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Flood resilience assessment from the perspective of urban (in)formality in Surat, India: Implications for sustainable development

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Abstract
Urbanization has resulted in increasing the pace of informality, specifically in developing countries like India. Informality is taking place at locations that are exposed to various hazards, and therefore, resilience building of both informal and formal settlements is needed to achieve sustainable development. Resilience assessment is key in defining appropriate area-specific resilience measures. Given that, this research assesses the resilience of formal and informal settlements of Surat city in India and presents implications for sustainable development. To assess resilience, an indicator-based approach was taken, using a household survey to collect the data. Analysis suggests that the resilience of formal and informal settlements is significantly different. Key differences were found in physical and institutional resilience, where informal settlements were found to be significantly less resilient than formal settlements. Several measures, such as gender-sensitive education and livelihood programs, as well as mobile water and sanitation, have positive implications for sustainable development. Overall, the study can guide disaster managers and policy makers to adopt a strategic and more targeted approach to strengthen resilience and achieve sustainable development.

Keywords Sustainability · Resilience building · Indicators · Disaster risk reduction · Climate change adaptation · Informality

1 Introduction

Rapid urbanization has resulted in 57% of the world's population living in urban areas and has been most pronounced in developing economies in the last decade (United Nations 2022a). Urbanization has increased the pace of informality in cities, while formalization has slowed down (Ghani und Kanbur 2013). A recent IPCC report suggested that this trend of urbanization has resulted in concentrating human vulnerability to climate change and associated hazards in informal settlements (IPCC 2022). The impacts are particularly observed in socially and economically marginalized urban communities that predominately

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reside in informal settlements, while the majority of such settlements are located in hazardous locations (IPCC 2022). Thus, the interaction between the urbanization process and climate change and climatic events (e.g., floods, storms, heat waves) has undermined the resilience of the urban poor, particularly those living in informal settlements (Williams et al. 2019).

Climatic events, particularly floods, have significantly increased in recent years. There is sufficient evidence that climatic changes further intensify such events (IPCC 2018), and especially frequency and magnitude of floods are likely to increase (Jongman 2018). Several studies show that along with climatic changes, human activities have an important role in altering water cycles that have resulted in serious repercussions for society (see, e.g., Abhishek et al. 2021; Abhishek and Kinouchi 2021; Xiong et al. 2022). In the last two decades, 100,000 lives have been lost, more than 1.5 billion people were affected, and economic losses of around US$ 540 billion occurred only because of floods (EM-DAT 2020), which can be attributed to natural causes or human interventions. These impacts are significantly higher in low-income and developing countries due to limited financial and technical resources, resulting in a lack of resilience (Birkmann et al. 2022a, b). These differences in flood impacts and resilience are not only between countries but also within counties and cities, particularly when considering the formality and informality of urban fabric.

Several international commitments and agreements have indicated the importance of resilience building for achieving sustainability in human settlements, predominantly in informal settlements. Sustainable Development Goal (SDG) 11 targets to make cities and human settlements safe, resilient, and sustainable. SDG 13 aims to combat climate change and its impacts by strengthening resilience (United Nations 2022b). The New Urban Agenda has also called to enhance the resilience of both formal and informal settlements and prepare them to respond to disasters (United Nations 2017). Similarly, the Paris Agreement and recent COP 27 also committed to increasing resilience to contribute to sustainable development (UNFCCC 2015). In this regard, assessing resilience is central to developing appropriate area-specific measures to build resilience that contribute to long-term sustainability, especially in those countries where growing informality is a big challenge.

In India, one in six urban residents lives in informal settlements/slums, constituting about 93 million people (Barnes and Sawhney 2021). These informal dwellers contribute over 7.5% of urban GDP as of 2013 (Debroy 2013). Nevertheless, the majority of such settlements are food insecure, highly dense and polluted, lack basic services, safe housing structures, sustainable livelihoods, and the right to land, and are developed in areas that are often exposed to natural hazards, e.g., along river banks (Barnes and Sawhney 2021; Bentley et al. 2015; Nihar et al. 2023). India is at a very high risk of climate change impacts and is ranked 7th on the Global Climate Risk Index, particularly due to massive floodings caused by erratic monsoons (Eckstein et al. 2021). These events have caused massive loss of human lives, particularly in informal settlements, and economic losses worth billions of dollars (Pathak 2022). According to the World Risk Index (WRI), India was "poorly prepared" to cope with the "climate impacts," rendering it more vulnerable to serious natural disasters (Behlert et al. 2020).

Given the aforementioned situation, a comparative assessment of resilience in formal and informal settlements is needed to better guide area-specific measures to enhance resilience. In India, previous studies have either focused on resilience in general at the city level (Jain und Bashir Bazaz 2016; Joerin et al. 2014; Waghwala und Agnihotri 2019) or informal settlements (Aboulnaga et al. 2021; Rumbach und Shirgaokar 2017; Satterthwaite et al. 2020; Thakore et al. 2022). Comparative studies have been done focusing on heat stress (Mahadevia et al. 2020), exposure and vulnerability to flooding (Kit et al. 2011;

Mahadevia et al. 2019), and linking migration with resilience (Link et al. 2021). However, a comprehensive assessment of flood resilience with multiple indicators representing various societal aspects of formal and informal settlement has rarely been conducted. In addition, the role of resilience assessment in guiding sustainable development has been paid little attention, particularly in the context of India. Considering the research gaps, this research answers the following research questions using a case study of Surat City in India (see details in Sect. 3):

- How does the resilience of flood-affected communities living in formal settlements differ from those living in informal settlements?
- Which dimensions contribute significantly to the resilience of formal and informal settlements in Surat?
- What are the implications of resilience assessment for sustainable development?

To address the research questions, first, the theoretical and conceptual perspectives on resilience, and its linkages with sustainability are explored in Section 2. Sect. 3 provides the overall methodology of the research. Results are presented and discussed in Sect. 4, while Sect. 5 describes the implications of resilience assessment for sustainable development. Section 6 concludes the study.

2 Perspective on resilience and its linkages with sustainability

2.1 Concept and frameworks of resilience

Resilience has emerged as a widely acknowledged concept in the development agenda, meaning ability to adapt, bounce back, and recover from internal and external stresses (Manyena 2006). This concept has been used to define the capacities and abilities of individuals, communities, nations, and systems to withstand threats, disruptions, and disturbances (Rana 2020). With roots in various fields of study, such as psychology and health, environmental sciences and ecology, engineering and infrastructure planning, and business, continuous efforts have been made to understand the construct of resilience. Despite these efforts, the concept remains challenging due to the numerous existing definitions, approaches, theories, assessments, and frameworks.

