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Climate change vulnerability assessment of urban informal settlers in Nepal, a least developed country

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ABSTRACT

Urban poor with limited resources and residing in precarious informal settlements are often one of the most vulnerable populations to climate variability and change. The present study seeks to assess the vulnerability of informal settlers to climate variability and change. Drawing from natural hazards, politico-economic, and ecological resilience strands of vulnerability literature we developed an integrated set of indicators for vulnerability assessment. The vulnerability of informal settlement dwellers was assessed in the hilly district of Kathmandu and the plain regions of the Nawalpur district of Nepal by collecting primary data from 300 randomly selected households, 150 from each district. Communities living in informal settlements experienced higher exposure to climate risk with lower adaptive capacity. Informal settlements with scarce resources, depilated infrastructure, fewer livelihood opportunities and knowledge gaps pose considerable vulnerability to climate variability and change. Our findings reveal that the inhabitants of informal settlements in the plain region are more vulnerable than that of the informal settlements of the hilly region due to higher exposure and sensitivity and lower adaptive capacities of the informal settlers of the plains. Enabling factors such as livelihood diversification, improved infrastructure, health facilities, social capitals, and support from local government with contextual policies and interventions, can facilitate better adaptation among the informal settlers and make them resilient to climate variability and change.

1. Introduction

Over 55% of the world's population resides in urban areas, which is expected to rise to 60% by 2030 and 66.4% by 2050 (UN-DESA, 2019). The projected urban population growth in the less developed regions will increase to 2 billion by 2050 with a 90% increase in Asia and Africa (Satterthwaite et al., 2020). Due to spatio-temporal interdependences (Xu et al., 2019), such expansion is a complex geographical process, which increases the complexities of urban sustainability (Xu et al., 2016). The urban poor is among the world's most deprived communities, with low human, natural, social, physical and financial assets (Williams et al., 2019; Alcayna-Stevens, 2015). Besides, climate change has exacerbated the vulnerability of the urban poor and marginalized communities (Moser and Stein, 2011).

The term 'informal settlement' refers to urban settlements that developed outside the formal system of planning and land use, built structures, health and safety, and often occupied by the poor. With the projected rates of urban population growth in developing and least-developed nations by 2050, large populations may eventually reside in informal settlements (Satterthwaite et al., 2020). Owing to located mostly in ecologically sensitive and marginal areas, the informal settlements often lack resources, assets, and proper facilities and means to cope with and recover from disaster impacts (Wekesa et al., 2011). Climate change often aggravates property loss, health hazards, and income disruptions in informal settlements (Béné et al., 2012), making the urban poor one of the most vulnerable populations in the world (Alcayna-Stevens, 2015). Given the clear links between vulnerability and deprivation in urban areas as well as the lack of disaster response capabilities (Gencer, 2008), an understanding of urban poverty needs to be established for insights into addressing climate change and vulnerability in these areas.

Household-level vulnerability and adaptive capacity assessments

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aimed at generating awareness among planners could help minimise such deficiencies by reducing exposure and vulnerability to hazards (Pandey et al., 2016). They can also promote adaptive responses enhancing sustainability and urban resilience (IPCC, 2014). Nevertheless, research on informal environments, their specific socio-ecology, unique economy and culture (Alcayna-Stevens, 2015), and the knowledge about the impacts of climate change on urban poor is very crudely understood (Moser et al., 2010; IPCC, 2014). The primary reason for a significant scientific knowledge gap can be attributed to the legal status of these settlements, scarcely available demographic data (Satterthwaite et al., 2020), and existing social exclusion from urban planning processes of these poor communities (Moser et al., 2010).

Developing countries often face extreme impacts of climate change due to poor adaptation abilities and restricted natural disaster coping capacities (IPCC, 2013). The fusion of climate change with regional economics and urbanisation produces new vulnerability trends (Moench et al., 2017) for developing nations, resulting in increased vulnerability of urban residents (Mitchell et al., 2015). Slum-dwellers are extremely vulnerable on account of their socio-ecological characteristics in Manila (Alcayna-Stevens, 2015). Low natural and human assets reduce the adaptive capacity of slum-dwellers of Indian Himalayas (Pandey et al., 2018a). Nepal, a least developed mountainous country, is especially susceptible to climate change and is at high risk due to its fragile ecosystem, unstable geology, and complex topography (Gerlitz et al., 2015). It has witnessed a recent rise in mean temperatures, unpredictable precipitation, and more erratic and prolonged droughts and such unprecedented climate conditions have increased the country's extreme events in terms of flash floods, landslides, glacial lakes outburst floods and droughts (Poudel et al., 2020) with significant impacts on the country's overall socio-ecological systems (Shrestha and Aryal, 2011). Nepal ranked 17th among the countries most affected by climate change and related threats (Karki et al., 2020).

Although by 2018, the urban population in Nepal was only about 20%, it will be amongst the world's top ten fastest urbanising countries during 2018–2050 (UN-DESA, 2019). The fast-growing urban areas of a least developed nation, characterised by a high level of poverty, informality, unemployment, and a high degree of environmental risks, often face a significant challenge of climate risks (Williams et al., 2019). The MoUD (2015) of Nepal estimates that about 10% of the total urban population comprises squatters referred to as '*sukumbasi*'. The dwellers of *sukumbasi* have no legal rights. Lack of tenure security, inadequate access to infrastructure and public utilities, inaccessible health facilities, current social exclusion, and increased crime and violence aggravate the vulnerability of Nepal's informal settlers (Bakraina, 2015).

Considering the extremely high vulnerability of Nepal's urban poor residing in informal settlements, the study aims at exploring the following research questions:

- What are the levels of vulnerabilities of the urban poor residing in the informal settlements in the hilly and plain regions of Nepal?
- What are the associations of vulnerability with various situational factors?
- What are the appropriate options to address the climate change vulnerability of urban informal settlers in Nepal?

In the remaining part of the paper, we present the theoretical framework followed by the profile of the study area. Section 2 details out methods comprising the procedure of data collection, methods of vulnerability assessment and Chi-square method for association analysis. Section 3 presents the results and provides the discussion for generalisation of the results in a similar context. Finally, we present the salient findings of the paper in the conclusion section.

1.1. Theoretical framework

There exist three strands for vulnerability literature—natural hazards, politico-economic, and ecological resilience. The natural hazards (NH) strand considers vulnerability as a function of exposure (Cutter, 1996), the politico-economic (PE) perspective perceive it as poverty and marginalisation (Bohle et al., 1994), while the ecological resilience (ER) discourse perceives vulnerability as the lack of resilience (Turner et al., 2003). The natural hazards strand mainly encompasses structural factors pertaining to proximity to a hazard and inefficient infrastructure and attempts to assess the potential biophysical threat and losses (Cutter, 1996). These losses form the basis of potentially vulnerable systems (Eakin and Luers, 2006). The politico-economic framework underlines heterogeneity in political, economic, and social structures of a population and explains its differential exposure, impacts, and capability to bounce back and adapt to future threats (Eakin and Luers, 2006). Ecological resilience perspective sees vulnerability as the flipside of resilience. In order to facilitate research uptake in the policy arena and operationalisation of the vulnerability in an efficient way, key system property was captured using the index-based approach of vulnerability for the social-ecological system.

