International Journal of Disaster Risk Reduction 46 (2020) 101456

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: http://www.elsevier.com/locate/ijdrr

Geographic variation of resilience to landslide hazard: A household-based comparative studies in Kalimpong hilly region, India

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ARTICLE INFO

Keywords:
Resilience
Indicator
Landslide
Household
GIS
Spatial variation

ABSTRACT

Building resilience of households in landslide hazard-prone area can be a significant way of disaster risk reduction. Although the studies on resilience are increasing, assessing resilience to a localized disaster like landslide at household-based scale is still limited. This study proposes a set of indicators to evaluate the resilience of household considering the specific character of landslide hazard. Further, the study answers how and why the resilience level varies on the space. The study assigned resilience adopting an indicator-based approach where overall resilience value is composed of four dimensions: environmental, social, economic and physical. Each dimension is composed of several variables which are derived using a mix of GIS and participatory approaches. The weight of each variable and dimension was calculated using the min-max normalization method. The data was collected from 332 households in thirteen sites frequented by landslides in Kalimpong district of India. The surveyed households are located in both urban ($n = 112$) and rural areas ($n = 220$) and of different physiographic condition. The findings suggest that the households of rural areas in the eastern part of the ridge are less resilient and the households of urban area near the top of the ridge are relatively high resilient. The higher degree of exposure to landslide, unequal economic status, and unequal infrastructure development are the main causes of the variation of resilience among the households. Although the study focused on Kalimpong region, this research method could also be applied to other landslide-prone areas of the world.

1. Introduction

The casualty of landslides is significantly increasing worldwide, causing more than 4000 deaths annually [1]. The Himalayan region in India is one of the hotspots of deadly landslides [2]. Kalimpong hilly region is a part of the Himalaya and it is potentially a landslide-prone area in nature owing to various reasons like the location at the high rainfall and seismic zone, high weathering rate, toe erosion by rivers and numerous streams. The historical evidence depicts that 1899, 1915, 1950, 1968, 1996, 2007, 2015 experienced severe landslides leading to huge loss of life and properties in this region [3,4]. Apart from these major landslide events, the slow movement of land in the form of creeping, land subsidence is continuously damaging agricultural land and houses in built-up areas. The increase in frequency and severity is having a deleterious effect on the livelihood of mountainous communities in the form of a silent disaster. In such a fragile environment, the rapid growth of population and human settlement are reshaping the risk of landslides raising questions regarding sustainable development [5–7]. Although the problem of the landslide in Kalimpong is acute and suspected to cause future disaster, disaster risk reduction planning is inadequate in this region. It is less highlighted to the disaster governance and not adequately disseminated among the larger population beyond the region affected when the landslide occurred as a single event eventhough it had a significantly wider impact. On the other hand, Kalimpong is the habitation of 251,642 people [71], an important tourist spot of India and hub of indigenous culture. Although numerous disaster studies are conducted on the large urban settlement area, less studies are focused on the small urban places and the habitation area like Kalimpong located in the mountainous region of India [5]. Enhancing resilience is one of the fundamental steps towards reduction of the risk and to ensure sustainable development of the region.

The present study focuses on measuring the variation of the level of

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https://doi.org/10.1016/j.ijdrr.2019.101456
Received 5 September 2019; Received in revised form 15 December 2019; Accepted 18 December 2019

resilience to landslide hazards among the households of different sites taking into consideration both the urban[1] and rural area.[2] Further, the study analyzes the variation of resilience level. To achieve the objectives and for the development of the methodological framework, we treated resilience as the inherent capacity of a household to resist, absorb and recover efficiently to the loss of landslide hazard in a given place and time.

The methods of measuring resilience have changed with the change in disciplines. The definition and concept of resilience are diverse in different fields like technical, physical, psychological and social [8]. UNISDR [9] defined resilience as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions." Zhou et al. [10] categorized the perception of resilience into four ways such as "resilience as a biophysical attribute" [11–14], "resilience as a social attribute" [15–18], "resilience as a social-ecological system" [19–21], "resilience as an attribute of specific areas" [10,22,23]. The last concept of "resilience as an attribute of specific areas" has emerged as a combination of previous three concepts; biophysical, social, and socio-ecological attributes within a specific area. It puts more emphasis on local resiliency with which the local community can withstand the disaster without a large amount of assistance from outside the community [22]. Apart from the diverse theoretical perspective, numbers of methods have emerged to measure resilience, which can be broadly classified as indices, scorecards, and tools [24]. These various kinds of methods have been applied to the different context like multi-hazard [25,26], flood [27–30] cyclone [31,32] drought [10], earthquake [33,34] using different scale like household [35–37], region [38,39,72] or country (Siebeneck, Arlikatti, and Andrew 2015; [40,41]).

In the broad field of disaster studies, although the studies on the measurement of resilience are increasing, it is still inadequate to the landslide hazard. The study argues that landslide is a more localized hazard than other hazards like flood, drought, or earthquake. The risk of the landslide varies highly due to the variation of local physical condition in a mountainous region. In the Himalaya, the occurrence of landslide makes a favourable condition in its surrounding area for another landslide in future. Landslide does not occur only as a single event but it is also associated with other hazards like flood and earthquake. Since it is localized and discrete, lack of awareness and inadequate risk reduction strategy increase its cumulative loss than any other hazards. Therefore a different set of indicators are required for assessing resilience in this particular domain of disaster. Considering the specific character of the landslide, the study adopted several important indicators such as distance from the active slide, distance from drainage, degree of slope, temporal probability of landslide, density of landslide, subsidence activity, accessibility of roads during rainy season (road blockage incidence), which are not always relevant to other hazards. On the other, although numerous techniques are being developed for the prediction of landslide hazard, the issue of integrating the physical, socio-economic attributes in the domain of landslide studies has not been adequately addressed. In this context, the study can fill the gap of disaster studies providing a technique of resilience to landslide hazard. The study can also meet the goal of Sendai Framework for Disaster Risk Reduction (2015–2030) which puts emphasis on building resilient society [42].

1.1. Approach adopted in the present study

In the present study, resilience is looked as a social-ecological attribute within a specific area to depict the geographic variation of it. The study adopts an indicator-based approach [21,43] at the household level. The methodological framework is composed of four dimensions of resilience, i.e., environmental, social, economic, and physical (Fig. 1). The overall resilience index is developed by a combination of these dimensions. The environmental dimension is linked to landslide hazard and exposure. Social and economic dimension involves the socio-demographic, economic profile of households. The physical dimension reflects the accessibility of basic infrastructure like roads, hospital, emergency shelter with respect to the landslide hazard. In many studies of resilience, the institutional dimension is considered to be an important parameter to assess resilience. However, measuring and comparing institutional performance in household-based scale is difficult in these studies due to the fact that the location of the households is in different sites in the same administrative unit. The governmental strategy to landslide mitigation is almost similar in all of the places. Hence, it is difficult to measure the variation of institutional dimension with other dimensions on the same scale. Apart from its limitation, the advantage of this method is that it can measure the resilience of multi-dimensions in a single value and it can compare different dimensions of resilience easily.

