 0.6 0.8 1	Household that does not understand national warning system, represents inability of institution to convey proper early warning	Gain et al. (2015)
3	Household's awareness regarding emergency shelter	No Yes	1 0	Lack of awareness of household shows incapacity of institutions	Balica et al. (2009)
4	Household's awareness regarding evacuation routes	No Yes	1 0		
5	Availability and circulation of emergency plans to household	No Yes	1 0	Unavailability and no circulation of emergency plans by institutions may increase household vulnerability	Bollin and Hidajat (2006)
6	Household's knowledge of emergency protocols regarding floods	Very poor Poor Average Good Very good	1 0.8 0.6 0.4 0.2	Household not understanding local authority's emergency procedures will be more vulnerable	Ho et al. (2008)
7	Frequency of public awareness programs/drills attended by any household member (in number)	0 1 2	1 0.67 0.33	Low number of participation in drills and training shows inability of institution regarding awareness campaigns and drills	Bollin and Hidajat (2006)

Table 1 continued

S. No.	Indicators	Classes	Transformed values	Explanation	Empirical studies
Attitudinal vulnerability					
1	Household that has gone to their local government for assistance in the past 12 months	No Yes	1 0	Household that distrusts local governments might not follow their protocols, and not seek their help.	Hahn et al. (2009), Rana and Routray (2016)
2	Community having land use/zoning laws and household following them	No Yes	1 0	Household not following urban planning regulations will be more vulnerable	Balica et al. (2009), Rana and Routray (2016)
3	Community cooperation in disaster response	Very poor Poor Moderate Good Very good	1 0.8 0.6 0.4 0.2	Cooperation strength represents community attitudes and social networking towards helping each other and coping with floods	Pandey and Jha (2012)
4	Household believing in possibility of future occurrence of floods	Very low Low Moderate High Very high	1 0.8 0.6 0.4 0.2	Household not believing in flood likelihood might be more vulnerable	Ho et al. (2008), Miceli et al. (2008)
5	Household feeling afraid of flood	Not afraid Slightly afraid Neutral Afraid Very much afraid	1 0.8 0.6 0.4 0.2	Household not feeling afraid of flood will not seek preparedness measures against future flooding, and might be more vulnerable	Ho et al. (2008), Miceli et al. (2008), Terpstra and Gutteling (2008)
6	Household fearing potential destruction of their houses/assets	Very low Low Moderate High Very high	1 0.8 0.6 0.4 0.2	Household fearing potential destruction of their houses might be less vulnerable	Miceli et al. (2008), Terpstra and Gutteling (2008)
7	Household's level of trust and following government disaster risk reduction programs and policies	Very low Low Moderate High Very high	1 0.8 0.6 0.4 0.2	Household not agreeing with government initiatives will not follow them and increase household vulnerability	Rana and Routray (2016)

[a] USD 1 = 122.50 Pakistani rupees (August 2018)

middle to high income groups, and most of them were involved in industrial jobs and private businesses.

In Muzaffargarh community, most of the surveyed households were poor to middle income and worked in the agricultural sector, and around 12% of the household members were unemployed, making those households highly vulnerable. Almost 33% of the households had taken out a loan, and around 20% lived in rented houses. Around 7% of the households had a member working outside the flood-prone community, which could decrease the vulnerability of these households. Significantly, 82% of the households had no other asset (land/house outside flood-prone area), making them economically challenged.