Resilience is a complex concept studied and understood through various frameworks and discourses. Some studies have described resilience through its various characteristics, such as efficiency, strength, adaptability, persistence, anticipation, ability to return to an equilibrium state, ability to withstand external shocks, maintain the functionality of a system, mitigate and recover from hazards, adapting and surviving, creating opportunities from disturbances, bouncing forward, and thriving in uncertain systems (Adger 2000; Bruneau et al. 2003; Dovers und Handmer 1992; Holling 1973; Folke et al. 2010; Folke 2006; Norris et al. 2008). In the disaster and climate change domains, resilience is often viewed as a dynamic process that varies across space and time, as explained by the DROP model (Cutter et al. 2008). Another study proposed the DRIFT framework for analyzing resilience (Manyena et al. 2019). The MOVE framework considered resilience as a part of vulnerability assessment (Birkmann et al. 2013). Thus, the current discourse emphasizes the need

to capture the multidimensionality and multifaceted characteristics inherent in the concept of resilience.

Resilience, as a multidimensional concept, has been operationalized based on need, context, depth, and scope (Rana 2020). Research studies have conceptualized it based on social, economic, physical, and institutional dimensions (Ainuddin und Routray 2012; Cutter et al. 2008; Rana et al. 2021). Social resilience refers to the ability of individuals and communities to counter and recover from disruptions caused by natural hazards. It encompasses individual abilities, social networks, and community resources that can be mobilized to reduce vulnerabilities and increase coping capacities (Saja et al. 2019). Economic resilience, on the other hand, deals with enhancing the capacities of communities to mitigate the economic costs of disruptions and recover quickly (Rose 2004, 2007; Xie et al. 2018). Physical or infrastructural resilience deals with the integrity of the built environment to withstand the impacts of natural hazards. This includes the design and construction of buildings, infrastructure, and other assets to withstand natural hazards and minimize the damage caused by such hazards (Godschalk 2003; Twigg 2007). Lastly, institutional resilience explains the institutional readiness and response capacities in dealing with natural hazards. It encompasses the ability of organizations and institutions to prepare, respond, and recover from natural hazards (Lee et al. 2013). Therefore, it is important to consider the context and characteristics of communities to assess resilience. Limited studies have tried to capture all different dimensions of resilience, especially through the lens of urban informality.

2.2 Resilience for the perspective of urban (in)formality

Resilience against natural hazards can be shaped by various factors, including the socioeconomic and physical characteristics of formal and informal settlements (Deely et al.2010; Owusu Twum und Abubakari 2019; Satterthwaite et al. 2020; Wekesa et al. 2011). Generally, formal settlements tend to be planned, with proper infrastructural facilities and services, whereas informal settlements may be unplanned, with inadequate facilities and poor infrastructure (Godschalk 2003). Formal settlements are equipped with basic facilities such as electricity, water, and sanitation, and communities living in such settlements tend to have access to these resources. On the other hand, informal settlements, such as slums and squatter settlements, may lack these basic facilities and may be characterized by poor living conditions and a lack of land ownership (Aßheuer et al. 2013).

Research has shown that informal settlements are often found in floodplains or near hazard sources, making them more vulnerable to natural hazards such as urban flooding (Jamshed et al. 2020a, b, c; Rana and Routray 2016, 2018; Shah et al. 2019). Moreover, the institutional and governance systems in informal settlements are often weak in enforcing proper building codes and regulations (Milbert 2006; Wekesa et al. 2011; Ziervogel et al. 2016). Thus, the structures in informal settlements may not be able to withstand natural hazards. However, social support within informal settlements may be more prevalent than in formal settlements, which could be a key factor in increasing resilience (Shahid et al. 2022a, b).

On the other hand, it has been observed that informal settlements exhibit higher levels of social capital and cohesion, thereby bolstering their resilience in the face of natural hazards (Aldrich and Meyer 2015; Shahid et al. 2022a, b). Informal channels for information dissemination, communal support networks, and collective action contribute to swift disaster recovery within these settlements (Nakagawa and Shaw 2004). Moreover, these

settlements often serve as hubs for informal economies and livelihoods, offering safety nets that aid in a more effective rebound (Satterthwaite et al. 2020). Similarly, indigenous and localized solutions are frequently employed within informal settlements, which can yield valuable insights into community-driven approaches for enhancing disaster resilience (Rana et al. 2022). These studies underscore the inherent potential for strengthening the resilience of informal settlements.

Recognizing that numerous factors and characteristics can influence resilience, it becomes imperative to comprehend the unique considerations associated with such settlements prior to initiating any strategies aimed at disaster risk reduction or climate change adaptation. By doing so, the ultimate outcome will be the improvement of urban resilience.

2.3 Linkages between resilience building and sustainability

The concepts of resilience and sustainability are closely related and have significant implications for urban development (Tobin 1999). Both concepts call for systems that can withstand and adapt to shocks, and recover from them (Dovers und Handmer 1992; Leichenko 2011). Some researchers have referred to community resilience as an indicator of social sustainability (Magis 2010). Building resilience against urban flooding can be an effective way to promote pathways to sustainable urban development (Meerow et al. 2016; Roostaie et al. 2019; Vogel et al. 2007). Resilience is also linked to other global development concepts such as vulnerability, capacity, and adaptation (Rana 2020; Sapountzaki 2012; Vogel et al. 2007). Therefore, measures taken to mitigate the impacts of urban flooding can also result in sustainability. In addition, several international commitments and agendas have emphasized strengthening resilience to achieve sustainable development (see Sect. 1). Thus, resilience building provides an important link to attain sustainability, and for that, a comprehensive assessment of resilience is needed that could help identify appropriate area-specific measures. This study contributes by understanding urban resilience through a multidimensional approach in formal and informal settlements.

3 Methodology

In order to answer the research questions, first, the case study areas were selected. Secondly, a non-probabilistic sampling technique was used to calculate the sample size, and then a household survey was conducted to collect the required data. Lastly, the index was developed by following a set of steps (see Sect. 3.3).

3.1 Case study area

Surat is the 8th largest city in India and is a major port city in the northwest. The city is located between latitudes 21°03′ N to 21°18′ N and longitudes 72°42′ E to 72°55′ E, and Tapi River flows between the city. According to the 2011 census, the population of Surat is 4.5 million, which is an estimated 7 million in 2021 (SMC 2022), indicating that the city has experienced a dramatic growth in population over the past decade. Half of this population consisted of migrant workers induced by the rapid growth of the diamond and textile industries. This migration has led to the creation of several informal settlements, particularly along the river or other streams. As per Surat Municipal Corporation (SMC), more than 20% of the population lives in informal settlements, and the majority of these

settlements are located within 500 m of rivers and streams (see Figure S1 in supplementary material). More than half of the informal settlements in Surat have no access to proper electricity and safe sanitation, while lack of drainage results in water logging after rainfall events and provides perfect conditions for diseases like malaria and dengue (Verchick 2018). In Surat, there is a large number of informal settlements, which contrast starkly with formal settlements in the city both in terms of physical structures and socioeconomic aspects.