The research study consists of five sections. The second section which comes after the introduction section describes the geographical characteristics of the study area The third section covers the materials and methodology. This section explains the data collection method, rationality behind the selection of indicators, the weight assignment of indicators and development of the resilience index. The fourth section covers the results and discussion. In this part, the variation of the resilience value of environmental, economic, social, physical dimensions, and overall resilience among the different sites are explained. Next, the variation of resilience among the households of the urban and rural area is discussed. Further, the limitation of the method and future of the study are discussed. In the fifth section conclusion and recommendation deals with future actions to be taken up by the local government, policymakers, and the scientific community for disaster risk reduction strategies at the micro-level.

2. Study sites

The research area is located in Kalimpong district of West Bengal bounded by River Teesta in the west and Relli River in the east (Fig. 2). It is the part of Darjeeling-Sikkim Himalayan region which is highly rigid, folded, complex, highly metamorphosed and disturbed by various geotectonic movements [44–46]. The climate of the region is subtropical high land type with wet summer and dry winter. Most of the rainfall happens during monsoon season from June to September [47]. Average annual rainfall of this region is 250–300 cm [48]. The population is clustered and highly dense in the urban area which is located near in the top of the ridge and relatively stable part of the region. Whereas rural area is located surrounding the urban centre and at the bottom of the ridge. In the rural area, the population is sparse and scattered. Apart from the landslide, the region is prone to multiple natural hazards like earthquake, storm, forest fire [7].

We studied 13 most potential landslide affected sites in this region (Figs. 2 and 3). The study sites are 1. Poshyore area, 2. Nassey gaon, 3. Mangal Dara and Chibo Basti, 4. Narseregaon (Mangal Basti), 5. Dhobidhara, 6. Topkhana and Gattekhola, 7. Lower Echhey, 8. Khasgaon (Sindepong), 9. Bhamay Gaon (Sindepong), 10. Dungra, 11. Gairigaon (Lower Bong Basti), 12. Adikari Gaon (Bong Basti), and 13. Subba gaon and Tairigaon (Bong Basti) (Fig. 2 and Table 1). Poshyore area, Nassey gaon, Mangal Dara and Chibo Basti, Narseregaon (Mangal Basti) are located in the eastern side of the ridge. In Poshyore area, landslides have occurred in the form of debris slide and debris flows in every monsoon

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[1] Urban is considered as the area under municipality boundary of Kalimpong.

[2] Rural is considered as the area under Village Panchayat. In India, Village panchayat is the lowest level of governance unit in the three tier decentralised governance structure; along with block panchayat and district panchayat.

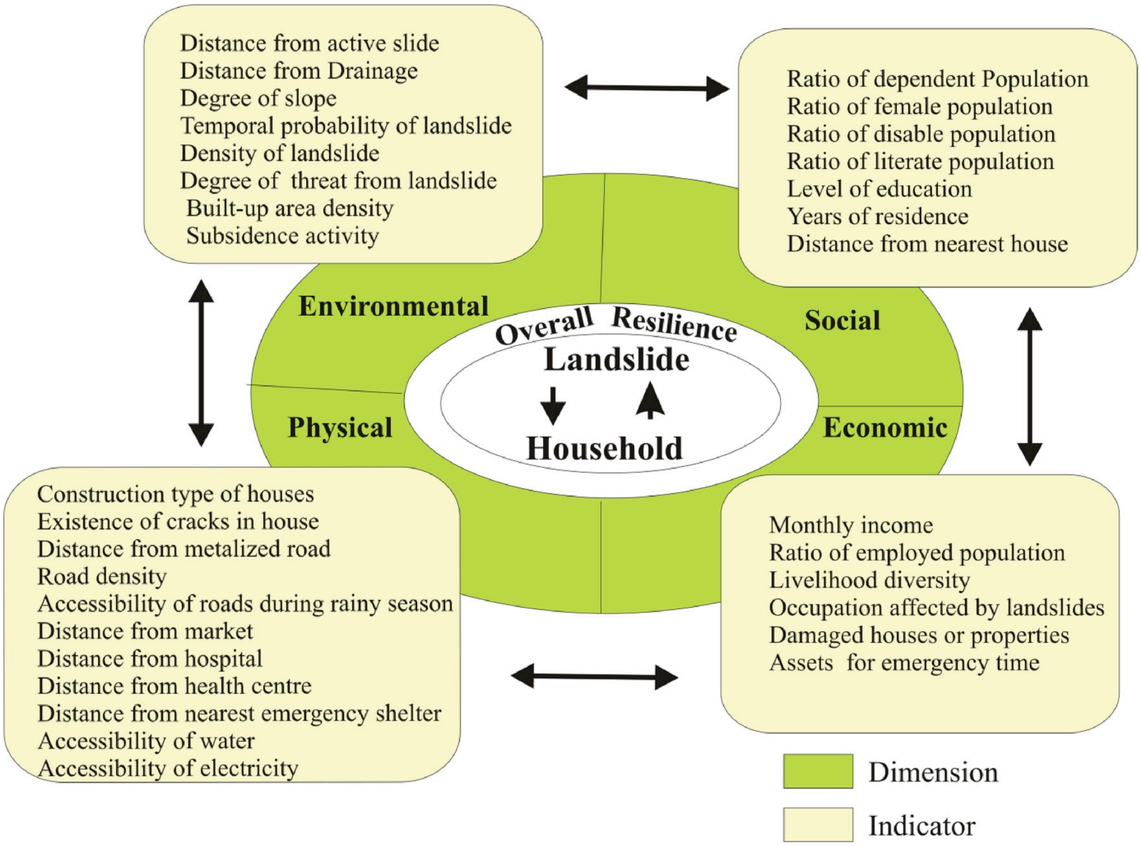


Fig. 1. The framework of dimensions and indicators for measuring resilience to landslide hazard.