The economic vulnerability index of households varied from 0.28 to 0.77 in Rawalpindi community, 0.35–0.77 in Sialkot community, and 0.48–0.89 in Muzaffargarh community. The average value was 0.58 in Rawalpindi, 0.60 in Sialkot, and 0.64 in Muzaffargarh. In terms of overall economic vulnerability, a significant difference ($F = 8.309$, p value = 0.001) was also observed among the three communities (Table 3). In the Rawalpindi community, around 23% of the surveyed households were economically vulnerable, while around 24% and 9% of the households were vulnerable in Sialkot and Muzaffargarh, respectively. This difference can be attributed to the fact that the number of earning members and house/land ownership was higher

Table 2 Social vulnerability to urban flooding in Dhok Ratta, Hajipura, and Khangarh City, Punjab Province, Pakistan (HHs = Households; $n = 210$)

City	Classes	Very low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Dhok Ratta, Rawalpindi	Range	< 0.39	0.39–0.49	0.49–0.60	> 0.60		Min = 0.286	$F = 9.988$
	No. of HHs	18	21	16	15	70	Max = 0.714	df = 2
	%	25.7	30.0	22.9	21.4	100	Mean = 0.489	p value = 0.001
							SD = 0.111	
Hajipura, Sialkot	Range	< 0.32	0.32–0.42	0.42–0.52	> 0.52		Min = 0.229	
	No. of HHs	7	32	22	9	70	Max = 0.622	
	%	10	45.7	31.4	12.9	100	Mean = 0.415	
							SD = 0.078	
Khangarh City, Muzaffargarh	Range	< 0.36	0.36–0.48	0.48–0.59	> 0.59		Min = 0.257	
	No. of HHs	17	32	11	10	70	Max = 0.706	
	%	24.3	45.7	15.7	14.3	100	Mean = 0.442	
							SD = 0.107	
Total	No. of HHs	42	85	49	34	210		
	%	20.00	40.47	23.33	16.19	100		

Table 3 Economic vulnerability to urban flooding in Dhok Ratta, Hajipura, and Khangarh City, Punjab Province, Pakistan (HHs = Households; $n = 210$)

City	Classes	Very Low	Low	Moderate	High	Total	Descriptive Statistics	ANOVA
Dhok Ratta, Rawalpindi	Range	< 0.40	0.40–0.52	0.52–0.64	> 0.64		Min = 0.280	$F = 8.309$
	No. of HHs	2	8	44	16	70	Max = 0.770	df = 2
	%	2.9	11.4	62.9	22.9	100	Mean = 0.586	p value = 0.001
							SD = 0.086	
Hajipura, Sialkot	Range	< 0.45	0.45–0.56	0.56–0.66	> 0.66		Min = 0.350	
	No. of HHs	8	10	35	17	70	Max = 0.770	
	%	11.4	14.3	50.0	24.3	100	Mean = 0.600	
							SD = 0.094	
Khangarh City, Muzaffargarh	Range	< 0.58	0.58–0.68	0.68–0.78	> 0.78		Min = 0.480	
	No. of HHs	23	19	22	6	70	Max = 0.890	
	%	32.9	27.1	31.4	8.6	100	Mean = 0.648	
							SD = 0.100	
Total	No. of HHs	33	37	101	39	210		
	%	15.71	17.61	48.09	18.57	100		

in Muzaffargarh community. Overall, with respect to economic vulnerability, around 19% of the surveyed households were highly vulnerable.

4.3 Physical/Infrastructural Vulnerability

Almost half of the surveyed households lived in highly vulnerable floodplains, and some had even built houses inside levees and embankments. These houses were built illegally inside the floodplains when the floods had receded last time. Generally, most of the houses were semidetached, single story, and built almost 20 years ago. Only a few households were living in adobe houses. In terms of infrastructural services, almost every household had access to electricity, radio, a landline, and a mobile, which can decrease vulnerability. But provision of clean drinking water and improved sanitation varied among communities, which can increase the vulnerabilities of already exposed communities.