In this study, vulnerability is considered as a propensity to be adversely affected and assessed through the IPCC framework based on the three dimensions of vulnerability—exposure, sensitivity and adaptive capacity. Exposure is considered as the presence of people, assets, livelihoods, species or ecosystems in settings that could be adversely affected. Sensitivity is defined as the factors affecting a system or species to be harmed. The vulnerability arises due to a lack of capacity to cope and adapt, and adaptation-related responses. Thus, adaptive capacity is defined as the ability of natural and human systems to adjust to potential damage. In this study, all three strands were considered for defining the dimensions of vulnerability as exposure dimensions from natural hazards and politico-economic literature, sensitivity and adaptive capacity dimensions from politico-economic and ecological resilience literature (see colour codes in Table 1). The vulnerability has a positive relationship with the system's exposure and sensitivity and a negative relationship with the system's adaptive capacity (IPCC, 2007). The study used a bottom-up approach to access the vulnerability of informal settlements (Pandey et al., 2018a, b) with the notion that the actual realisation of the impacts of climate change may influence the sensitivity and adaptive capacity of the dwellers such as experience and skills, which ultimately modify the vulnerability (Das et al., 2020).

The vulnerability was estimated by developing a composite index based on selected indicators of all the three dimensions of vulnerability following the literature such as Pandey and Jha (2012), Pandey et al. (2018 a, b); Gupta et al. (2019); Omerkhil et al. (2020a), Sekhri et al. (2020). The approach considered household capacity in terms of the available natural and built resources as measures for addressing the vulnerability. Various socio-economic and biophysical indicators contributing to vulnerability under the changing climate and coping strategies for addressing the vulnerability were also considered for vulnerability measurements.

Exposure was assessed based on seventeen indicators focusing on the location, livelihood options and the individual by assessing the exposure due to climate, the impact of climate, impact of disasters and hygiene affecting on daily productive activities of the individuals and the households (Table 1). The sensitivity was measured based on twenty-nine indicators focusing on the association for modifying the environment, economic and social settings of the dwellers leading to disturbing the livelihood along with a focus on the labour force i.e. the prime component of household welfare for the dwellers through evaluating the health and psychological factors of the individual and the households (Table 1). The adaptive capacity revolves around thirty-three indicators capturing all the features of the deprived dwellers in terms of the decision capability, infrastructure, technology and resource support, besides the social and economic status of the households leading to coping with the stresses of climate change (Table 1). A large number of attributes was considered with the view that the minute variability among the deprived and low entitled households may be captured in a precise

Table 1
Components, dimensions, indicators and their functional relationship with vulnerability.

Component	Dimension	Description	Indicator	Relationship with vulnerability	References
Exposure	Climate (C)	Exposure from variation in climate parameters	Temperature	Positive	Das et al., 2020; Gerlitz et al., 2016
			Rainfall	Positive	
			Hot days	Positive	Pandey and Jha, 2012
			Cold days	Positive	
	Impacts of changing climate (Ic)	Exposure from severity of climate related disasters	Water availability	Positive	Das et al., 2020; Gerlitz et al., 2016
			Severity of flood	Positive	
			Severity of drought	Positive	Gerlitz et al., 2016; Pandey and Jha, 2012
			Severity of cold	Positive	
			Human health	Positive	
	Impact of disaster (Id)	Impact of last natural disaster	Loss of household member	Positive	Das et al., 2020; Gerlitz et al., 2016
			Home destruction	Positive	
			Income source	Positive	
			Domestic animals	Positive	Omerkhil et al., 2020a
			Health	Positive	
			Education	Positive	
	Hygiene (Hy)	Stress on health due to waste	Outside waste	Positive	Pandey et al., 2018a
			Own waste disposal	Positive	
Sensitivity	Environmental well-being (EvW)	Sensitivity due to environmental impacts	Population pressure	Positive	Pandey et al., 2018b
			Health	Positive	
			Development work	Positive	
			Climate change	Positive	
			Water quality	Positive	
			Waste disposal	Positive	
			Drainage	Positive	
	Economic well-being (EcW)	Sensitivity due to economic impacts	Population pressure	Positive	Pandey et al., 2018b
			Health	Positive	
			Development work	Positive	
			Climate change	Positive	
			Water quality	Positive	
			Waste disposal	Positive	
			Drainage	Positive	
	Social well-being (SW)	Sensitivity due to social stress	Population pressure	Positive	Pandey et al., 2018b
			Health	Positive	
			Development work	Positive	
			Climate change	Positive	
			Water quality	Positive	
			Waste disposal	Positive	
			Drainage	Positive	
	Protective function (Pe)	Sensitivity due to diseases	Disease incidence	Positive	Pandey et al.,2018a
			Insect incidence	Positive	
	Productive Function (Labour) (Pt)	Sensitivity on labour due to impact of	Rainfall	Positive	Pandey et al., 2018a
			Water quantity	Positive	
			Air temperature	Positive	

		changing climate	Health	Positive	
			Solid waste	Positive	
			Drainage	Positive	
Adaptive capacity	Decision capability (DC)	Decision making capability	Age	Negative	Pandey et al., 2018a
			Gender	Negative	
			Education	Negative	
	Infrastructure (I)	House and housing amenities	House type	Negative	Pandey et al., 2018a
			Electricity	Negative	
			Sanitation facility	Negative	
	Economic support (Es)	Availability of assets	Household assets	Negative	Pandey et al., 2018b
			Major energy support	Negative	Das et al., 2020
			Drinking water sources	Negative	
	Social support (Ss)	Social networking	Assistance from others	Negative	Omerkhil et al., 2020a
			Community cultivation	Negative	
	Livelihood (L)	Income sources	Occupation	Negative	Jha et al., 2017
			New activity	Negative	
			Change in livelihood	Negative	
	Food (F)	Food and water availability	Food availability	Negative	Jha et al., 2017
			Water availability	Negative	
			Food sufficiency	Negative	
			Alternate food source	Negative	
	Health (H)	Prevention for diseases	Health facility	Negative	Pandey et al., 2018a
			Prevention for diseases	Negative	
			Water purification	Negative	
	Resource (R)	Provision of amenities	Grants/food/water	Negative	Pandey et al., 2018a
			Sanitation facility	Negative	
			House/housing material	Negative	
			Training	Negative	Pandey et al., 2018b
			Information	Negative	
	Technology (T)	Provision of technology for safety	River training	Negative	Das et al., 2020
			Rising of roads	Negative	
			Embankments	Negative	
			Homestead plinth raising	Negative	
	Coping strategy (Cs)	Strategies for coping	Civic body support	Negative	Pandey et al., 2018a; Das et al., 2020
			Government support	Negative	
			Small entrepreneurship	Negative	
			Forest resource extraction	Negative	
			Fish extraction from river	Negative	
			Illegal activities	Negative	

Note: Colour code for the strands of literature as red for NH; blue for PE and green for ER

manner. Table 1 also presents the relationship of each indicator with the vulnerability.