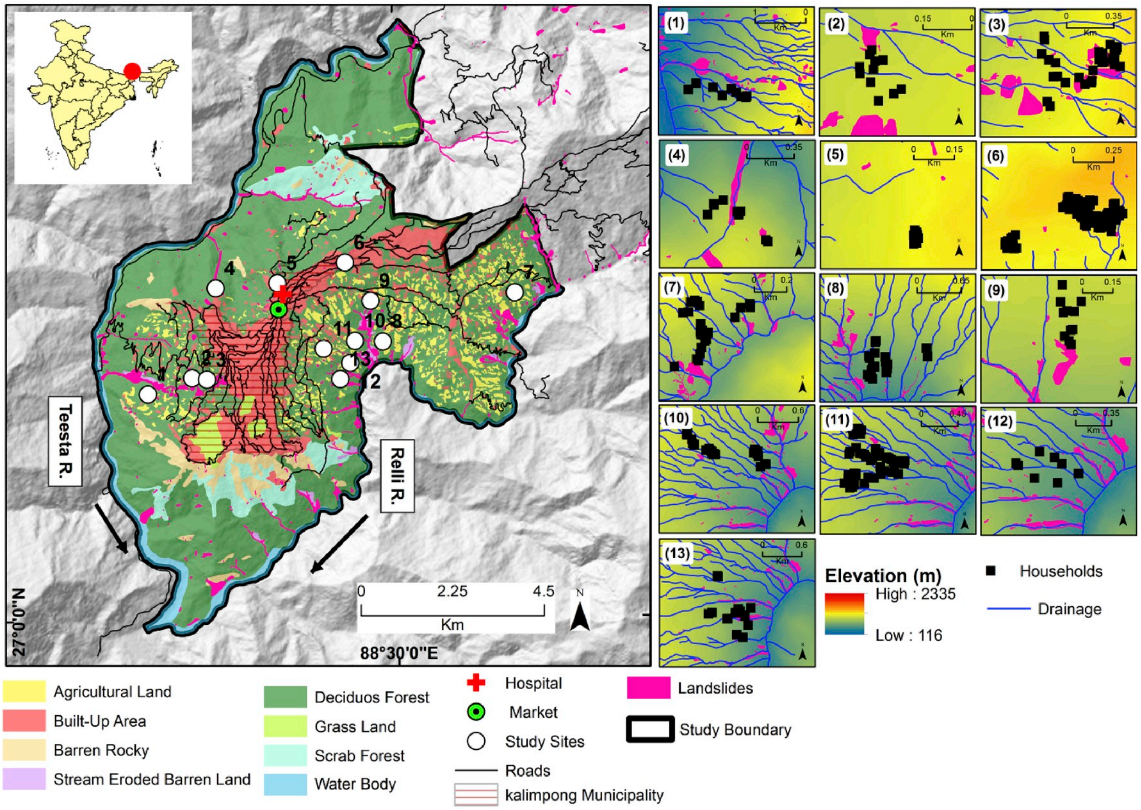


Fig. 2. Location and landscape of the study area and different sites of the case study.

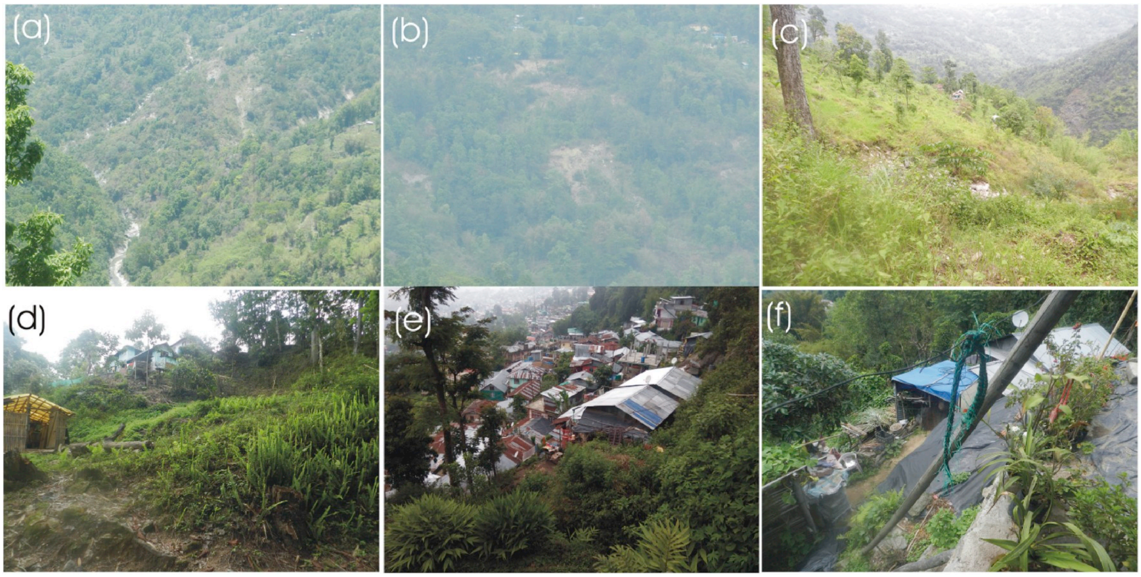


Fig. 3. Exposure of surveyed households to the different landslide-prone sites of the study: (a) Dungra and Bong Basti (b) Sidelpong (c) Subba Gaon in Bong Basti (d) Nasegaon (e) Topkhana (f) Magal Dara.

Table 1
The number of the surveyed households and population among the thirteen sites of the study area.

Sites	Location within mauza/wards of Kalimpong District	Number of the surveyed houses	Total population in the surveyed houses
1. Poshyore area	Kalimpong Khasmahal, Mangber Forest	9	46
2. Nassey gaon	Kalimpong Khas mahal	13	55
3. Mangal Dara and Chibo Basti	Kalimpong Khas mahal, Kalimpong Municipality-ward17	38	186
4. Narseregaon (Mangal basti)	Kalimpong Khas mahal	10	42
5. Dhobi dhara	Bhalukhop Khas Mahal	8	46
6. Topkhana and Gattekhola	Kalimpong Municipality- Ward 7	82	411
7. Lower Echhey	Icha Khas Mahal	33	173
8. Khasgaon (Sindepong)	Sindepong Khas mahal	23	30
9. Bhamay Gaon (Sindepong)	Sindepong Khas mahal	11	53
10. Dungra	Dungra	27	122
11. Gairigaon (Lower Bong Basti)	Bong Khas Mahal	54	294
12. Adikari Gaon (Bong Basti)	Bong Khas Mahal	8	43
13. Subba gaon and Tairigaon (Bong Basti)	Bong Khas Mahal	16	86

season due to erosion activities of Poshyore Khola (Stream). This Khola (stream) is reshaping largely due to the accumulation of numerous small streams and high runoff induced by urbanization in the upper part of the ridge. Debris flow is the main cause of disconnectivity from the main road which links the area with the market and hospital in the central part of the area. Nassay gaon is exposed to old landslide deposition, which occurred in 1968, and it gets reactivated annually during the monsoon season. Mangal Dara and Chibo Basti experienced huge landslide in 1968 and faced fatal landslide in 2009 and 2015. The landmass of this area is creeping and subsiding downward, which is the major cause of damage of the roads and houses. Narseregaon (Mangal Basti) is vulnerable to landslide due to the steep slope and unstable mass, which got destabilized especially after the 2015 landslide. The slide caused the death of five persons and damage of many houses. Dhobi Dhara, Topkhana and Gattekhola are located near the top of the ridge. These areas are densely populated and experience with small landslides in each year. Steep slope and erosion of Gattekhola are the main causes of landslide in the Topkhana and Gattekhola area. In this area, major landslides occurred due to heavy rainfall during 2015. Lower Echhey, Khasgaon (Sindepong), Bhamay Gaon (Sindepong), Dungra, Gairigaon (Lower Bong Basti), Adikari Gaon (Bong Basti), Subba gaon and Tairigaon (Bong Basti) located in the eastern part of the ridge (Fig. 2). The area is less populated and dominated by agricultural activities. These areas are facing acute problem due to landslide in the form of subsidence, debris slide, and debris flow every year. The toe erosion of Relli River and numerous streams and unconsolidated slope material are the main causes of landslides in this region.