Being located on the banks of the Tapi River and in the coastal zone, flooding has been a recurrent event in the city (Waghwala and Agnihotri 2019). The city faces a triple flooding threat. First, from changing rainfall patterns, especially more frequent and intensive events during the monsoon, i.e., June to September (Srivastava et al. 2022). In 2022, Surat received 35% more excessive rainfall than average (Srivastava et al. 2022). Second, from the Tapi River and Ukai Dam upstream, as well as from 30 km of streams spreading in the city, and third, from the Arabian Sea (Parth 2019). Bhat et al. (2013) maintained that 90 percent of Surat's geographical area has witnessed climate-related events such as fluvial and pluvial flooding, coastal and cyclonic storms, or inundations caused by high tides and sea-level rise (Bhat et al. 2013; Srivastava et al. 2022). Several flood events have occurred in the past, with floods in 1979, 1990, 1994, 1998, and 2006 being the most devastating. The flood event of 2006 inundated 75% of the city area, took the lives of 150 people, and caused extreme economic damages worth billions of dollars (Bhat et al. 2013). Moreover, in every monsoon season, several areas (both formal and informal settlements) of the city are submerged in knee-deep water with foul-smelling and unhygienic sewage water running in the streets (Parth 2019). Thus, floods expose several areas in the city and could affect people at risk, which points to the need for resilience assessment.

Surat is divided into seven SMC administration zones. Two zones were selected, namely the Central and West zones, as these zones represent varied population densities and a mixture of formal and informal settlements prone to flooding (see Fig. 1). The Central zone is 8.2 square kilometres in area, with a population density of around 50 thousand persons per square kilometre. Out of the 0.4 million population, more than 50,000 (12.5%) live in informal settlements. The West zone constitutes an area of 87 square kilometres, with 0.45 million people and more than 26,000 (5.8%) living in informal settlements. Figure 1 shows the overview of both case study sites.

3.2 Sampling and data collection

In this research, a non-probabilistic sampling technique was adopted to collect the sample. That was done because the exact location and number of households affected by past flooding were not known within the exposed areas selected as case studies. Therefore, a sample of 120 households (60 from formal settlement and 60 from informal settlement) was purposively collected by the authors. A household survey was conducted over a period of two weeks to collect data on various resilience aspects through face-to-face interviews using a structured questionnaire (see questionnaire in supplementary material). The questionnaire contains multiple-choice questions, dichotomous questions, and Likert scale questions. Based on the literature (see Sect. 2), information on various socioeconomic, infrastructure, and institutional aspects was gathered that were relevant to the resilience and corresponded to the indicators (see Table 1). The purpose of the survey was explained, and verbal consent was taken at the beginning from each household. For data collection, enumerators

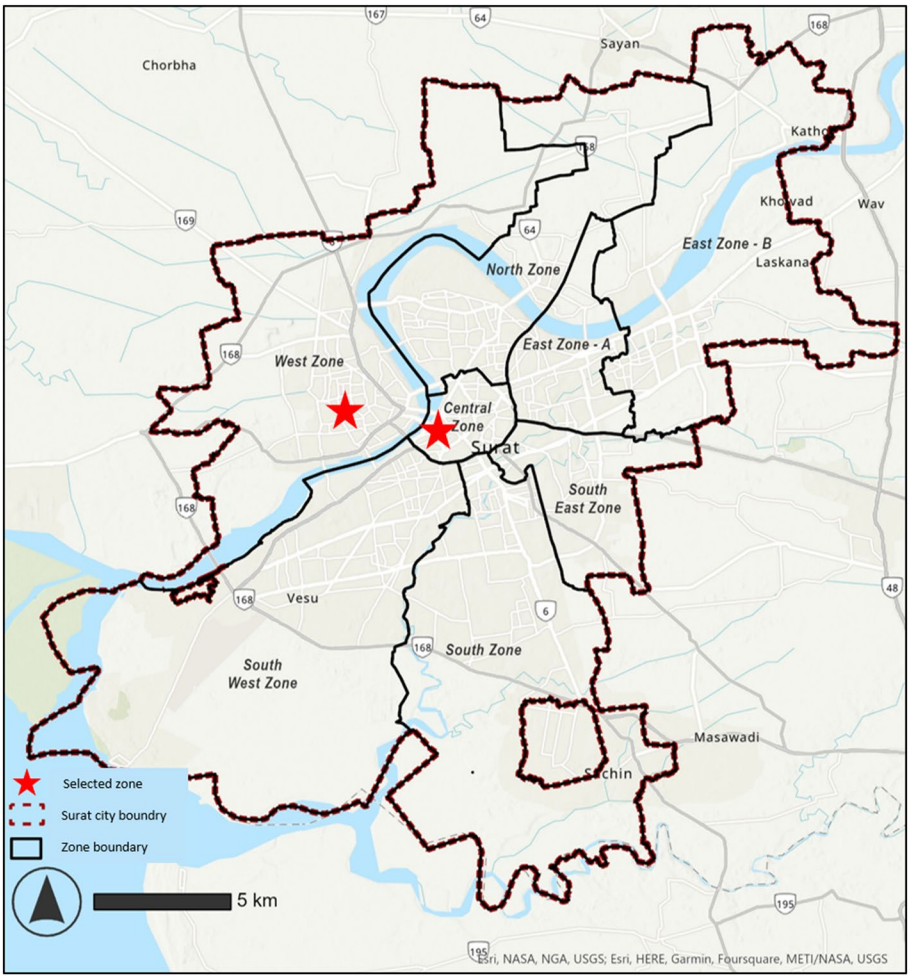

Fig. 1 Administrative zones of Surat city with River Tapi and other waterways passing through the city. Two areas with red stars show the selected zones where the household survey was conducted. (*Source*: based on SMC 2022)

were hired who surveyed households under the supervision of the second author. All communication was conducted in Gujarati and Hindi languages.

3.3 Construction of a composite index

An index-based approach is used in this research. The composite index helps to simplify multidimensional phenomena by providing a single metric that is easy to understand and communicate (OECD 2008; Tate 2012; Birkmann and Welle 2015, 2016). This approach has been widely used in disaster or climate change resilience assessment studies (e.g., Cutter et al. 2014; Qasim et al. 2016a, b; Feldmeyer et al. 2021). For the construction of the

Table 1 Resilience indicators representing respective dimensions, their explanation and supporting literature

No	Indicators	Classification	Scores	Explanation	Supporting literature
Social resilience					
SR1	Age of household head	> 50	0.33	Elderly household heads have less resilience during a flood event in terms of mobilizing and evacuating their family	Cutter und Finch (2008); Cutter et al. (2014); Guillard-Gonçalves et al. (2015)
		35–50	0.66		
		< 35	1		
SR2	Education level	No education	0.25	A higher level of education will increase their understanding of preparedness and response activities	Shahid et al. (2022a, b); Rana et al. (2020, 2021); Ryghaug (2011); Anderson (2012)
		Primary	0.5		
		Secondary	0.75		
		College/University	1		
SR3	Household size	< = 2	0.33	Larger household sizes show that more people can support each other in case of a flood event	Guillard-Gonçalves et al. (2015); Rana et al. (2020)
		3 to 5	0.66		
		> 5	1		
SR4	Woman headed household	No	0.5	Females have, in general, less physical strength and limited mobility during evacuation activities, as well as access to financial aid	Guillard-Gonçalves et al. (2015); Haveman und Wolff (2004); Rana et al. (2021)
		Yes	1		
SR5	Awareness of flood impacts	No awareness	0.25	Knowledge regarding flood impacts improves household response measures	Anderson (2012)
		Low awareness	0.5		
		Moderate awareness	0.75		
		High awareness	1		
SR6	Awareness of coping and adaptation strategies	No awareness	0.25	Awareness of coping and adaptation measures increases the ability of households to cope with a flood by minimizing their damage	Anderson (2012); Shahid et al. (2022a, b); Cutter et al. (2014)
		Low awareness	0.5		
		Moderate awareness	0.75		
		High awareness	1		
Economic resilience					