2. Methods

2.1. Profile of study area

Of the many informal settlements in Nepal, two in the hilly district of Kathmandu (Sinamangal and Manohara) and two settlements in the plains of Nawalpur district (Rithepani and Botegaun) were selected based on distinct socio-economic and environmental characteristics such as proximity to rivers, commercial units, industrial units, and waste disposal sites (Figs. 1 and 2; Table 2).

Kathmandu, located in the middle-mountain region of Nepal, covers an area of 899 km^2 (Thapa and Murayama, 2010). The region, falls within the subtropical cool temperate zone, with an average summer temperature between 19 °C and 27 °C and an average winter temperature between 2 °C and 20 °C. Rainfall mostly occurs between June and August with an average rainfall of about 1,400 mm and 75% of average humidity (Pant and Dangol, 2009). The Simamangal and Manohara informal settlements are among the oldest and are home to the oldest informal settlers, clustered along riverbanks and surrounded by residential and commercial areas. Both settlements are marked by depilated infrastructure (Fig. 2), non-existent safe drinking water supply, and overcrowding with wage labour and household work as the dwellers' primary occupation.

The Nawalpur district covers parts of terai, inner terai, and the lower hilly regions. The climate of the district ranges from tropical to temperate, where a tropical climate prevails in the southern part while the northern part has a temperate climate with an average annual rainfall of 1811 mm (Giri, 2015). The Rithepani and Botegaun informal settlements are located within the municipalities of Nawalpur district on the bank of frequently flooding rivers and dense forests. The settlements lack basic infrastructure and amenities, including drainage, sanitation, and access to roads (Fig. 2).

2.2. Data collection

Based on the theoretical framework a household level questionnaire was designed and conducted during January–March 2020. The questionnaire contained questions as per the selected indicators for different dimensions of the vulnerability. Before administering the questionnaire, it was pre-tested and some redundant questions were deleted. The final questionnaire for survey contained four sections: the first section dealt about the general information about the household such as demographic and socio-economic characteristics of the households. The second

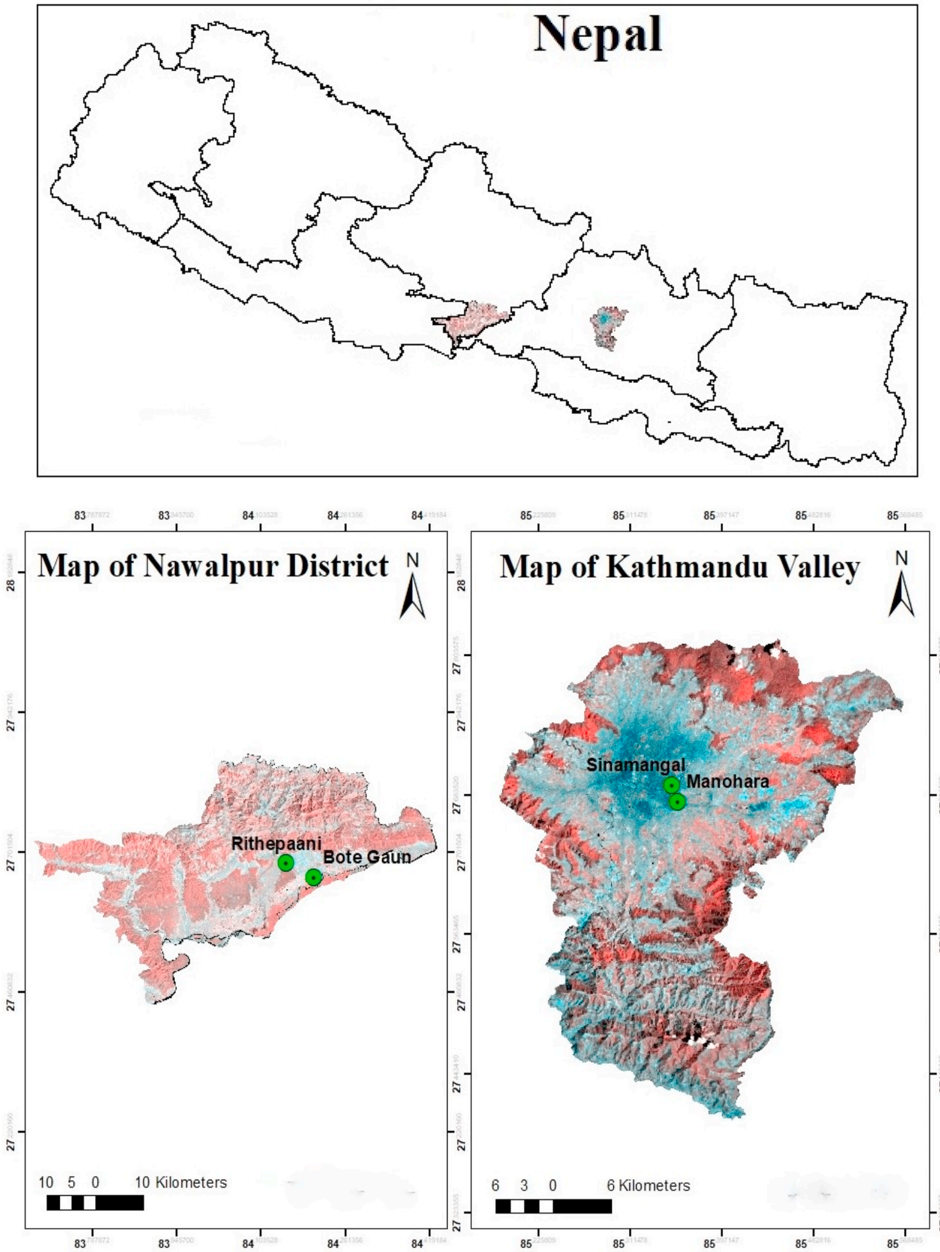

Fig. 1. Map of the study area with locations of the informal settlements studied.

section included questions on changes in climate parameters, waste management, and impacts of climate change and disasters on lives, property and income sources of the households in the last decade. The third section focused on sensitivity, exploring challenges on environmental, economic and social aspects faced by the households. The questions in the section were focused to measure the challenges for productive and protective functions of household welfare that occurred due to environmental, economical and social impacts. The fourth section focused on various internal and external strengths of the household leading to support, cope and adjust to the ill-impacts of climate change. This section included the questions about the external support received from government, civil body, neighbours, and available amenities, technology and infrastructure to the household; however, the internal characteristics focused on the information about the decision making capability and livelihood options of the household to adjust to the changes (Table 1).