3. Methodology

The data of the research is collected adopting the household-based field survey, GIS and satellite image interpretation techniques. Field survey (2017, 2018) covers 332 households in the different parts of the Kalimpong region. The data collection proceeds as follows:

First, the questionnaire is developed on the basis of pilot survey (2016 December) and literature. Second, the study sites were selected as a pocket of the most landslide-prone area based on field observation, interview with local people and the disaster manager of the Kalimpong District. Active landslide in Kalimpong region is mostly widening, enlarging and retrogressive in nature. Therefore, the surrounding area of landslide became destabilized after initiation. Based on our field survey we have determined the 300 m buffer zone of the landslide as a vulnerable site. Since the slope displacement highly depends on local physiographic condition accordingly we have modified the boundary of the buffer zone restricting it within the same slope aspect of the watershed. We also taken assistance from the local leader of the residents to demarcate the boundary of the site and prepared a field map. The households located within the boundary are considered as the target of the survey. However, the household survey has been carried out based on the presence of member of each households Since the distribution of households surrounding the slide area is uneven, the number of households in the different sites is not equal, i.e.,1. Poshyore area (n = 9), 2. Nassey gaon (n = 13), 3. Mangal Dara and Chibo Basti (n = 38), 4. Narseregaon (n = Mangal Basti) (n = 10), 5. Dhobidhara (n = 8),6. Topkhana and Gattekhola (n = 82), 7. Lower Echhey (n = 33), 8. Khasgaon (Sindepong) (n = 23), 9. Bhamay Gaon (Sindepong) (n = 11), 10. Dungra (n = 27), 11. Gairigaon (Lower Bong Basti) (n = 54), 12. Adikari Gaon (Bong Basti) (n = 8), 13. Subba gaon and Tairigaon (Bong Basti) (n = 16) (Table 1). Among the total 332 households, 112 households are located in the urban areas, and 220 households are located in rural areas. The surveyed households of the urban area are located in Kalimpong Municipality - Ward 7 and 17 where the total number of household is 910. The rural area covers mauza of Kalimpong Khasmahal, Mangber Forest, Icha Khas Mahal, Sindepong Khas mahal, Dungra, Bong Khas Mahal where collectively 7129 households are located. However, the total number of vulnerable household is understudied and unrecorded in this region. Therefore, we selected the surveyed household based on judgment. The judgment follows the principle that the household should be located within the predefined boundary of the sites near active landslides. The households are located in the different parts of the physiographic location of Kalimpong like the top of the ridge, the eastern part of the ridge, western part of the ridge and are also located in a different pattern of landscape like urban and rural. It reflects the diversity of Kalimpong region and can reduce the problem of generalization of the sample. The distribution of our surveyed households in the different landscape with respect to landslides affected area is illustrated in Fig. 2.

Third, data were collected through semi-structural interview with the residents of each household. The question of the interview involves the time of landslide, damage details due to landslide, years of residence, details of the houses, the social and economic profile of the household, impact of landslide on livelihood, adaptation strategy against landslide etc. These questions of the interview are predetermined by our questionnaire. Apart from it we also interviewed the residents about the reason of living in landslide-prone area, personal experience of catastrophic landslide event (like 1968), their problems caused by landslide and their opinions on how to reduce the risk of landslide. This kind of interaction helps us to understand the process of the resilience of the residents.

We also derived data from high-resolution satellite images (DigitalGlobe GeoEye-1, WordView-2) and ALOS Digital Elevation Data. The location of each household, active landslides and basic infrastructures were recorded through GPS reading, which was further exported to GIS platform leading to the development of a resilience index. The detail of data sources and data collection technique is represented in Table 2. After collecting the data, the resilience index is developed. The process of resilience index development is discussed below:

3.1. Selection of indicators

The resilience indicators are selected based on past literature, field observation, interview with local people and the disaster manager of Kalimpong District. Many information of the indicators were gained by using GIS and based on perceptions of people, which depend on subjectivity and participation of residents. Hence, the indicators are quantitative (q), semi-quantitative (sq), qualitative data (p). The detail of indicators and computation method for weight derivation is discussed in Table 2.

3.1.1. Environmental

Environmental dimension demonstrates the exposure of each household to landslide hazard. It is composed of seven variables, i.e., distance from an active slide, distance from drainage, degree of slope, exposure to the degree of temporal probability zone of landslides, exposure to the density of building area, exposure to subsidence zone, exposure to degree of density zone of landslides, degree of threat from landslide. The houses located in the vicinity of an active slide is more susceptible to future damages [49]. In the study region, most of the landslide is retrogressive, widening and enlarging in nature and hence, the distance to active slide is of paramount importance to determine the resilience of a household. Drainage is the source of debris flow and debris slide, which contributes the significant damages of properties [43]. Many houses of this region are located near the drainages and face acute problems during the rainy season. The local people gradually lose their agricultural land due to stream erosion. Consequently, urbanization accumulates risk-increasing runoff of stream water. The degree of slope causes the instability of a region [50–53]. A higher degree of slope creates favourable condition for soil erosion and mass wasting [69]. Therefore, households exposed on a higher slope is more susceptible to landslide damages. Temporal probability is one component of hazard. Temporal probability indicates the chance of frequency of landslide occurrence within a given period. A higher temporal probability zone has a higher chance of landslide consequence. In this study, the annual probability of landslide was calculated on the basis of the Poisson distribution model [54–56]. The density of building area indicates the population density. High population density negatively impacts on emergency management during the disaster. Secondly, high dense area and inadequate open space compel people to live in a favourable area of the landslide, which reduces the resilience of a household. The impact of loss is high in high dense area due to high exposure. Subsidence indicates the instability and movement of landmass, which is the major cause of damages of houses and agricultural land. In all these active landslide sites subsidence is common. Although its activity varies in different places. Due to the inadequacy of instrument measurement, the activity of subsidence is classified into the high and low category based on the perception of the people and field observation. Density zone of landslides indicates the area of active landslides per unit area. It indirectly reflects the in-stabilization activity of an area in which households are exposed. Landslide is the major cause of threat to the mountainous community. The degree of threat is classified into three categories based on the reaction of local people such as high, moderate, and low. In high category, people have a severe threat and are compelled to move to other places during rainy season. Whereas, people of moderate category experience threat of a landslide but are not compelled to move to other places. The people have less fear of landslide in low category.