Table 1 (continued)

No	Indicators	Classification	Scores	Explanation	Supporting literature
ER1	Monthly household income (Indian rupee-INR)	< 5000 (< 60 Euro)	0.25	Low-income households are less resilient because of their limited ability to recover from flood hazards	Cutter et al. (2014, 2016); Rana et al. (2021); Qasim et al. (2016a, b)
		5000–10000 (60–120 Euro)	0.5		
		10,000–20000 (120–240 Euro)	0.75		
		> 20,000 (> 240 Euro)	1		
ER2	Economic dependency ratio *(total earning members/household size)*	< 1	0.33	A higher dependency ratio means that multiple earning members are present in a household	Jamshed et al. (2020a, 2020c); Rana und Routray (2018b)
		1 to 1.5	0.66		
		> 1.5	1		
ER3	Ownership of house	Tenant	0.5	House owners can repair, renovate, or reconstruct the house in case of collapse due to flooding	Shah et al. (2017); Ahmad und Afzal (2020)
		Owner	1		
ER4	Ownership of transport mode	No	0.5	Vehicle ownership improves household mobility during a flood event	Rana et al. (2021); Cutter et al. (2014)
		Yes	1		
ER5	Diversification of income sources	No	0.5	An alternative source of income increases resilience: if one source is damaged due to a flood, people can rely on other sources for survival	Rana et al. (2021); Jamshed et al. (2020c, 2020b); Guillard-Gonçalves et al. (2015)
		Yes	1		
Physical resilience					
PR1	Housing condition	Adobe/Wood/Tent	0.5	House constructed with reinforced material is capable of withstanding prolonged contact with flood waters	Cutter et al. (2014); Satterthwaite et al. (2020); Ahmad und Afzal (2020)
		Reinforced material	1		
PR2	Access to safe drinking water	No	0.5	Households having a lack of access to safe drinking water are less resilient	Cutter et al. (2016); Cutter (2016); Tierney (2012); Rana et al. (2021); Jamshed et al. (2019a); Soshino et al. (2018); Sethi et al. (2021)
		Yes	1		

Table 1 (continued)

No	Indicators	Classification	Scores	Explanation	Supporting literature
PR3	Access to proper sanitation facilities	No	0.5	Households having restricted access to sanitation facilities are less resilient	Cutter et al. (2016); Cutter (2016); Tierney (2012); Rana et al. (2021); Jamshed et al. (2019a); Soshino et al. (2018); Sethi et al. (2021)
		Yes	1		
PR4	Availability of electricity backup	No	0.5	Access to electricity backup can increase a household's capacity to cope	Kabir et al. (2018); Hammond et al. (2015; Phung et al. (2016)
		Yes	1		
PR5	Structural measures to deal with heavy rain and flooding	No	0.5	Implementation of structural measures, e.g., sealing roofs or sealing walls and barriers (beams, levees, floodwalls), can increase household capacity to deal with heavy rain and flooding	Jamshed et al. (2020b); Ahmad und Afzal (2020); Mård et al. (2018)
		Yes	1		
Institutional resilience					
IR1	Support from NGOs and Municipality	No	0.5	Households having access to evacuation camps or receiving grants to compensate for their losses can recover earlier	Jamshed et al. (2020c); Slavíková et al. (2021)
		Yes	1		
IR2	Early warning alarm for flood hazards	No	0.5	Early warning of flood hazards enables people to move themselves and their belongings to a safe place to minimize losses	Cools et al. (2016); Perera et al. (2020); Thielen-del Pozo et al. (2015); Pappenberger et al. (2015)
		Yes	1		
IR3	Availability of waste disposal system	No	0.5	The availability of a disposal system reduces the risk of blockage of the drainage system in case of a flood event	Lamond et al. (2012)
		Yes	1		
IR4	Provision of drinking water filtration facility	No	0.5	The provision of filtered drinking water protects people from the risk of infectious diseases	Cutter (2016); Guillard-Gonçalves et al. (2015); Paul und Routray (2011)
		Yes	1		

Table 1 (continued)

No	Indicators	Classification	Scores	Explanation	Supporting literature
IR5	Frequency of water supply per day	< 6 h	0.25	Obstructed water supply reduces household resilience	Guillard-Gonçalves et al. (2015); Paul und Routray (2011)
		6 to 12 h	0.5		
		12–24 h	0.75		
		24 h	1		
IR6	Frequency of electric supply per day	< 6 h	0.25	Obstructed electric supply would interrupt services like telecommunication and hamper access to information and warning	Kabir et al. (2018); Hammond et al. (2015); Phung et al. (2016)
		6 to 12 h	0.5		
		12–24 h	0.75		
		24 h	1		

index, several conventional steps were followed, which are briefly explained in the following sections.

3.3.1 Data transformation

In the first step, data collected from households were transformed to scale all values between 0 and 1. For this purpose, distance to the reference method was used considering the categorical nature of the data (see OECD 2008, S. 85 for details). This method has been widely used for the development of vulnerability and resilience indices (e.g., Gain et al. 2015; Rana und Routray 2018a; Jamshed et al. 2020c). Keeping in view the categories of each indicator (depending on the number of classes) and the nature of those indicators, transformed values were equally divided between 0 and 1. Table 1 provides the distribution of transformed values for each indicator.

3.3.2 Indicator selection

The selection of indicators was mainly based on two criteria; (a) indicators should be supported by relevant literature, (b) indicators should not be redundant, i.e., they do not have very high multicollinearity. In addition to that, three experts (working in the field of disaster management and climate change) were also consulted regarding the appropriateness of the indicators. Thus, the combination of the indicators to devise the index is specific to the context of the case study area and novel. Based on the mentioned criteria, at first, 24 indicators were selected based on literature analysis and distributed in different resilience dimensions, i.e., social, economic, physical, and institutional (see Table 1). Later, a correlation analysis between indicators was performed. A rule of thumb is that if two indicators show a correlation coefficient of more than 0.8, one must be removed. Our correlation analysis shows that two indicators showed a very high correlation with the other two indicators (see Table S1). This has resulted in eliminating 2 indicators. All the selected 22 indicators with supporting literature are presented in Table 1, while the correlation matrix of selected indicators is available in the supplementary material (see Table S1). The data for indicators were collected through a household survey (see Sect. 3.2).