We adopted a random sampling approach to select 300 households from these four settlements (Table 2). After briefing on the study and receiving consent, the interview was conducted with respondents aged 18 years and above. Based on respondents' preference, the interview was conducted in the local language. The collected data was used for the vulnerability analysis as per section 2.3.

2.3. *Vulnerability assessment*

Selected indicators were based on the regional context and available literature (Pandey and Jha, 2012; Pandey et al., 2018a, b; Gupta et al., 2019; Omerkhil et al., 2020a). Based on the vulnerability relationship, the quantified indicators were standardised and indexed for vulnerability analysis (Pandey et al., 2018a, b). The following formulae were used for normalisation:

For indicators (I) impacted vulnerability positively, i.e., increase vulnerability (Eq (1)),

Fig. 2. Photographs of informal settlements in hilly and plain region.

Table 2
Geographical location of informal settlements and the number of sampled households in hilly and plain region.

Region	Informal settlement	Characteristics	Longitude	Latitude	Altitude (m)	Approx. Number of households	Surveyed households
Hilly	Sinamangal	Oldest settlements, proximity to Bagmati river, vicinity of industrial, commercial and waste disposal sites	27°41′28″N	85°20′59″E	1294	750	75
	Manohara	Oldest settlements, Proximity to Manohara river, vicinity of industrial, commercial and waste disposal sites	27°40′44″N	85°21′23″E	1301	700	75
Plain	Rithepani	Experience regular flooding, near a Loka river, and dense forests	27°40′56″N	84°09′10″E	228	300	84
	Botegaun	Experience regular flooding, near a Baula river, and dense forests	27°39′31″N	84°12′09″E	167	150	66

$$I = \frac{(X_i - Min)}{Max - Min} \quad (1)$$

For indicators (I) impacted vulnerability negatively, i.e., decrease vulnerability (Eq (2)),

$$I = \frac{(Max - X_i)}{(Max - Min)} \quad (2)$$

Where.

X_i is the value of indicator X for ith household.
Max represents the maximum value of all the values of X indicator.
Min represents the minimum value of all the values of X indicator.

The weighting for each indicator was estimated according to the relative importance of the individual indicators based on the method promoted by Iyenger and Sudarshan (1982). The formula for the method (Eq (3)) is as follows:

$$W_i = k \Big/ \sqrt{Var(y_i)} \text{ where, } k = \left(\sum_1^m \frac{1}{\sqrt{Var(y_i)}} \right)^{-1} \quad (3)$$

Here, W_i represents the weight of the ith indicator such that $0 < W_i < 1$ and the sum of all 'm' number of weights is equal to one., y_i is the normalised value of ith indicator, Var (y_i) is the variance of y_i and m is the number of indicators.

The index for all the three dimensions of vulnerability is the weighted sum of all the considered indicators for the dimensions.

The *exposure assessment* was based on the following equation (Eq (4)) using four dimensions - climate variability (C); impacts of changing climate (Ic); impact of disaster (Id); and hygiene (Hy).

$$Exposure\ index\ (E) = \frac{(C + I_c + I_d + H_y)}{4} \quad (4)$$

The *sensitivity assessment* was based on the following equation (Eq (5)) using five dimensions - environmental well-being (EvW); economic well-being (EcW); social well-being (SW); protective function (Pe) and productive function (labour) (Pt).

$$Sensitivity\ index\ (S) = \frac{(E_vW + E_cW + SW + Pe + Pt)}{5} \quad (5)$$

The *adaptive capacity assessment* was based on following equation (Eq (5)) using ten dimensions - decision capability (DC); infrastructure (I); economic support (Es); social support (Ss); livelihoods (L); food (F); health (H); resource (R); technology (T) and coping strategy (Cs).

$$\text{Adaptive capacity index (A)} = \frac{(\text{Dc} + \text{I} + \text{Es} + \text{Ss} + \text{L} + \text{F} + \text{H} + \text{R} + \text{T} + \text{Cs})}{10} \quad (6)$$

The vulnerability index (VI) of the system was estimated by considering the closeness of the system to the most vulnerable state, i.e. the ideal (terrible) state by the following formula (Eq (7)) with high VI for a system represents closeness to the most vulnerable state (Omerkhali et al., 2020a, b).

$$\text{VI} = 1 - \sqrt{\frac{[\{(1 - \text{W}_1\text{E})^2 + (1 - \text{W}_2\text{S})^2 + \text{W}_3\text{A}^2\}]}{3}} \quad (7)$$

Where W_1, W_2 and W_3 are the weights of the dimensions, i.e., exposure, sensitivity and adaptive capacity.

2.4. Chi-square method for association analysis

We conducted the Chi-square test to analyse the association between vulnerability, sensitivity, and adaptive capacity (the two internal characteristics of the system) with three contextual factors considered for both regions. Household capacity is assessed through income, assets, health, and education. Therefore, the contextual factors were taken as the number of working days (an indirect measure of income-earning opportunities), the number of rooms (a measure of the strength of assets), and disease incidence (a measure of sanitation, health and labour). Vulnerability, sensitivity, and adaptive capacity were categorised as low, medium, high, and very high based on their quartile distribution, but contextual factors were divided arbitrarily into three classes as (2–3 days), (4–5 days), and (6–7 days) for the number of working days, (1–2), (3–4), and (5 and above) for the number of rooms while considering the increase, decrease, and no change regarding disease incidence.

3. Results

3.1. Demographic and socio-economic characteristics

Low assets of the poor informal settlers restrict them to be resilient against external stressors including climate change. The feeble housing structures and routine maintenance requirements were attributable to the temporal nature of homes and fear of eviction from authorities. A comparative socio-demographic profile of respondents across the informal settlements studied is presented in Table 3. Underlying resource deficiency has further exacerbated climate change-related risks in both regions. All households across regions bought foodstuffs from markets with some reporting food insufficiency for about three months. Affordability and accessibility to food are crucial factors in shaping the vulnerability of low-income urban residents, while food insecurity prevalent in these communities can further increase susceptibility to hazards (Tacoli, 2013).

Table 3
Socio-demographic profile of respondents (in %) in hilly and plain region.