3.1.2. Social

In this study, seven indicators are considered to measure social resilience index, which encompasses demographic, educational, and social networking aspect of the region. The demographic aspect includes indicators such as the ratio of dependent population (below five years and above 65 years), the ratio of female population, ratio of disabled people in a household. It is considered that children, old person, female, and disabled population face the greatest problem during disaster time due to immobility and other physical incapability [57]. Education is the most important component to built a resilient society. The level of education increases awareness about disaster and environmental circumstances. It helps to develop skill and capacity to prevent disaster. Years of residence is associated with the experience of a region. Experience and learning from past disaster help to make a better decision to cope with future disaster [19]. The social network is positively related to the level of resilience. In this study, the distance from the nearest house is considered a social network indicator. Generally, people got the first response from his nearest houses during the disaster [58]. Hence, a long distance from the nearest house in a mountainous region can pose a problem in getting quick response during emergency time. Distance between houses also hinders the process of information dissemination.

3.1.3. Economic

The economic resilience is composed of six indicators such as monthly income, the ratio of the employed population, number of occupation (livelihood diversity), assets, occupation affected by landslide directly, damaged houses or properties due to disaster in last five

Table 2
Details of the indicator in each dimension of resilience.

Dimension	Indicators	Relationship to resilience	Computation Method	Data Collection technique and sources	Indicator type
Environmental	Distance from active slide	+	$(\textit{actual distance} - \textit{min. distance})/(\textit{max. distance} - \textit{min. distance})$	Satellite Image Interpretation, GIS, GPS	q
	Distance from drainage	+	$(\textit{actual distance} - \textit{min. distance})/(\textit{max. distance} - \textit{min. distance})$	Satellite Image Interpretation, GIS, GPS	q
	Degree of slope	−	$(\textit{actual value of slope} - \textit{min. slope})/(\textit{max. slope} - \textit{min. slope})$	DEM, GIS	q
	Temporal probability of landslide	−	$(\textit{actual probability} - \textit{min probability})/(\textit{max. probability} - \textit{min. probability})$	Satellite Image Interpretation, GIS, GPS	q
	Density of landslide	−	$(\textit{actual density} - \textit{min. density})/(\textit{max. density} - \textit{min. density})$	Satellite Image Interpretation, GIS, GPS	q
	Degree of threat from landslide	−	$(\textit{actual weight} - \textit{min. weight of threat})/(\textit{max. weight} - \textit{min.weight of threat})$	Interview	p
	Built-up area density	−	$(\textit{actual density} - \textit{min. density})/(\textit{max. density} - \textit{min. density})$	Satellite Image Interpretation, GIS, GPS	q
	Subsidence activity	−	$(\textit{actual weight} - \textit{min. weight of threat})/(\textit{max. weight} - \textit{min.weight of threat})$	Interview and Field Observation	p
Social	Ratio of dependent Population	−	$(\textit{number of dependent population})/(\textit{total number of population in a household})$	Interview	q
	Ratio of female population	−	$(\textit{number of female population})/(\textit{total number of population in a household})$	Interview	q
	Ratio of disable population[a]	−	$(\textit{number of disable population})/(\textit{total number of population in a household})$	Interview	q
	Ratio of literate population[b]	+	$(\textit{number of literate population})/(\textit{total number of population in a household})$	Interview	q
	Level of education	+	$[(\frac{\textit{Population above primary}}{\textit{total number of population}} \times \frac{1}{4}) + (\frac{\textit{population above secondary}}{\textit{total number of population}} \times \frac{1}{3}) + (\frac{\textit{population above intermediate}}{\textit{total number of population}} \times \frac{1}{2}) + (\frac{\textit{population above graduation}}{\textit{total number of population}} \times 1)]/2$	Interview	sq
	Years of residence	+	$(\textit{actual years of residence} - \textit{min. years of residence})/(\textit{max. years of residence} - \textit{min. years of residence})$	Interview	q
	Distance from nearest house	−	$(\textit{actual distance} - \textit{min. distance})/(\textit{max. distance} - \textit{min. distance})$	Satellite Image Interpretation, GIS, GPS	q
Economic	Monthly income	+	$(\textit{actual distance} - \textit{min. income})/(\textit{max. income} - \textit{min. income})$	Interview	q
	Ratio of employed population	+	$(\textit{employed population})/(\textit{total population in a household})$	Interview	q
	Livelihood diversity	+	$(\textit{actual number} - \textit{min. number of occupation})/(\textit{max. number} - \textit{min. number of occupation})$	Interview	q
	Occupation affected by landslides	−	yes = 1; no = 0	Interview	p
	Damaged houses or properties due to disaster within last five year	−	yes = 1; no = 0	Interview	p
	Assets for emergency time	+	$(\textit{actual number} - \textit{min. number of accessts})/(\textit{max. number} - \textit{min. number of accessts})$	Interview	q
Physical	Construction type of houses	+	Pacca = 1 Kaccha = 0	Interview and Field Observation	p
	Existence of cracks in house	−	$(\textit{actual weight} - \textit{min. weight of cracks})/(\textit{max. weight} - \textit{min. weight of cracks})$	Interview and Field Observation	p
	Distance from metalized road	−	$(\textit{actual distance} - \textit{min. distance})/(\textit{max. distance} - \textit{min. distance})$	Satellite Image Interpretation, GIS, GPS	q
	Road density	+	$(\textit{actual density} - \textit{min. density})/(\textit{max. density} - \textit{min. density})$	Satellite Image Interpretation, GIS, GPS	q
	Accessibility of roads during rainy season	−	$(\textit{actual number} - \textit{min. number of incidence})/(\textit{max. number of incidence} - \textit{min. number of incidence})$	Interview, Field Observation, Satellite Image Interpretation, GIS, GPS	q
	Distance from market	−	$(\textit{actual distance} - \textit{min. distance})/(\textit{max. distance} - \textit{min. distance})$	Satellite Image Interpretation, GIS, GPS	q
	Distance from hospital	−	$(\textit{actual distance} - \textit{min. distance})/(\textit{max. distance} - \textit{min. distance})$		q

(*continued on next page*)

Table 2 (*continued*)

Dimension	Indicators	Relationship to resilience	Computation Method	Data Collection technique and sources	Indicator type
				Satellite Image Interpretation, GIS, GPS	
	Distance from health centre	–	$(\textit{actual distance} - \textit{min. distance})/(\textit{max. distance} - \textit{min. distance})$	Satellite Image Interpretation, GIS, GPS	q
	Distance from nearest emergency shelter	–	$(\textit{actual distance} - \textit{min. distance})/(\textit{max. distance} - \textit{min. distance})$	Satellite Image Interpretation, GIS, GPS	q
	Accessibility of water	+	$(\textit{actual weight} - \textit{min. weight of water accessibility})/(\textit{max. weight} - \textit{min. water accessibility})$	Interview and Field Observation	p
	Accessibility of electricity	+	$(\textit{actual weight} - \textit{min. weight of water accessibility})/(\textit{max. weight} - \textit{min. water accessibility})$	Interview and Field Observation	p

Note: Quantitative (q), Semi-quantitative (sq), qualitative data (p).