3.3.3 Weighing and aggregation

Weights are important to consider since they have a significant effect on the overall composite index (OECD 2008). Moreover, indicators or their dimensions have differential importance both statistically and theoretically (Birkmann et al. 2021). Several methods exist to calculate the weights (OECD 2008, p. 31). In this research, the weights were derived using the statistical model, and Principal Component Analysis (PCA) was adopted. This approach assigns weights based on the statistical quality and reliability of data and is therefore useful to provide more credible results based on collected data. The weights were calculated for each dimension of resilience using four steps (see also OECD 2008, p. 89 for details). First, the correlation structure of the data was checked, as indicated in Sect. 3.3.2. Secondly, a certain number of latent factors were identified that represent the data where each factor depends on the loadings, which measure the correlation between dimensions and latent factors. Factors were chosen considering eigenvalues and their contribution to the total variance. In the third step, a rotation of factors was done. In the fourth step, the square of factor loadings after rotation was calculated and normalized to construct the

final weights for each dimension (OECD 2008). The weights are presented in Table 2. For aggregation, the linear arithmetic equation was used (see Eq. 1). This aggregation method has been widely used in disaster or climate resilience literature (e.g., Cutter et al. 2014; Shah et al. 2018; Jamshed et al. 2020a, 2019b). The values of indicators in each dimension were averaged and multiplied by the weight of that particular dimension. Afterward, the final weighted values of all dimensions were added and divided by the number of dimensions to get the final index value (see sample calculation in supplementary material).

$$\text{Resilience Index (RI)} = \frac{\sum_{i=6}^{n} \text{SRXi/n(wi)} + \sum_{i=5}^{n} \text{ERXi/n(wi)} + \sum_{i=5}^{n} \text{PRXi/n} + \sum_{i6}^{n} \text{IRXi/n(wi)}}{\text{N}} \tag{1}$$

Xi is the score of indicators resulting from transformation. n is the number of indicators in each dimension. w_i is the weight of the respective dimension. N is the number of resilience dimensions.

3.3.4 Index validation

Index validation is a vital step that helps to increase reliability and build confidence in the composite index results (OECD 2008; Brito et al. 2019). Several statistical analyses are used to validate the index (see OECD 2008; Tate 2012; Welle und Birkmann 2015; Birkmann et al. 2022a; Feldmeyer et al. 2020 for details.). In this research, a reliability and sensitivity analysis were used to validate the index indicators and their results. Reliability analysis describes the degree of accuracy and internal consistency of index indicators (OECD 2008). Cronbach's alpha is widely used to measure internal consistency (Jamshed et al. 2020c). Secondly, sensitivity analysis was performed to increase the confidence of the composite index using Monte Carlo simulations. The result of sensitivity analysis further justifies the indicator selection and robustness of the results (Jamshed et al. 2020a; Sorg et al. 2018).

In terms of reliability analysis, Cronbach alpha was calculated. Literature suggests that the alpha value of 0.6 and above indicates a good degree of internal consistency and reliability (OECD 2008; Sorg et al. 2018; Hamidi et al. 2020). Cronbach's alpha for all the resilience indicators was found to be 0.816, which displays strong reliability and suitability of indicators to assess resilience. The sensitivity analysis shows that all the indicators used were relevant for resilience assessment. Figure 2 (left) shows that the curve for each resilience dimension is steep, and a steeper curve indicates that indicators are relevant in explaining resilience. Box plots in the middle and right (Fig. 2) show that values of indicators that represent different dimensions are above "0" which depicts the usefulness of indicators in explaining overall resilience (see Welle und Birkmann 2015; Jamshed et al. 2020a, 2020c; Feldmeyer et al. 2020; Birkmann et al. 2022a for details on the interpretation

Table 2 Weights of respective resilience dimensions calculated using the PCA method

Resilience dimension	Weights
Social resilience (SR)	0.242
Economic resilience (ER)	0.194
Physical resilience (PR)	0.275
Institutional resilience (IR)	0.290

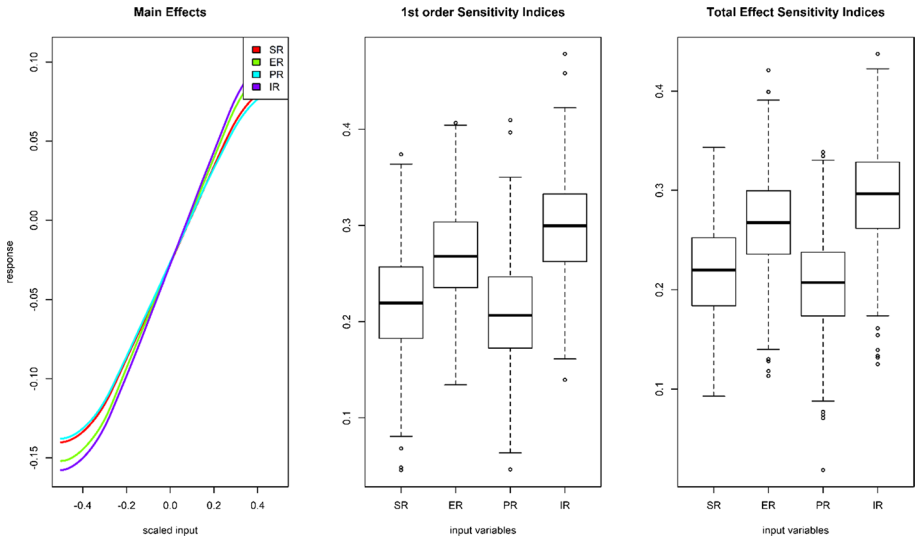

Fig. 2 Sensitivity analysis of indicators that represent different resilience dimensions (*SR* Social Resilience, *ER* Economic Resilience, *PR* Physical Resilience, *IR* Institutional Resilience)

of sensitivity analysis). Thus, all the indicators included in this study were relevant and valid for resilience assessment.

4 Results and discussion

The indicator-based assessment provides interesting results for different dimensions of resilience when comparing formal and informal settlements. The following sections present the socioeconomic profile of respondents and detailed findings of different dimensions of resilience.

4.1 Socioeconomic profile of respondents

The analysis of socioeconomic profile provides some interesting results. A vast difference can be seen in socioeconomic profiles of residents of formal and informal settlements (see Table 3). Regarding gender, 40% of respondents are female in formal settlements, while 48% are female in informal settlements. In terms of education level, a high percentage (43%) of respondents in informal settlements have no formal education, while all (100%) of the respondents in formal settlements have gained some formal education. In terms of income, households in formal settlements have significantly higher incomes, where 72% have a monthly income higher than 20,000 Indian rupees, while only 13% of households in informal settlements have an income higher than 20,000 Indian rupees. Table 3 demonstrates that 100% of residents of formal settlements own a mode of transportation, with most owning a car or motorbike, while only 70% of informal settlers own a mode of transportation, and those who do tend to own a bicycle or motorcycle. This shows that socioeconomic profiles vary a lot regarding the type of settlement in a city and could also result

Table 3 Socioeconomic profile of respondents in formal and informal settlements in Surat city

Variables	Classes	Type of settlement		Total
		Formal (%)	Informal (%)	
Gender	Male	60	51.7	55.8
	Female	40	48.3	44.2
Education level	No education	0	43.3	21.7
	Primary	11.7	35	23.3
	Secondary	33.3	18.3	25.8
	College/University	55	3.3	29.2
Monthly household income (in Indian Rupees)	< 5000	0	1.7	0.8
	5000–10000	0	33.3	16.7
	10,000–20000	28.3	51.7	40
	> 20,000	71.7	13.3	42.5
Ownership of mode of transport	No	0	30	15
	Yes	100	70	85

in varied levels of resilience. The next sections provide a detailed assessment of different resilience dimensions.