The physical vulnerability index of households varied from 0.17 to 0.46 in Rawalpindi community, 0.18–0.30 in Sialkot community, and 0.18–0.80 in Muzaffargarh

Table 4 Physical and infrastructural vulnerability to urban flooding in Dhok Ratta, Hajipura, and Khangarh City, Punjab Province, Pakistan (HHs = Households; $n = 210$)

City	Classes	Very low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Dhok Ratta, Rawalpindi	Range	< 0.25	0.25–0.32	0.32–0.39	> 0.39		Min = 0.179	$F = 9.714$
	No. of HHs	24	41	2	3	70	Max = 0.468	df = 2
	%	34.3	58.6	2.9	4.3	100	Mean = 0.271	p value = 0.001
							SD = 0.050	
Hajipura, Sialkot	Range	< 0.21	0.21–0.24	0.24–0.27	> 0.27		Min = 0.186	
	No. of HHs	17	24	21	8	70	Max = 0.308	
	%	24.3	34.3	30.0	11.4	100	Mean = 0.238	
							SD = 0.026	
Khangarh City, Muzaffargarh	Range	< 0.34	0.34–0.49	0.49–0.64	> 0.64		Min = 0.186	
	No. of HHs	59	6	1	4	70	Max = 0.802	
	%	84.3	8.6	1.4	5.7	100	Mean = 0.296	
							SD = 0.121	
Total	No. of HHs	100	70	24	15	210		
	%	47.61	33.80	11.42	7.14	100		

community. The average value was 0.27 in Rawalpindi, 0.23 in Sialkot, and 0.29 in Muzaffargarh. Regarding overall physical vulnerability, a significant difference ($F = 9.714$, p value = 0.001) was also observed among the three communities (Table 4). In the Rawalpindi community around 4% of the surveyed households were deemed vulnerable, while around 11% and 6% of the households were vulnerable in Sialkot and Muzaffargarh, respectively. Households of Rawalpindi community belonged to a metropolitan region, and they enjoyed better access to physical and infrastructural amenities over other two study sites. Overall, with respect to physical vulnerability, around 7% of the surveyed households were highly vulnerable.

4.4 Institutional Vulnerability

Institutional vulnerability included reach and efficiency of early warning systems, risk communication, and emergency planning by institutions. A significant difference ($\chi^2 = 25.507$, p value = 0.001) was observed regarding the reach of early warning systems. More than half of the households (51%) in the study areas did not receive any kind of warning the last time a flood occurred in the community. This inefficiency can be attributed to the nonexistence of district management authority, and no local agency was officially delegated with this responsibility. Moreover, respondents stressed that without informing nearby settlements, local institutions often break embankments to save critical infrastructure. Around 72% and 73% of the households were unaware of the location of emergency shelters and evacuation routes, respectively. Around 95% of the households did not have access to emergency plans, increasing their vulnerability. Almost 96% of the household members had never attended any kind of awareness program or mock drill to cope with flooding. Households asserted that local administrations had not helped them prepare for flood hazards and mitigation.

The institutional vulnerability index of households varied from 0.28 to 1.0 in Rawalpindi community, 0.31–0.94 in Sialkot community, and 0.13–1.0 in Muzaffargarh community. The average value was 0.85 in Rawalpindi, 0.63 in Sialkot, and 0.76 in Muzaffargarh. In terms of overall institutional vulnerability, a significant difference ($F = 27.970$, p value = 0.001) was observed between the three study areas (Table 5). The highest vulnerability was observed in the Rawalpindi community where 67% of the surveyed households were highly vulnerable, while around 24% and 44% of the surveyed households were highly vulnerable in Sialkot and Muzaffargarh, respectively. In Rawalpindi, institutions were not actively disseminating emergency plans and protocols, hence raising vulnerability of the Rawalpindi metropolitan.