[a] Definition of disability according to The Rights of Persons with Disabilities Act, 2016. "Person with a disability" means a person with long term physical, mental, intellectual or sensory impairment which, in interaction with barriers, hinders his full and effective participation in society equally with others.

[b] The Census 2011 defines a literate person as, "a person aged seven and above who can both read and write with understanding in any language, is treated as literate.

years. The monthly income indicates the economic ability of a household. The people having high economic ability is more capable of recovering after the disaster [49,59,60]. The ratio of the employed population in a household reflects the dependency in an economy. High ratio of the employed population in a household increases coping capacity [34]. A household having numerous occupation is more resilient to disaster [61,62]. Divergent livelihood provides an alternative source of income even after the disruption of the economy of a household due to disaster. Assets (livestock, agricultural land, TV, radio, mobile phone) provides economic supports as they can be sold off after the disruption. Apart from it, TV, radio or mobile phone help to disseminate early warning about the disaster. The occupation of the people, especially those who are depended on agricultural activities, is highly affected by landslide in this region. It makes people economically insecure and reduces resilience capacity. Houses or properties damaged by a disaster within the last five years is considered to be an indicator of resilience because damaging houses, animal husbandry, and property due to landslide are very prevalent in Kalimpong region. In our study, most of the households were affected by the latest 2015 disaster. People invest a large portion of their income in recovering the damages, which reduces the capacity to absorb any future disaster. Hence, people who are already affected by previous landslides are less resilient economically.

3.1.4. *Physical*

The infrastructural development plays a vital role in determining the resilience level of a region. The present study includes eleven indicators to measure physical resilience. These indicators are construction type of houses, degree of cracks in the house, distance from the metalized road, road density, accessibility of roads during the rainy season, distance from market, distance from the hospital, distance from the health centre, distance from nearest emergency shelter, accessibility of water, accessibility of electricity. Construction type is an important indicator to demonstrate the resistance of a house [70]. The concrete walls are more resistant than non-concrete walls to the process of landslides [63]. In this study, both pacca and kaccha houses were found. The pacca houses are concrete which are generally made of cement, brick, stone or wood. Whereas kaccha houses are non-concrete (Census of India 2011). It is generally built with mud, wood, bamboo or cloth. Existence of cracks in a house reduces its resistance level to landslide disaster [64]. The houses have faced landslide and earthquake frequently in this region. Hence, cracks are common in most of the houses. The houses are classified into three categories based on observable cracks such as high, moderate, and low. The high category covers the houses where cracks are found on the floor, wall, and roof significantly, and repairing is needed urgently. Whereas, in the moderate category, cracks exist in the floor or wall or roof and repairing is necessary but not urgently. The cracks are minor and less significant in the houses of low category. Connectivity is pivotal to enhance the resilience of a region. The vehicle movement is important for the evacuation of people and moving logistics during the disaster. Hence, distance from the metal road is considered to be an indicator of physical resilience. The household located in the high-density zone of the road is more resilient. The density of roads indicates accessibility and connectivity of communication in a region [65]. It increases redundancy during the disaster. The density of road is calculated as the total length of roads per sq. km using line density tool in Arc GIS. In the mountainous region, accessibility of roads during normal condition is different from rainy season time season when frequent landslide occurrence leads to blockage and cutting off connectivity [43]. It adversely impacts on livelihood and everyday life of the mountainous community. In Kalimpong, this phenomena is also common during the rainy season. Therefore, the accessibility of roads during rainy season is considered to be as an important indicator of resilience building. The past road closure due to landslides indicates the performance of accessibility of roads during the rainy season.

Hence, this degree of accessibility is calculated based on the number of landslide occurrence on the roads which connect the household location with the main service centre (Kalimpong market). Most of the people in Kalimpong is depend on the market for purchasing food items and earning livelihoods. Distance affects the accessibility in the mountainous and rugged environment like Kalimpong. The distance from hospital and health centre indicates access to health services and facilities. In the study region main hospital is located in Kalimpong town on which all the surrounding villages depend for the medical services. The households located far from the hospital face an acute problem during the rainy season and hazard. Emergency shelter is essential for the evacuation of people during disaster. Hence, a household located at a closer distance to emergency shelter is more resilient. Access to water is an important component for measuring resilience. It is vital for economic activities and daily life activities. The streams are the main source of water in this region. In recent times, the area is facing an acute problem of water scarcity due to rapid urbanization and population growth. We classified access to water into three categories, such as high, moderate, and low. In the high category, the household gets water from both government and private source. In the moderate category, households depend solely on the private source and face water scarcity during winter and summertime. In the households of low category access to water depends solely on private source water and it is irregular throughout the year. Electricity is essential to operate any economic activities and service during, pre and post-disaster situations. Based on the service of electricity, we classified it as a low, moderate, and high category. In the low category, households do not get electricity for more than half of duration of a day in monsoon time. In the high category, households do not get electricity only during the time of the extreme event.

3.2. Assigning weight to the indicators

Assigning the weight of resilience to each indicator quantitatively is difficult, especially in data scarcity regions like lacking landslide velocity, volume, and interacting properties of the element. Secondly, the evolution of different spectra of resilience like social, economic, environmental, and physical in a scale makes it difficult to measure in a rigid quantitative method. Hence, we adopted a semi-quantitative method to measure the level of resilience. We have considered that each dimension has equal importance in contributing to resilience. The dimensions are composed of both continuous and categorized variables. The continuous variables were derived by standardization of its raw value (Table 2) whereas weight of categorized variables were determined subjectively according to the importance of the category (i.e., “3″ for High, “2″ for moderate, “1″ for low), and the final value was normalized by min-max method (Table 2).