4.2 Social resilience

Social resilience was assessed with household education levels, age structures, knowledge of flood impacts, and relevant coping and adaptation strategies. The minimum and maximum index values of social resilience are not very different among settlement types, i.e., the index values of social resilience range from 11.4 to 22.8 for formal settlements and from 10.4 to 21.8 for informal settlements. However, Fig. 3 shows that the mean values of the social resilience index differ significantly ($t = 5.326$; df = 118; $p = 0.000$) among formal ($\bar{x} = 17.76$) and informal settlements ($\bar{x} = 15.21$). In addition, the difference between social resilience categories of formal and informal settlements is significant ($\chi 2 = 26.786$; p-value = 0.000). Table 4 shows that 45% of households in the informal settlement are categorized as having low resilience, and only 5% have very high resilience to deal with the flood, while only 15% in the formal settlement have low resilience; the majority of households (42%) have very high resilience.

Overall, informal settlements have lower social resilience and are associated with different factors (see also Figure S2 in supplementary material). A higher resilience in formal settlements is associated with a higher level of education, while in informal settlements, 50% of households have no education. Qasim et al. (2016a, b) and Drzewiecki et al. (2020) maintain that education attainment increases the understanding of protective and preparedness measures, thus helping make communities more resilient. Secondly, the majority of informal settlers (more than 70%) have no or limited awareness of the impacts of flooding nor of measures to cope and adapt to such impacts, while around 65% in the formal settlement have an awareness of impacts and measures to deal with it. This points to the fact that education level influences the degree of awareness regarding flood impacts and knowledge of coping and adaptation, as it has been suggested by Drzewiecki et al. (2020) and

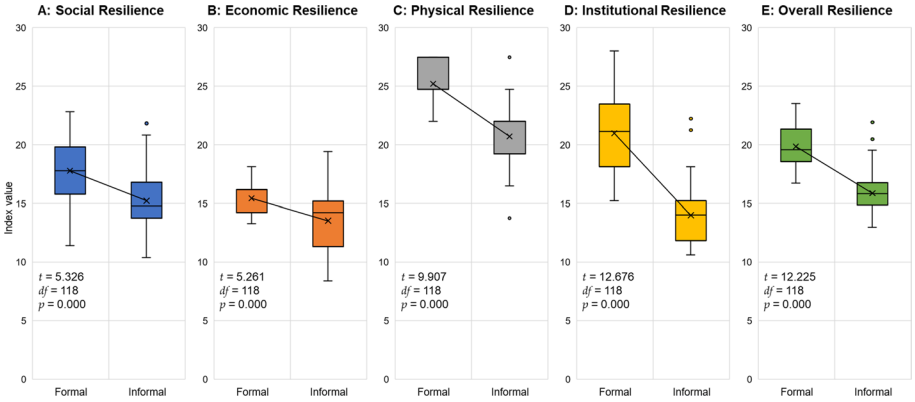

Fig. 3 Boxplots show the difference between the resilience of formal and informal settlements with respect to social **A**, economic **B**, physical **C**, and institutional **D** dimensions. Overall resilience is shown in Fig. 3E. The moderate outliers are represented by (°). The values under box plots show the outcome of the "*t*-test" where '*t*' show the *t*-test coefficient, 'df' shows the degree of freedom and '*p*' is the probability of rejecting the null hypothesis, and a value lower than 0.05 shows the difference between formal and informal settlement is statistically significant

Anderson (2012). Thus, education and awareness aspects were key in defining the social resilience of formal and informal settlements.

4.3 Economic resilience

Economic resilience was examined using indicators, e.g., income levels and sources, earning members, and ownership of the house and mode of transport. The analysis shows that there is a significant difference between the minimum and maximum index values of economic resilience in the case of formal (13.3 and 18.1, respectively) and informal (8.4 and 19.4, respectively) settlements (Fig. 3). Similarly, the average index value of economic resilience is 15.4 for formal settlement and 13.5 for informal settlement, which differs significantly. Moreover, it is found that around 46% of households in the formal settlements have medium to low economic resilience, while 83% of households in informal settlements fall under these categories (see Table 4), showing a highly significant difference ($\chi 2 = 24.120$; p-value $= 0.000$).

Our results reveal a significant difference in the economic profiles of the residents of formal and informal settlements (see also Figure S2 in supplementary material). Compared to the formal settlement, 85% of households in informal settlements belong to a monthly income group of 5000–20000 INR (60–240€). On the other hand, 72% of households in formal settlements have an income of more than 20,000 INR (> 240€). Several studies found that people with higher income levels can more easily recover and can implement better measures to cope and adapt (Jamshed et al. 2020c; Rana et al. 2021; Birkmann et al. 2022a; Birkmann et al. 2021; Rana et al. 2020). The economic dependency ratio is slightly higher in informal settlements, which indicates that multiple members of a household are income earners. This can be associated with the fact that informal settlers are engaged as low-income wage labourers and usually involve multiple members of their families in different jobs to make ends meet.

Table 4 Resilience level of households residing in formal and informal settlements with respect to different dimensions

Dimensions	Categories/Levels	Formal settlements		Informal settlements		Chi-square test	
		N	%	N	%	$\chi 2$ value	*p*-value
Social	Low	9	15.0	27	45.0	26.786	0.000
	Medium	12	20.0	12	20.0		
	High	14	23.3	18	30.0		
	Very High	25	41.7	3	5.0		
	Total	60	100.0	60	100.0		
	Mean	*17.76*		*15.21*			
	Std. Dev	*2.660*		*2.572*			
Economic	Low	7	11.7	27	45.0	24.120	0.000
	Medium	21	35.0	23	38.3		
	High	27	45.0	7	11.7		
	Very High	5	8.3	3	5.0		
	Total	60	100.0	60	100.0		
	Mean	*15.42*		*13.53*			
	Std. Dev	*1.259*		*2.488*			
Physical	Low	8	13.3	53	88.3	68.076	0.000
	Medium	0	0	0	0		
	High	34	56.7	3	5.0		
	Very High	18	30.0	4	6.7		
	Total	60	100.0	60	100.0		
	Mean	*25.18*		*20.69*			
	Std. Dev	*1.763*		*3.011*			
Institutional	Low	0	0	33	55.0	77.593	0.000
	Medium	7	11.7	21	35.0		
	High	28	46.7	4	6.7		
	Very High	25	41.7	2	3.3		
	Total	60	100.0	60	100.0		
	Mean	*20.96*		*13.99*			
	Std. Dev	*3.383*		*2.594*			
Overall Resilience	Low	0	0	30	50.0	69.867	0.000
	Medium	8	13.3	22	36.7		
	High	24	40.0	6	10.0		
	Very High	28	46.7	2	3.3		
	Total	60	100.0	60	100.0		
	Mean	*19.83*		*15.85*			
	Std. Dev	*1.736*		*1.824*			

Ownership of houses and modes of transport is significantly higher in formal settlements (see also Figure S2 in supplementary material). Studies have indicated that ownership of a house allows its occupants to make structural changes more easily and independently compared to those who live in rented houses (Shah et al. 2017; Ahmad und Afzal

2020). Additionally, it is found that the majority of households do not plan to diversify their income source in both settlements considering future flood events. This is also associated with limited opportunities and skill levels of households, particularly in informal settlements. Overall, households in formal settlements are economically more resilient due to better income levels and ownership of assets.