4.5 Attitudinal Vulnerability

Around 94% of the households had never approached local institutions to seek help or advice regarding flood preparedness. Respondents indicated that they distrusted the local institutions, probably because of the institutions' failure to disseminate early warnings. Lack of communication between exposed households and local institutions can also be attributed to illegally built houses in the floodplains, restricting households from seeking help

Table 5 Institutional vulnerability to urban flooding in Dhok Ratta, Hajipura, and Khangarh City, Punjab Province, Pakistan (HHs = Households; $n = 210$)

City	Classes	Very low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Dhok Ratta, Rawalpindi	Range	< 0.46	0.46–0.64	0.64–0.82	> 0.82		Min = 0.286	$F = 27.970$ df = 2
	No. of HHs	3	5	15	47	70	Max = 1.000	p value = 0.001
	%	4.3	7.1	21.4	67.1	100	Mean = 0.847	
							SD = 0.156	
Hajipura, Sialkot	Range	< 0.47	0.47–0.62	0.62–0.78	> 0.78		Min = 0.314	
	No. of HHs	30	8	15	17	70	Max = 0.943	
	%	42.9	11.4	21.4	24.3	100	Mean = 0.634	
							SD = 0.187	
Khangarh City, Muzaffargarh	Range	< 0.34	0.34–0.56	0.56–0.78	> 0.78		Min = 0.133	
	No. of HHs	1	6	32	31	70	Max = 1.000	
	%	1.4	8.6	45.7	44.3	100	Mean = 0.761	
							SD = 0.165	
Total	No. of HHs	34	19	62	95	210		
	%	16.19	9.04	29.52	45.23	100		

officially, because local institutions might start litigation measures against them. Around 96% of the respondents believed that people in their community did not follow building regulations and zoning laws. Interestingly, around 86% of the households did not believe in community cooperation when floods strike, highlighting the underutilization of social capital. Respondents were of the opinion that everyone looks after themselves, and no one pays much attention to the people around them in disaster settings. Despite the classification of urban centers exposed to high flood risk by the National Disaster Management Authority (NDMA), only about 20% of the surveyed households believed that there is the possibility of future flood occurrence. Only a meagre 6% of households trusted government initiatives for disaster risk reduction and climate change adaptation. This indicates the poor perceptions and fatalistic attitudes of households that are hindering them from pursuing precautionary and mitigation measures against flood hazards.

The attitudinal vulnerability index value of households varied from 0.54 to 0.91 in Rawalpindi community, 0.51–0.94 in Sialkot community, and 0.48–0.82 in Muzaffargarh community with an average value of 0.79, 0.75, and 0.68 in the three cities, respectively. Regarding overall attitudinal vulnerability, a significant difference ($F = 36.577$, p value = 0.001) was observed among the

Table 6 Attitudinal vulnerability to urban flooding in Dhok Ratta, Hajipura, and Khangarh City, Punjab Province, Pakistan (HHs = Households; $n = 210$)

City	Classes	Very low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Dhok Ratta, Rawalpindi	Range	< 0.63	0.63–0.72	0.72–0.82	> 0.82		Min = 0.543	$F = 36.577$
	No. of HHs	4	8	23	35	70	Max = 0.914	df = 2
	%	5.7	11.4	32.9	50	100	Mean = 0.794	p value = 0.001
							SD = 0.080	
Hajipura, Sialkot	Range	< 0.62	0.62–0.72	0.72–0.83	> 0.83		Min = 0.514	
	No. of HHs	3	13	52	2	70	Max = 0.943	
	%	4.3	18.6	74.3	2.9	100	Mean = 0.759	
							SD = 0.069	
Khangarh City, Muzaffargarh	Range	< 0.57	0.57–0.65	0.65–0.74	> 0.74		Min = 0.486	
	No. of HHs	6	11	32	21	70	Max = 0.829	
	%	8.6	15.7	45.7	30.0	100	Mean = 0.685	
							SD = 0.080	
Total	No. of HHs	13	32	107	58	210		
	%	6.1	15.2	50.1	27.6	100		

Table 7 Multidimensional vulnerability to urban flooding in Dhok Ratta, Hajipura, and Khangarh City, Punjab Province, Pakistan (HHs = Households; $n = 210$)