3.3. Measuring resilience index and mapping

In the first step, the composite weight of each resilience dimension for each household was calculated using Eq. (1). The final weight of each dimension was derived using Eq. (2)

$$CWD_x = \sum_{i=1}^{n} W_{Ix} \tag{1}$$

where, CWD_x = composite weight of dimension $"x,"$ W_{Ix} = weight of each indicator under dimension $"x";$

$$WD_x = \frac{CWD_{xa} - min\{CWD_x\}}{max\{CWD_x\} - min\{CWD_x\}} \tag{2}$$

where, WD_x=weight of dimension “ x”, CWD_{xa} = composite weight of dimension $"x"$ of household “a”; $min\{CWD_x\}$ = minimum composite weight of dimension $"x"$ among all households. $max\{CWD_x\}$ = maximum composite weight of dimension $"x"$ among all households.

The composite index of overall resilience was derived by the aggregate of all dimension value of resilience (i.e., environmental, social, economic, physical) using Eq. (3). Finally, the resilience value of each household was calculated by the normalization of composite resilience index value (Eq. (4)).

$$CRI = \sum_{i=1}^{n} WD \tag{3}$$

where CRI = composite resilience index

$$RI = \frac{CRI_a - min\{CRI\}}{max\{CRI\} - min\{CRI\}} \tag{4}$$

where, $"CRI_a"$ is the composite resilience index value of household “a”; “ $min\{CRI\}$” is the minimum composite resilience index value among all households; “ $max\{CRI\}$” is the maximum composite resilience index value among all households.

The final weight of each resilience dimension and overall resilience index value range from 0 to 1. The values were exported into Arc GIS platform and classified into four categories as very low (<0.25), low (0.25–0.5), moderate (0.5–0.75) and high (>0.75) using equal interval method.

After computation of resilience value of all households, the relationship of each indicator and overall resilience value was analyzed using multiple regression method in SPSS tool. In multiple regression method, 32 indicators are considered as independent variables, and the resilience index value is considered as the dependent variable.

The households are distributed not only among the different characteristics of the sites but also in different region like urban and rural. Hence, the variation of resilience value between the households of the urban and rural area was also analyzed. To explore the degree of variation of environmental, social, economic, physical dimension and overall resilience between urban and rural areas, we used MANOVA. In MANOVA, environmental, social, economic, physical, and overall resilience values are considered as the dependent factors whereas the urban and rural area is the fixed factor.

4. Results and discussion

The index value of overall resilience and its four dimensions among the households are illustrated in Fig. 4 and Fig. 5. Average mean weight of each indicator among the households of different sites has been attached in Annexure Table A1. The detailed results are explained below:

4.1. Environmental dimension

Environmental dimension of resilience is measured by aggregating eight variables namely proximity to active slide, distance from drainage, degree of slope, degree of threat from landslide, exposure to degree of temporal probability of landslides, density of building footprint area, subsidence activity, and density of landslides. The result shows only 6.63% of total households have very low resilience and 7.53% of households have high resilience value (Fig. 5). Most of the households (~86%) fall under the low and moderate category of resilience level. The environmental resilience is lowest in Subba gaon and Tairigaon (Bong Basti) where mean environmental resilience value is 0.30. The highest environmental resilience value is found in the Dhobidhara (M = 0.82). In Nassey gaon and Narseregaon (Mangal Basti), environmental resilience value is also low (M = 0.36) (Table 3 and Fig. 6). Subba gaon and Tairigaon (Bong Basti) are exposed on the high landslide-prone area, and most of the households of this site are located in the vicinity of the landslide. The continuous toe erosion of Relli river is grasping the land from the lower part of the area to the upper area in the form of a landslide. Many houses (6 among 16 households) are shifted from the lower part of the area to the upper area. Generation of numerous cracks shows evidence of high instability of the area. Nassey gaon is exposed on the pocket of the old and reactivated landslide area. The existence of numerous active landslide in the vicinity of houses and high density of landslide is one of the causes of the high risk of the area. In Narseregaon (Mangal Basti), steep slope and instability of land after slide 2015 pose a high risk to the exposed households. The high degree of threat of landslide in the sites of Subba gaon and Tairigaon (Bong Basti), Nassey gaon, Narseregaon (Mangal Basti) compels people to move to another place during the rainy season. However, all the sites are under a threat of landslide and need mitigation to enhance resilience.

4.2. Social dimension

In the households, the level of resilience in the social dimension is higher than in any other dimension. Only 2.7% of households came under the low category of social resilience. About 60% of households have moderate to a high level of social resilience (Fig. 5). Social resilience is less varied among the sites of the study area (Table 3 and Fig. 6). In Adikari Gaon (Bong Basti) has relatively less social resilience (M = 0.40), and Khasgaon (Sidepong) has the highest social resilience (M = 0.68) value relative to other places (Table 3). The ratio of literate population, years of residence is relatively high among the household of Khasgaon than other sites. The social network is high in Kalimpong

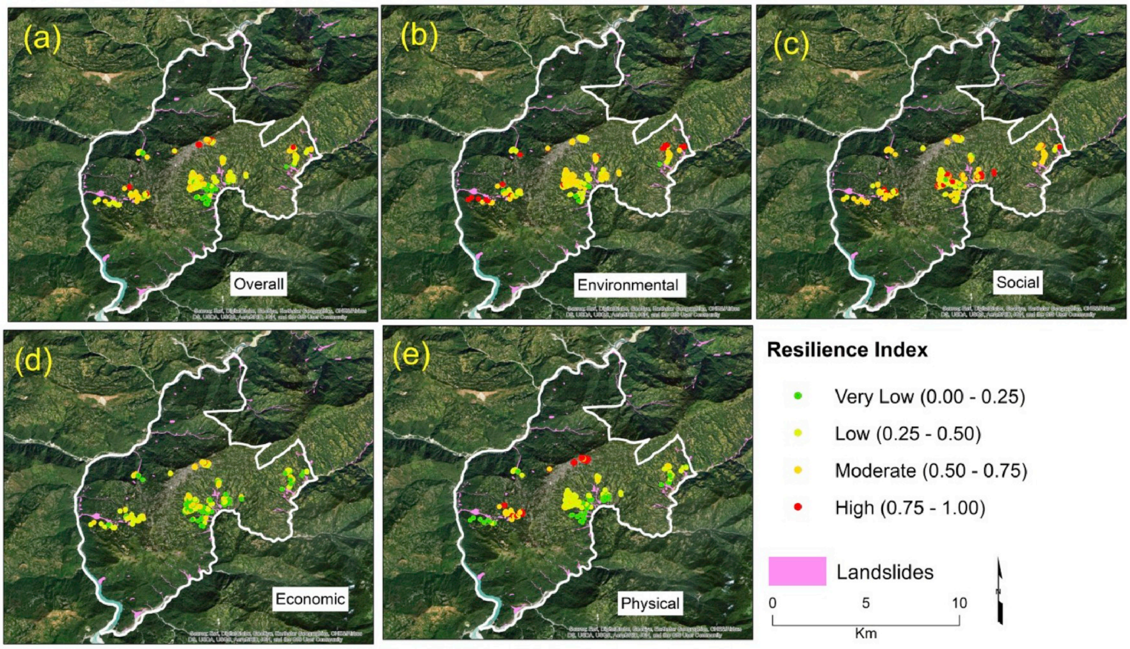


Fig. 4. Spatial distribution of the resilience index among households.