The chi-square test shows whether or not there is a significant difference between levels of resilience and types of settlement.

4.4 Physical resilience

The assessment of physical resilience includes aspects of housing conditions, access to basic infrastructure facilities (safe drinking water, sanitation, electricity, etc.), and the application of structural measures in the case of heavy rain and flooding. The index values for physical resilience ranged from 22.0 to 27.5 in formal settlements and 14.0 to 27.5 in informal settlements (see Fig. 3). There is a significant difference ($t = 9.907$; df = 118; $p = 0.000$) between the average index values of formal ($\bar{x} = 25.18$) and informal settlements ($\bar{x} = 20.69$), as shown in Fig. 3. The results suggest that 87% of households in the formal settlements have very high resilience, while only 10% of households in informal settlements fall within these categories (see Table 4). Thus, physical resilience differs between formal and informal settlements ($\chi 2 = 77.593$; p-value = 0.000).

The very low physical resilience of informal settlements can be associated with the type of houses people are living in and limited access to basic services (see also Figure S2 in supplementary material). Our analysis shows that more than 73% of households in informal settlements live in adobe or wooden houses (locally called katcha houses). In contrast, in formal settlements, all households live in houses construed with reinforced material (concrete and masonry). Several studies have argued that such katcha houses are the least resilient to flooding and can easily be washed away in case of flooding (Ahmad und Afzal 2020; Jamshed et al. 2020c; Rana und Routray 2018b). Secondly, more than 40% of households in informal settlements do not have any access to clean water and sanitation. These households use open fields for sanitation, which are breeding grounds for diseases. Birkmann et al. (2022a) and Rana et al. (2021) maintain that communities with limited access to clean drinking water and sanitation are the least resilient, while these factors increase the risk of waterborne diseases and create other severe health issues in the population, particularly in case of disasters.

On the other hand, it is surprising that residents of informal settlements take more structural measures to protect against flood and heavy rain than formal settlements, thus adding to their physical resilience. Results show more than 88% of informal settlers implement structural measures, while in formal settlements, only 68% of households implement measures. However, structural measures in informal settlements mainly include adding waterproof covers on the roofs and building blockades on door entrances. In formal settlements, such measures are not needed, as houses are constructed with reinforced material where structural changes are difficult to implement. Nevertheless, residents of formal settlements improve the drainage of roofs and also raise the platforms of house entrances. Moreover, informal settlers live on river banks in fragile houses and are the first to be affected by floods, leading them to implement more measures. This was also found true for Lahore city, in Pakistan (Zia et al. 2023). A study shows that people who live in close proximity to rivers rely on structural measures and reinforce flood protection measures (Ali et al. 2022; Mård et al. 2018). Ahmad und Afzal (2020) and Shah et al. (2017) also found that

higher proximity to hazards positively affects the implementation of structural protection measures.

4.5 Institutional resilience

The institutional resilience in Surat was studied in terms of early warning systems, waste disposal services, support from local public and private institutes, and how frequently basic services like water and electricity are provided by the local institutions. The results show that institutional resilience index values for formal settlements range from 15.2 to 28.0, while for informal settlements, the values range between 10.6 and 22.5, thus showing a great difference between the minimum and maximum values (see Fig. 3). Considering mean index values of institutional resilience for formal ($\bar{x} = 20.96$) and informal ($\bar{x} = 13.99$) settlement, the difference is statistically significant ($t = 12.676$; $df = 118$; $p = 0.000$). In addition, more than 87% of households in formal settlements report institutional resilience as high to high while only 11% fall within these categories in informal settlements (see Table 4). Overall, the level of institutional resilience between formal and informal settlements varies significantly ($\chi 2 = 77.593$; p-value $= 0.000$).

Institutional resilience is found to be the most important in terms of the type of settlements. Several factors were associated with such a huge difference in resilience levels (see also Figure S2 in supplementary material). Our analysis found that the majority of households (60%) in informal settlement does not have access to a proper waste disposal system, while in formal settlements, a waste disposal system was fully available to all households. In formal settlements, proper community waste bins were provided, and waste was regularly collected by SMCs, while in informal settlements, settlers threw waste in open drains and empty plots. Studies in India indicate that disposal of waste in drains results in losing drainage capacity (even blocking them), and drainage systems are unable to cope with an increasing volume of water and, as a result, cause high floods and harbour disease vectors (Gupta und Nair 2011; Lamond et al. 2012).

Another important aspect is the provision of municipal services, e.g., community water filtration facilities and continuous water and electricity supply. These factors are important for building resilience in the case of floods to facilitate normal life in these areas (Ray und Tewari 2018). Our analysis suggests that 94% of households in informal settlements do not have water filtration facilities in their area. Similarly, none of the households in informal settlements have a continuous 24-h supply of water and electricity, and the majority (more than 88%) received a supply of fewer than 12 h a day. The situation is much better in formal settlements. The provision of proper water and electricity supply systems is a key responsibility of local public institutions that not only show their institutional capacities but also add to the resilience of the general public (Kabir et al. 2018). Moreover, unavailability or outages of electricity can lead to interruption of water supply and telecommunication networks (Hammond et al. 2015). This could hamper the dissemination of flood warnings as well.

Dissemination of flood warnings is extremely important in the case of a hazard. Our results show that none of the households received flood warnings in the informal settlements, and only 25% received them in the formal settlements in the last flood event. This indicates the inefficiency of local institutions in communicating risk (Rana und Routray 2018a; Balica et al. 2009), in addition to several social and non-technical barriers (Shah et al. 2023). Several studies have indicated how effective the early warning systems are in saving lives and properties of people if properly and timely communicated and thus make

communities resilient (Cools et al. 2016; Perera et al. 2020; Thielen-del Pozo et al. 2015; Pappenberger et al. 2015). Therefore, improvement in early warning communication is needed in Surat to strengthen institutional resilience that is free from any social and technical barriers (see Shah et al. 2023). Another important factor that represents institutional resilience is how local institutions support people in the event of a flood, e.g., in terms of aid. It is found that 83% of households in informal and 80% in formal settlements did not receive any kind of support (financial aid, relief items, etc.) from local institutions in the last flood event, indicating limited institutional resources to provide relief to affected people. Aid (monetary or nonmonetary) has the potential to enhance the resilience of communities (Slavíková et al. 2021). Jamshed (2021) also shows how financial aid could improve the situation of affected communities, allow them to recover quickly, and make them prosperous. Overall, the limited availability of municipal services in informal settlements can be linked to their illegal status, where people squat on the land, due to their illegal status and the lack of provision of public services to residents by the public authorities, which leads to accessing these services illegally which itself is a hazard e.g., due to unsafe water and illegal electricity connections which can cause electrocution (Kavish 2021; Kacker und Joshi 2012; Satterthwaite et al. 2020).