Parameter	Hilly		Plain	
Age Groups (years)	Male	Female	Male	Female
0–18	54.61	45.39	43.37	56.63
18–36	47.39	52.61	46.89	53.11
36–55	52.17	47.83	54.27	45.73
55 and above	54.88	45.12	42.68	57.32
Education Level	**Hilly**		**Plain**	
Illiterate	46.00		49.00	
Primary	23.00		28.14	
High School	22.69		17.33	
Intermediate	6.00		4.00	
Bachelor and above	2.31		1.53	
Type of House	**Hilly**		**Plain**	
Permanent	13.33		02.67	
Semi-Permanent	66.67		58.00	
Temporary	20.00		39.33	
House Ownership	73.33		91.33	
Household with electricity	97.33		82.00	
In house toilet facility	86.00		92.00	
Source of drinking water	**Hilly**		**Plain**	
Open source	28.00		03.33	
Hand pump	38.67		30.67	
Tap	18.00		66.00	
Purchased water	15.33		0.00	
Profession	**Primary**	**Secondary**	**Primary**	**Secondary**
Service	18.67	2.67	17.33	0.67
Shopkeeper	10.00	10.00	08.67	01.33
Self employed	16.67	36.00	15.33	55.33
Remittance	11.33	01.33	10.67	01.33
House help	0.67	16.67	0.00	0.00
Wage labor	38.00	30.00	47.33	40.67
Rack pickers	4.66	03.33	0.67	0.67

3.2. Exposure assessment

Most critical exposure components have been identified based on people's perceptions of climate change over the last ten years and impacts due to the severity of extreme events. Respondents noted an increase in the severity of floods and droughts. The occurrence of climate-related disasters like floods and droughts has increased (Table 4). As noted during the survey, the upgrades of nearby road systems have also worsened the floods in these informal settlements. Approximately 20% of respondents reported the loss of income and around 37% of respondents had health-related problems due to floods in both regions. Respondents in both regions reported deterioration of water quality as a result of flooding. Exposure to solid waste was also a major concern for informal settlers. Forty-five per cent of households in the plain region reported open and scattered disposal of solid wastes. The openly dumped waste provides habitat for organisms by leaching toxins into the soil and acting as a vector for diseases (Davis, 2007). Groundwater contamination, breeding of flies and bad odours near solid wastes disposal sites act as habitats for reptiles (Dodman et al., 2015).

The perception data for exposure assessment were classified into four components: climate, impacts of changing climate, the impact of a disaster, and hygiene. Based on the analysis, residents in the plain region were found to be more exposed to climate parameters (0.099), impacts of changing climate (0.239), impacts of disaster (0.068) and hygiene (0.099) than residents in the hilly region who had comparatively low exposure to climate parameters (0.097), impacts of changing climate

Table 4
Respondents' perception of climate parameters, climate extremes and water availability (in %) in hilly and plain region.

Parameter	Hilly			Plain		
	Increase	Decrease	No change	Increase	Decrease	No change
Temperature	70.67	01.33	28.00	76.00	00.67	23.33
Rainfall	10.67	80.00	09.33	61.67	73.33	10.00
Number of hot days	82.67	02.00	15.33	85.33	01.33	13.34
Number of cold days	13.33	72.00	14.67	14.00	69.33	16.67
Severity of drought	58.67	26.00	15.33	72.67	22.00	05.33
Severity of flood	67.33	26.00	06.67	40.67	44.66	14.67
Severity of cold	80.67	12.67	06.66	77.34	21.33	01.33
Water availability (Summer)	0.00	84.00	16.00	0.00	82.00	18.00
Water availability (Winter)	0.00	76.00	24.00	0.00	70.67	29.33
Water availability (Autumn)	01.33	42.00	56.67	06.00	33.33	60.67

(0.237), impacts of disaster (0.037), and hygiene (0.073). The average score of the exposure index was (0.505) for the plain region and (0.444) for the hilly region (Table 5; Fig. 3).

3.3. Sensitivity assessment

Sensitivity to climate change was estimated based on the environmental and socio-economic well-being of households, their severity, and respondents' perception of protective function. All the sensitivity factors pertaining to environmental, social, and economic well-being were rated high by respondents in both regions. However, the top environmental challenges faced by households were water quality and waste disposal and, reportedly, health expenditure caused the most considerable economic distress. Forty-seven per cent of respondents in the hilly region and 40% in the plain region rated environmental challenges as very severe. This correlates strongly with rapid environmental degradation due to untreated wastewater disposal into water bodies and unmanaged solid waste in both regions.

Informal settlement respondents expressed concern about the increasing population pressure. They categorically stated that an increase in population would further increase their vulnerability in terms of reduced employment opportunities, increased waste generation, and severely limited mobility. Moreover, overcrowding made them vulnerable to communicable diseases such as tuberculosis, meningitis and acute respiratory disorders (Sclar et al., 2005). About 50% of respondents from both regions identified these economic and social challenges as very severe. Fifty-three per cent of hill respondents and 58% in the plain region reported an increase in the incidence of diseases like diarrhoea, cholera, fungal skin infections, malaria, typhoid, and seasonal fevers. The respondents stated that the fundamental causes of increased illness in communities were degradation of water quality, poorly managed climate, lack of health facilities, and malnutrition. Twenty-four per cent and 22% of respondents in the hills and plains also recorded an increased incidence of insects in recent years. Poor awareness of climate change among residents has been observed in both regions. Thirty-nine per cent of respondents in the area were not aware of climate change and its effects; only 7% indicated that climate change was a moderate issue. Some respondents described climate change in the temperature and rainfall variability trends. None of the households was reported to have developed plans to address the potential impacts of climate change.

Table 5
Estimates of components, dimensions and indicators of exposure in the hilly and plain region.

Dimension	Indicator	Value			
		Hilly		Plain	
Climate variability	Temperature Rainfall Hot days Cold days	0.097	0.444	0.099	0.505
Impacts of changing climate	Water availability Human health Severity of drought Severity of flood Severity of cold	0.237		0.239	
Impact of disaster	Loss of household member Home destruction Domestic animals Income sources Health Education	0.037		0.068	
Hygiene	Waste disposal Own waste disposal	0.073		0.099	

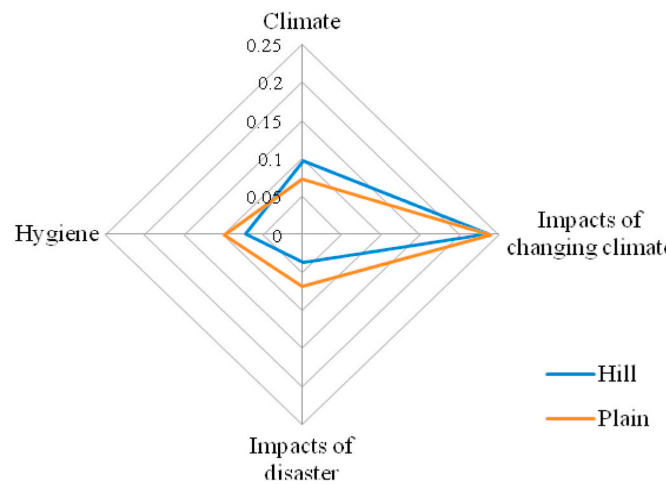

Fig. 3. Spider diagram of exposure of the hilly and plain regions.

Climate-change sensitivity was assessed through five components: environmental well-being, economic well-being, social well-being, protective function, and labour. Results showed that respondents were more sensitive to economic well-being (0.139), protective function (0.081), and labour (0.233) in the plain region compared to respondents in the hilly region. The latter were more sensitive to environmental well-being (0.078) and social well-being (0.102). The overall scores for the sensitivity index were (0.602) and (0.617) for the hilly region and plain region, respectively (Table 6; Fig. 4).