City	Classes	Very low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Dhok Ratta, Rawalpindi	Range	< 0.51	0.51–0.55	0.55–0.60	> 0.60		Min = 0.474	$F = 32.726$
	No. of HHs	14	24	24	8	70	Max = 0.645	df = 2
	%	20.3	34.3	34.3	11.4	100	Mean = 0.553	p value = 0.001
							SD = 0.040	
Hajipura, Sialkot	Range	< 0.46	0.46–0.50	0.50–0.54	> 0.54		Min = 0.419	
	No. of HHs	9	37	18	6	70	Max = 0.591	
	%	12.9	52.9	25.7	8.6	100	Mean = 0.495	
							SD = 0.035	
Khangarh City, Muzaffargarh	Range	< 0.44	0.44–0.51	0.51–0.59	> 0.59		Min = 0.368	
	No. of HHs	2	23	37	8	70	Max = 0.669	
	%	2.9	32.9	52.9	11.4	100	Mean = 0.536	
							SD = 0.053	
Total	No. of HHs	25	84	79	22	210		
	%	11.90	40.00	37.62	10.47	100		

three communities (Table 6). In the Rawalpindi community, around 50% of the surveyed households were deemed vulnerable. Around 2% and 30% of the households were vulnerable in Sialkot and Muzaffargarh, respectively. Newly migrated households in Rawalpindi community have not faced floods, thus their risk perception was poor, as compared to other two study sites. Overall, with respect to attitudinal vulnerability, around 28% of the surveyed households were highly vulnerable.

4.6 Multidimensional Vulnerability

The results in the previous sections highlight the five dimensions of vulnerability and emphasize the myriad factors that affect these dimensions. Different dynamics influence the flood vulnerability in the three urban centers. Muzaffargarh is prone to riverine floods, while Sialkot and Rawalpindi are prone to flash and pluvial floods, a marked difference in flood hazard sources. The degree of overall multidimensional flood vulnerability significantly ($F = 32.726$, p value = 0.001) varied among the study sites in the three urban centers (Table 7). In Rawalpindi and Muzaffargarh, about 12% of the surveyed households were highly vulnerable, while 9% of households in Sialkot were highly vulnerable. Overall, around 10% of households in the three surveyed urban communities were deemed highly vulnerable.

Figure 2 reveals interesting insights into each dimension of vulnerability, through average index values. Slight variations were observed in social, economic, and physical/infrastructural vulnerability among the three study sites. The variation was much more pronounced in terms of attitudinal and institutional vulnerability. Except in the economic vulnerability dimension, the surveyed households of the Muzaffargarh study site were most vulnerable in all other dimensions of vulnerability. The surveyed households of the Sialkot study site were least vulnerable in all dimensions except in the attitudinal vulnerability dimension. Attitudinal and institutional vulnerability were much higher than other vulnerability dimensions, signifying the poor risk perceptions of residents and distrust among the communities and the disaster management institutions. Overall, the average multidimensional vulnerability was more or less the same for all three urban communities. These findings show that there is a strong need to launch awareness campaigns and design risk communication strategies to enhance the flood risk perceptions of the communities and engage the local institutions with the communities to implement disaster risk reduction strategies effectively.

5 Conclusion

This study argues that vulnerability to urban flooding or any other hazard must not be treated as a single entity, but rather as a composition of social, economic, physical/infrastructural, institutional, and attitudinal factors, and proposes a multidimensional model to measure vulnerability. The study provides a clear and useful methodology, which can comprehensively measure the dimensional and aggregate degree of vulnerability. It is a simple, easy, and quick-to-use method, and can be employed by disaster risk experts regardless of professional background. The model