4.6 Overall resilience

The overall resilience was assessed by the weighted average of all four dimensions. The results show a clear difference between the resilience of formal and informal settlements (see Fig. 3), where the former is more resilient with an average value of 19.38 compared to the latter with an average value of 15.85 ($t = 12.676$; df = 118; $p = 0.000$). Table 4 shows that around 87% of surveyed households in formal settlements have very high resilience, while only 13% of households in informal settlements fall within these categories. Around 50% of surveyed households were found to have low resilience in informal settlements. Thus, there are significant differences in resilience levels of formal and informal settlements ($\chi 2 = 69.867$; p-value = 0.000). The lower resilience among the households of informal settlements corresponds primarily to physical and institutional aspects. Factors associated with these two dimensions have very low scores in informal settlements compared to formal ones (see Sects. 4.3 and 4.4).

5 Resilience assessment: recommendations and implications for sustainable development

The assessment has provided interesting results with several implications for sustainable urban development. A considerable difference between the resilience of formal and informal settlements has shown that different areas require different measures to strengthen resilience and achieve sustainability. First, in terms of social resilience, education, and awareness (of impacts and coping) levels were lower in informal settlements. Ryghaug (2011) and Anderson (2012) maintain that education and climate change knowledge are key to achieving resilient and sustainable development. Therefore, targeted educational programs are needed that not only focus on children's education but eliminate gender disparities and also offer adult literacy programs. Apart from conventional teaching, such programs should emphasize raising awareness about the impacts of climate change and its

adaptation. This would help achieve several targets of SDG 4 (quality education) and 13 (climate action) (United Nations 2022b).

In terms of economic resilience, the majority of residents of formal settlements were well off, while households in informal settlements had limited financial resources and lived in poverty, which led to lower economic resilience. Several studies have recommended that income diversifications increase income levels and hence enhance resilience (Jamshed 2021; Jamshed et al. 2020b; Jiang und Han 2018). In this respect, gender-sensitive and market-oriented income programs can be developed to lower poverty in urban settlements. Thus, such programs could benefit formal settlements in general and informal settlements in particular. Jamshed et al. (2020a, b, c) and Jamshed et al. (2018) indicated that such gender and market-oriented programs improve financial situations. Moreover, special attention should be given to the working conditions and working hours of the people as the majority of informal settlements are involved in waged and risky jobs that are sensitive to hazards like floods. This would help achieve several targets of SDG 1 (no poverty), 8 (decent work and economic growth), and 10 (reduced inequalities) (see United Nations 2022b).

Concerning physical resilience, several problematic issues were found in informal settlements. Inferior quality housing and lack of access to basic infrastructure were the key issues (see Sect. 4.3). These settlements need proper upgradation in terms of housing, water supply, and sanitation services. However, such programs might be difficult for those settlements that are located in flood-prone zones. As relocation might be extremely difficult and expensive, mobile water supply (both for drinking and domestic use) and sanitation services can be provided. Soshino et al. (2018) have shown how mobile toilets can help flood-affected areas to deal with sanitation issues. Informal settlements are at risk of several diseases due to a lack of access to sanitation and clean water, mobile health centres/clinics are an option to deal with basic infrastructure-related health issues (see, e.g., Sethi et al. 2021). The housing situation can be made better by hazard-proofing houses and training households on such techniques (Satterthwaite et al. 2020). Such initiatives would help achieve targets in SDG 6 (clean water and sanitation) and 11 (sustainable cities and community) (see United Nations 2022b).

Lastly, institutions need to be resilient to make resilient communities. Our findings suggest that institutions were generally less resilient, and local public and private institutions could not provide several services in informal settlements. A flood warning is an important tool to save lives and property during flood events. An effective and efficient flood warning system is needed for formal and informal settlements. Lack of waste management is an important cause of flooding (see Sect. 4.4). A community-based waste disposal system should be developed in informal settlements. Lamond et al. (2012) show that community-based measures are successful in improving the disposal of solid waste and reducing flood risk. In order to solve the issue of disrupted electricity supply, a decentralized system (solar energy) can be provided. This would reduce electricity theft and eliminate the other risk (e.g., electrocution) of flooding. Overall, implementation of such measure not only increase the resilience of communities but also help to achieve targets of SDGs 7 (affordable and clean energy), 11 (sustainable cities and community), and 13 (climate action) (see United Nations 2022b).

The linkages between resilience and sustainable development have been acknowledged by several international agencies and research institutes (see, e.g., United Nations 2022b; United Nations 2017; UNFCCC 2015; IPCC 2022). Our research suggests how resilience assessment can result in a differentiated understanding of resilience and help achieve sustainable development goals. The findings of this research have implications for other parts of the world, particularly countries in the Global South, where urban informality is

widespread, and many informal settlements experience similar issues (Satterthwaite et al. 2020), for example, in Ghana (Amoako 2018), Pakistan (Qasim et al. 2016a, b; Rana et al. 2022), and Bangladesh (Ahmed 2014). Additionally, some of the approaches discussed and suggested in this paper may be useful to building resilience to flooding and achieving sustainable development in developing countries.

6 Conclusions

Analysis of resilience using an index-based approach and in terms of settlement types—formal and informal—provides interesting insights into how flood resilience differs significantly within a small geographical area. People in formal and informal settlements have different socieconomic characteristics and needs, leading to different resilience levels. Despite knowing that informal settlements lacks basic physical infrastructure provision, it remains a key obstacle in building resilience and promoting sustainable development (research questions 1 and 2). The study emphasizes that resilience assessment and its dimensions remain essential in identifying issues that can help achieve sustainable development goals (research question 3). This research indicates that blanket solutions to flood risk reduction are not sufficient. Resilience is a multifaceted phenomenon and must not be overly generalized. Targeted, contextualized, and customized interventions are required to enhance each flood resilience dimension and achieve specific SDGs. In this respect, disaster managers and urban planners need to work together, as well as practitioners and relevant stakeholders. Thus, a more integrated and holistic approach would be required that caters to the needs of both formal and informal settlements, builds their resilience, and achieves sustainability simultaneously.

This research has some limitations that could be improved upon in future studies. First, due to financial and timely pressures, the study was conducted in a relatively smaller area with a smaller sample size. Indicators were selected based on literature, statistical approaches, and expert opinions. However, the participation of local stakeholders could have provided insights into some other aspects of resilience that might have been missed in this study. A more participatory approach to weighing the indicators would help make decisions and develop acceptable and effective strategies for the communities. Furthermore, a more extensive and comprehensive study that includes spatial analyses would provide more insights into adaptation that contributes to sustainable development. Nevertheless, the results can still be generalized for other areas of India and the Global South regarding issues around formality and informality.

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Declarations

Conflict of 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.

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