3.4. Adaptive capacity assessment

The adaptive capacity assessment was conducted based on households' social, economic and human capacity, as well as on the availability and accessibility of infrastructure, including health, technology, and communication facilities. Residents of low-income settlements often need assistance to improve adaptation measures against the impacts of climate change (Bartlett et al., 2009). Approximately 83% of

Table 6
Estimates of components, dimensions and indicators of sensitivity in hilly and plain region.

Dimension	Indicator	Value			
		Hilly		Plain	
Environmental well-being	Population pressure Health Development work Climate change Water quality Waste disposal Drainage	0.078	0.602	0.072	0.617
Economic well-being	Population pressure Health Development work Climate change Water quality Waste disposal Drainage	0.118		0.139	
Social well-being	Population pressure Health Development work Climate change Water quality Waste disposal Drainage	0.102		0.092	
Protective function	Disease incidence Insect incidence	0.078		0.081	
Productive Function (Labour)	Rainfall Water quantity Air temperature Health Solid waste Drainage	0.226		0.233	

respondents noted that they had not received any assistance during crises, either from the corresponding neighbourhood or from governmental or non-governmental institutions. Less than 25% of households were members of some social organisation, while about 50% of respondents confirmed about not providing any assistance to fellow dwellers during a crisis. Such community behaviour on the part of respondents demonstrates a less developed social networking system restricting residents to access social capital.

Roughly 32% of households in both regions reported having shifted livelihoods, while 26% had settled for additional income practices to mitigate problems like income loss due to floods, droughts, and inadequate wages. Approximately 35% of respondents in both regions reported engaging in small home-based enterprises to gain some subsistence income. Livelihood diversification in informal settlements has acted as a gateway to buffering against future security shocks and stress, environmental hazards, climate variability, informal work, lack of access to financial resources and lack of other forms of social protection (Gioli et al., 2019).

Ten per cent of households in the hilly region reported using underground water as an improvement to water shortages, while 76% of households reported having used water from nearby open sources. Sparse alternate water sources had compelled reduced use of water, reported 41% of respondents in the plain region. Most of them relied on water from rivers or canals that had been reported to dry up during summer. Very few respondents reported having sufficient food. Reducing the quality and quantity of food and missing meals is a typical coping response among the poor of the African informal settlements (Dodman et al., 2015). The two key factors contributing to food insecurity in households were poor and intermittent wages. The unavailability of health facilities was a major concern for 14% of respondents in the plain region. Almost 80% of households in hilly and 65% in the plain region used the mosquito-net as a preventive measure against diseases like malaria. No respondent reported regular check-up and around 33% used mosquito repellents in both regions. Seventy-nine per cent of households had access to television, while most respondents do not have access to newspapers. Access to information was considered essential for successful adaptation to climate change (Pandey et al., 2018b; Singh and Chudasama, 2021), yet 35% of households in both regions were deprived of any means of information.

Only 13% of respondents in the plain region received housing materials from the government for repairing their houses. Sixty per cent of households in the hilly region reported that building embankments and homestead plinths along the river were necessary to prevent rainwater and flooding. The need for urgent action to address infrastructure problems in informal settlements is highlighted by most of the residents to protect their homes from floodwater. Due to the proximity of the forest to both settlements in the plains, 21% of respondents reported logging, fodder, fuelwood, and medicinal herbs from the forest as their coping strategy. They also use water sources inside the forest for survival, placing pressure on the limited environmental resources (Alcayna-Stevens, 2015).

The adaptive capacity assessment was conducted by classifying all indicators under ten components as decision capability, infrastructures, economic support, social support, livelihood, food, health, resources, technology, and coping capacity. The scores of these indicators are presented in Table 7. Based on these results, the assessed adaptive capacity index for the hilly region and plain region was (0.506) and (0.406), respectively (Table 7; Fig. 5).

3.5. Vulnerability assessment

Due to higher exposure and sensitivity and lower adaptive capacities, the residents of informal settlements in the plain region are more vulnerable than that of the informal settlements of hill district (Table 8;

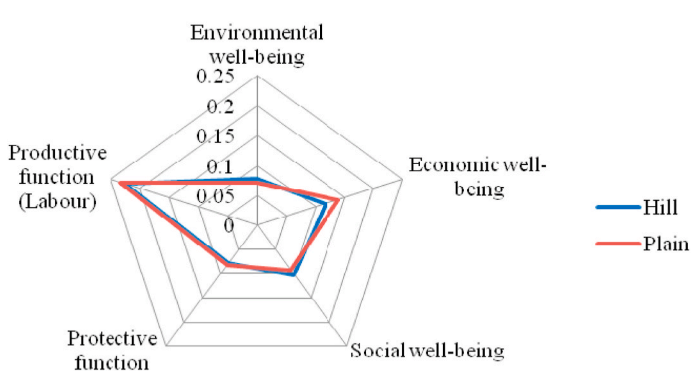

Fig. 4. Spider diagram of sensitivity of hilly and plain region.

Table 7
Estimates of components, dimensions and indicators of adaptive capacity in hilly and plain region.

Dimension	Indicator	Value			
		Hilly		Plain	
Decision capability	Age Gender Education	0.070	0.506	0.056	0.406
Infrastructure	House type Electricity Sanitation facility	0.070		0.055	
Economic support	Household assets Major energy support Drinking water sources	0.077		0.061	
Social support	Assistance from others Community cultivation	0.027		0.018	
Livelihoods	Occupation New activity Change in livelihoods	0.028		0.019	
Food	Food availability Water availability Food sufficiency Alternate food sources	0.033		0.020	
Health	Health facility Prevention for diseases Water purification	0.106		0.098	
Resource	Grants/Food/Water Training Sanitation facility Information House/housing material	0.038		0.036	
Technology	River training Rising of roads Embankments Homestead plinth raising	0.032		0.019	
Coping strategy	Civic body support Government support Small entrepreneurship Forest resource extraction Fish extraction from river Illegal activities	0.020		0.024	

Fig. 6). Factors like poor housing and squandered resources decreased economic and social support, and increased exposure to extremes linked to the environment may be attributed to increased vulnerability in the plains. Reduced health facilities and disease prevention activities also increase vulnerability in the plains. Other reasons for higher vulnerability involve poor sanitation and poor access to alternate water sources.

The core components of vulnerability dimensions often varied with the decision-making capabilities and the economic status of the households surveyed. Interestingly, the plain region indicated a higher sensitivity than the hilly region. However, for environmental and social well-being, hill inhabitants showed more sensitivity. Rapid population growth in the hilly region leading to fewer employment opportunities, environmental degradation, and existing social exclusion may be attributed to reduced environmental and social well-being. The respondents' vulnerability to climate change in the plains was also heightened by limited access to information, underscoring the need for formal dissemination of climate change information and related challenges. The informal settlement-related vulnerabilities across the two regions propel the assumption that is building individual and community adaptive capacity can enable the poor to overcome various climatic and non-climatic stressors.