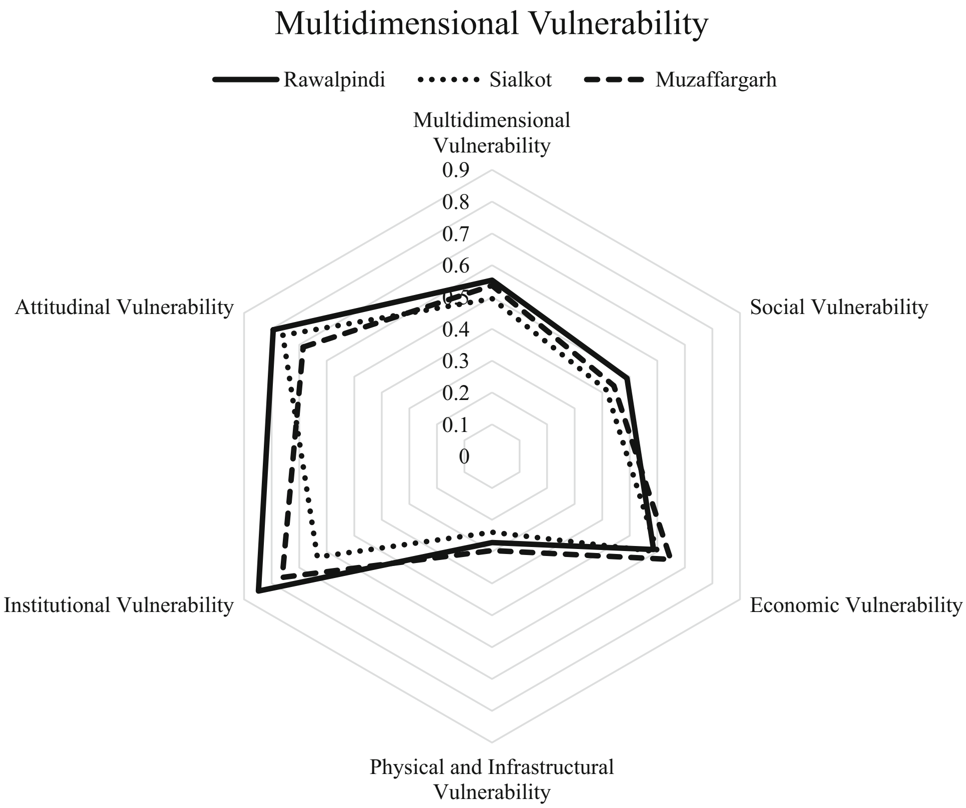

Fig. 2 Multidimensional vulnerability to urban flooding in Dhok Ratta (Rawalpindi), Hajipura (Sialkot), and Khangarh City (Muzaffargarh), Punjab Province, Pakistan

not only helps in identifying the most vulnerable populations, but also the exact dimensions that are making them vulnerable. The index value for each indicator can help in identifying the underlying factors responsible for an increase in vulnerability and can assist in highlighting a relevant course of action for disaster management. This can support local institutions in the formulation of emergency and recovery plans, awareness campaigns, and disaster risk reduction strategies, appropriate to each vulnerability dimension. Using adjusted sampling design, this flexible and robust methodology can be used at various spatial scales, urban or rural, and can also be used in the context of other natural hazards by streamlining disaster specific indicators. Depending on data availability, more indicators can be included or excluded in the vulnerability dimensions, for better reflection of local needs. This methodology can further be improved by incorporating statistical models for assigning weights, which may differ at different spatial scales. Differing levels of hazard and exposure must not be considered inconsequential, which might increase or decrease disaster risk as a whole.

This study further provides insights into the proposed methodology through its application in three flood-prone urban communities in Pakistan. The national development plans of Pakistan entail sector-wise development, into which various components of vulnerability fit perfectly. This study has found significant variations in all dimensions of vulnerability, especially institutional and attitudinal vulnerability. The results reveal that all three communities have fatalistic attitudes and poor risk perception. Institutions have been unable to provide appropriate awareness, training, and drills, which has amplified the vulnerabilities of the already exposed communities. District disaster management authorities are still absent at the ground level, and local institutions are managing floods on an ad hoc basis. This research will be instrumental for institutions and local governments concerned with disaster management and developing future strategies for disaster risk reduction, especially for flood-prone urban areas.

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