There is limited study on the vulnerability evaluation of informal settlers through index approach either in developing and developed nations. The vulnerability was assessed in different countries based on differential contextualization and settings. The vulnerability index score of the hilly and plain region in the present study were 0.51 and 0.57, respectively (Table 8). The vulnerability score of slum-dwellers in the Indian Himalayan region were 0.63 and 0.66 and attributed to low natural and human assets leading to reduce the adaptive capacity (Pandey et al., 2018a). Based on socio-ecological characterization, Alcayna-Stevens (2015) found that the slum-dwellers in Manila, Indonesia are extremely vulnerable. The livelihood vulnerability index based vulnerability of char dwellers of the riparian region of Gangatic Plain, India resulted in differential values with zone near to river (0.54); middle zone (0.44) and zone away to the river (0.42) (Das et al., 2020). However, the premises of the scores were different and apt for comparing within the domain of the settings.

3.6. Associational analysis

The Chi-square test results state that the number of working days has a significant association with sensitivity and adaptive capacity (Table 9). It is reported that households with a higher number of working days

Table 8
Estimates of vulnerability along with the components of the vulnerability in hilly and plain region.

Component	Hilly	Plain
Exposure	0.444	0.505
Sensitivity	0.602	0.617
Adaptive capacity	0.506	0.406
Overall Vulnerability	**0.509**	**0.569**

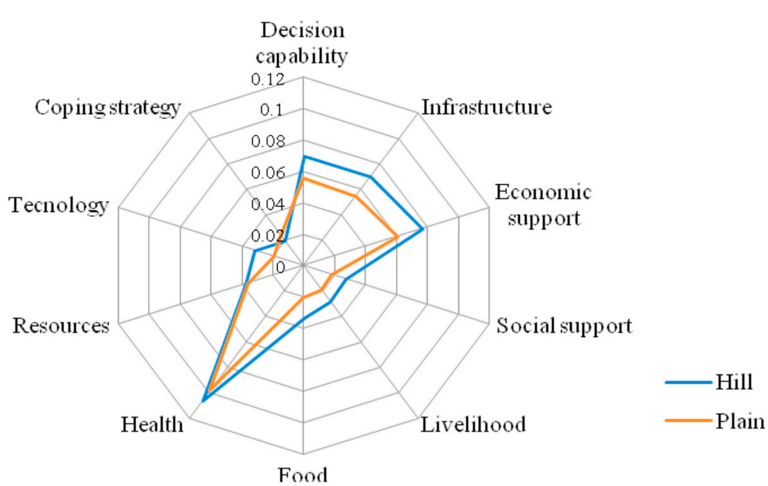

Fig. 5. Spider diagram of adaptive capacity of the hilly and plain region.

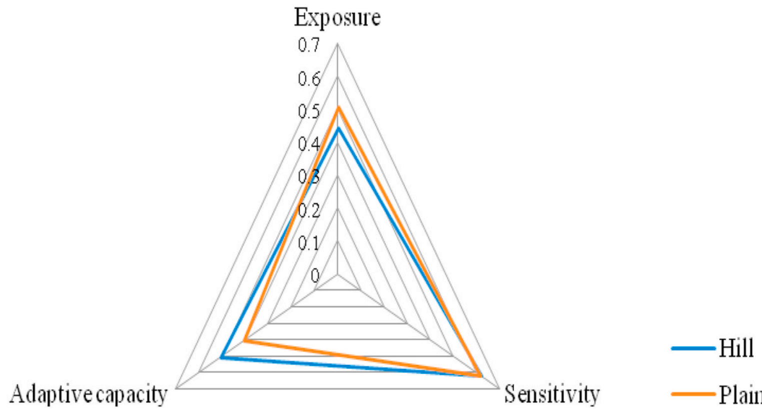

Fig. 6. Triangle diagram of dimensions of vulnerability in the hilly and plain region.

were less sensitive to climate change and had more adaptive capacity, which may be attributed to higher income thereby better economic status; this could facilitate countering the negative impacts of climate change. Contrary to expectations, respondents' number of working days did not have a significant relationship with vulnerability. Some households engaged in small entrepreneurial activities like manufacturing bamboo furniture, clay pots, and leaf plates ('*tapari*' in local language) for income generation. The non-significant relationship between working days and vulnerability may be attributable to these alternative sources of income. Households that have diversified livelihood strategies and can rely on their informal networks during shocks are relatively less vulnerable due to greater coping capability (Singh and Chudasama, 2021). As noted during the survey, some households in the settlements enjoyed considerable social support within the neighbourhood, along with borrowing and cash transfers during a crisis. In some households, incomes were often managed by renting rooms, albeit at nominal rates.

Expectedly, disease incidence has a significant relationship with household sensitivity and vulnerability. Households with an increased incidence of disease in recent years have been more sensitive to climate change-related impacts. Households with significant health problems need to devote a substantial portion of their resources to treating illnesses, which decreases their financial assets. Reduced financial capital, coupled with a reduced labour force, leads to increased sensitivity and reduced human and financial assets and overall household well-being. There was no significant association between disease incidence and adaptive capacity. As observed during the survey, households with single earning members had no choice except to work despite minor illness. This led to homogeneity among the classes while underscoring an insignificant association between the disease and adaptive capacity. Additionally, the diseases considered during the study were not necessarily critical, attributable as they were to floods and cold weather. Hampering well-being and disturbing daily sustenance, the diseases exerted a similar effect on adaptive capacity. Besides, the incidence of disease in the study areas was primarily associated with older people and children who were not included in the category of earnings.

The number of rooms, a measure of assets for these households, had a significant relationship with the adaptive capacity. Fewer rooms indicate more congestion, putting the residents at higher risk of respiratory infections and other communicable diseases (Sclar et al., 2005). As observed during the survey, unhygienic household conditions due to overcrowding induced residents' ill health. Generally speaking, deteriorating resident health conditions hampering the daily subsistence of poor households may have decreased adaptive capacity in the bargain. However, the number of rooms occupied shows a non-significant relationship with the sensitivity and vulnerability of households. This may be explained by the current non-linearity of the system. As observed during the study, the environmental, economic and social well-being factors recurred more or less similar across different groups irrespective of the occupancy of the number of rooms. The resident labour did not appear to be influenced by the number of rooms in the household, as almost all of them were dominated by day-to-day subsistence livelihood. Besides, the primary objective of these poor households was arranging provisions for their families while prioritising other basic amenities, thus accounting for the non-significant relationship identified (Table 9).

Table 9
Results of Chi-square test of association for the three contextual factors with sensitivity, adaptive capacity and vulnerability in hilly and plain region.

Component	Number of working days	Number of rooms	Disease incidence
Sensitivity	59.80*	8.09	72.34*
Adaptive capacity	48.04*	48.05*	11.18
Vulnerability	3.18	6.71	74.88*

*shows significant at 5% level of significance.

4. Discussion

The associational analysis revealed that a higher number of working days generally implies more income and an improvement in household economic and social well-being, thus reducing sensitivity; better economic support often enhances the household adaptive capacity. Since the vulnerable communities in the informal settlements have limited avenues to work, diversification of livelihoods could help boost their adaptive capacities. Moreover, poverty is detrimental for accessibility and availability of household welfare resource including livelihood options and therefore is instrumental for the higher vulnerability (Papageorgiou et al., 2020). The low sensitivity and high adaptive capacity of the informal settlers in the hilly region compared to the plains were attributed to better opportunities for income-earning opportunities, due to locational advantages in terms of being in the country's capital. The better employment prospect supported these peasants for subsistence livelihoods. However, the informal settlers in the plain regions were refrained by such opportunities and primarily depend on the local ecological resources, with less earning opportunities. Several accounts on vulnerable communities have categorically considered livelihood as constrained for coping with the stress and supporting the diversification such as for Western Indian Himalaya (Gupta et al., 2019; Pandey et al., 2018a); Eastern Indian Himalaya (Das et al., 2020); Afghanistan (Omerkhil et al., 2020b); arid and semi-arid India (Singh and Chudasama, 2021).

Though the hilly region households had better educational attainment, however, lack of formal education and awareness in both regions has served to catalyse their low adaptive capacities. The low education in the plain region was attributed to low in decision making by these households and therefore, the plain region households were more deprived due to climate change. The awareness about climate information and associated adjustment supports the informal settlers to adapt better to changing climate (Pandey et al., 2018b). The enhanced formal education to these settlements and the increased capacity to cope with climatic and non-climatic stressors will empower them to assert their rights while fetching them to better job opportunities (Deshpande et al., 2019). Our survey results demonstrate that relatively improved drainage systems, infrastructure, waste management, technology access, and health facilities have contributed to a better adaptive capacity to climate change for hill residents, as also reported by Pandey et al. (2018a). The unplanned development of built-up areas in informal settlements makes the local settlers vulnerable due to scarce basic municipal services, and inadequate government action. Therefore, it is crucial to improve basic infrastructure through programmes that integrate education, public health, solid waste management, sanitation, food security and employment (Pandey et al., 2018a; Das et al., 2020). Although the support from external sources such as the government, the civil body was low in both regions, the hilly region was in better shape, primarily due to the locational advantages. In this regard, these programmes need to be implemented through the local and national governing bodies to provide sustainable livelihoods for the poor while alleviating their vulnerabilities in a more pronounced manner. Such initiatives could enhance well-being while meeting the Sustainable Development Goal's objective of leaving no-one behind; this could potentially reduce disparities in public services and minimise the disadvantages of vulnerable communities in informal settlements. Multi-level and multi-scalar adaptation preparation at national and sub-national levels along with local planning, while building on local knowledge, is likely to render communities resilient to climatic shocks (Singh and Chudasama, 2017).

The problems of informal settlements emerge due to poor urban planning. Therefore, a holistic development plan including ecosystem management for land and natural resources, capacity-building, livelihood enhancement, adaptive governance, and disaster preparedness and protection, makes communities more resilient to climate variability and change (Singh et al., 2019). Local forest resources support adaptation to the informal settlers in a variety of ways including ecosystem services and acting as safety nets during adversities (Pandey, 2009). Nature-based regional planning may be an appealing adaptation option (Das et al., 2020). In this context, the New Urban Agenda (adopted in Quito in October 2016) provides lead to better urban planning through the integrated development planning that connects innovation with investment in social, ecological, and physical infrastructure, which could significantly increase the adaptive capacity of informal settlers. Participatory planning for infrastructure provisioning to address climate change and underlying drivers of risk in informal and underserviced neighbourhoods, the inclusion of indigenous and traditional knowledge and communication efforts could be effective.

5. Conclusions

The present study assessed the degree of vulnerability of informal settlements dwellers due to climate variability and change in the plains and hills of Nepal. The inhabitants of informal settlements in the plain region are more vulnerable to the informal settlements of the hilly region due to higher exposure and sensitivity and lower adaptive capacities of the informal settlers of the plains.

The environmental and economic vulnerabilities of informal settlements have a high correlation with their level of social attributes. Poor human conditions, coupled with hazardous and precarious locations, have raised the vulnerability of informal settlements in Nepal's hilly and plain regions. Resource deprivations, low employability, inadequate income, substandard sanitation and food insecurity are the prime causes of the settlement vulnerability. Lack of education, health facilities, and less accessible safety networks have also been identified as major underlying drivers.

Improvement in infrastructure and housing, along with public services provisions and better health provisions in informal settlements, is likely to improve their adaptive potential. The availability of adequate resources equipped with appropriate technologies and suitable infrastructure can help the vulnerable informal settlements to better prepare for disaster responses. Such fundamental issues, while working specifically to minimise exposure to climate hazards, may help reduce vulnerabilities by improving the adaptive capacity of informal settlements. Fair and equitable urban planning that guarantees the inclusion of unprivileged communities in informal settlements while incorporating equity into infrastructure and urban design may prove transformative in enhancing adaptive capacity and addressing current and future vulnerabilities.

Above all, this study has shown that the overall degree of vulnerability varies even among urban poor populations. The differential vulnerability indicates the role of spatial approaches in the design of informal settlement policies and programmes. It also highlights the need for more comprehensive and rigorous vulnerability research to explore the significant variations in the vulnerability levels of poor urban communities that undermine their ability to adapt and address risks. Further comprehensive research into the relationships between climate change and environmental variables could be more effective in identifying factors contributing to the biophysical vulnerability of poor urban communities. Given the exponentially increasing number of informal settlements, it is imperative to establish local, national and global guidelines and programmes to ensure sustainability in urban adaptation management and planning.

Dimensions and indicators of this study are drawn from natural hazards, politico-economic, and ecological resilience strands of literature. Although the social-ecological systems are considered to be complex systems our index-based approach of vulnerability assessment, owing to its simplicity, help facilitate better operationalisation of the vulnerability situation and thus better research uptake in the policy arena. The method used has the strength of capturing even the minor differences across different comparison units and therefore may apt for providing solutions for the appropriate differential adaptation protocol.

CRediT authorship contribution statement

Monika Giri: Conceptualization, Formal analysis, Writing – original draft, conceptualise and designed the study, collected the data with support of GB, analysed the data and written the paper, interpreted the analysis. **Ganga Bista:** Formal analysis, collected the data with support of GB, interpreted the analysis, read and modified the paper. **Pramod K. Singh:** read and modified the paper. **Rajiv Pandey:** Conceptualization, Formal analysis, conceptualise and designed the study, interpreted the analysis, read and modified the paper. All four have contributed extensively for data interpretation and discussions.

Declaration of competing interest

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

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