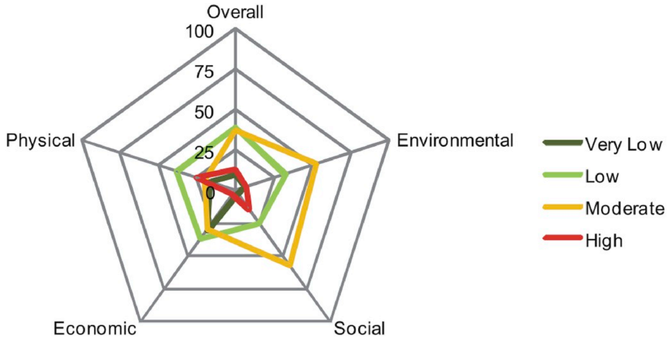


Fig. 5. Percentage of all households in the categories of overall resilience and its dimensions.

region, which is one of the positive sides of resilience. Although the distance from nearest houses are not equal in all places. In Khasgaon (Sindepong), Subba gaon and Tairigaon (Bong Basti), some houses are scattered and isolated. Therefore, it is difficult to disseminate information during disaster among these households.

4.3. *Economic dimension*

Livelihood and economic prosperity are highly affected by landslide in this region. The result shows that only 3.3% of households have high economic resilience. More than 30% of households belong to the very low category of economic resilience (Fig. 5). Topkhana and Gattekhola are most resilient ($M = 0.50$) whereas Subba gaon, and Tairigaon (Bong Basti) is least resilient (mean value 0.23) in terms of economic dimension (Table 3 and Fig. 6). Most of the people of Subba gaon and Tairigaon (Bong Basti) have low monthly income, low employed population and their economy depends mainly on agricultural activities. Subba gaon and Tairigaon (Bong Basti) have experienced fatal landslides recently in 2007, 2009, 2012, 2015. The agricultural land of 10 surveyed households was affected by the landslide and eight households completely lost their agricultural land. Houses and properties were also damaged due to disaster within the last five years significantly. A similar case also found in Lower Echhey, where economic resilience is also very low ($M = 0.25$) (Table 3). Many cracks were generated due to the 2011 earthquake in the agricultural field of Lower Echhey, which is the main cause of initiation of numerous shallow debris slide and slow movement of land like subsidence and creek. It damaged agricultural land of 23 households significantly out of 33 surveyed households. Hence, both of the areas are destabilized economically due to landslide and most of the people were compelled to give up the agricultural activities and engaged themselves in different temporary jobs like that of a carpenter, building construction worker and driver. As the economy of Topkhana and Gattekhola is not depended on agricultural activities, it is less affected by the landslide. The income level of this site is relatively higher than that of other sites. Hence, the resilience capacity of the household in this site is relatively higher than that of other sites.

4.4. *Physical dimension*

The physical dimension is composed of housing condition and basic services of infrastructure like road, health, water, and electricity services. About 134 houses among the 332 houses are kaccha, which is composed of wood and mud. In most of the houses (~65%) crack is found significantly, and about 30% of house is severely cracked and need urgent protection for upcoming monsoon (field survey). The roads and basic infrastructure are developed more on the top of the ridge. Hence, the physical resilience of Topkhana and Gattekhola ($M = 0.82$), Dhobi dhara ($M = 0.78$), Mangal Dara and Chibo Basti ($M = 0.68$) is relatively high. The physical resilience is lowest in Poshyore area, Subba gaon, and Tairigaon (Bong Basti) (Table 3 and Fig. 6). The mean physical resilience value in this region is 0.18. It follows Khasgaon (Sidepong) and Adikari Gaon (Bong Basti) where mean physical resilience value is 0.21 and 0.26 respectively (Table 3). The area is less resilient physically because of poor connectivity. Roads of the area are less dense and the main road is frequently blocked by landslide during monsoon season. The main hospital and market are located on the top of the ridge. The market area is associated with the bank, ATM, shops, bus stand, school, and other services. The dwellers of Subba gaon and Tairigaon (Bong Basti), Poshyore area, Khasgaon (Sidepong) and Adikari Gaon (Bong Basti) live far away from this service-centre area and are adversely affected in the event of road closure by heavy rainfall and landslides in the monsoon season. The study finds that overall, about 25% of

Table 3

Descriptive statistics of the overall resilience index and its various dimension among the different sites of the study area.

Sites	Overall Resilience				Environmental Dimension				Social Dimension				Economic Dimension				Physical Dimension			
	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD
1	0.68	0.30	0.47	0.98	0.98	0.63	0.76	0.10	0.91	0.28	0.61	0.16	0.52	0.03	0.35	0.14	0.30	0.06	0.18	0.08
2	0.66	0.25	0.42	0.14	0.71	0.19	0.36	0.19	0.79	0.15	0.50	0.20	0.58	0.12	0.41	0.13	0.73	0.29	0.52	0.13
3	0.93	0.20	0.61	0.16	0.78	0.00	0.48	0.16	0.86	0.29	0.60	0.15	0.86	0.14	0.48	0.16	0.88	0.44	0.68	0.13
4	0.66	0.25	0.42	0.14	0.71	0.19	0.36	0.19	0.79	0.15	0.50	0.20	0.58	0.12	0.41	0.13	0.73	0.29	0.52	0.13
5	0.87	0.48	0.77	0.12	0.91	0.67	0.82	0.11	0.65	0.25	0.57	0.12	0.68	0.28	0.46	0.13	0.97	0.54	0.78	0.13
6	1.00	0.39	0.67	0.14	0.75	0.29	0.50	0.12	0.90	0.16	0.58	0.15	1.00	0.15	0.50	0.16	1.00	0.56	0.82	0.09
7	0.76	0.06	0.42	0.17	1.00	0.02	0.61	0.23	0.76	0.10	0.61	0.12	0.67	0.01	0.25	0.17	0.57	0.13	0.30	0.10
8	0.65	0.16	0.41	0.12	0.71	0.43	0.56	0.08	0.92	0.26	0.68	0.16	0.72	0.08	0.29	0.17	0.40	0.00	0.21	0.11
9	0.75	0.26	0.45	0.15	0.76	0.38	0.61	0.11	0.75	0.02	0.51	0.19	0.70	0.00	0.29	0.22	0.57	0.27	0.42	0.11
10	0.79	0.14	0.48	0.13	0.62	0.33	0.54	0.07	1.00	0.29	0.64	0.19	0.77	0.08	0.34	0.20	0.63	0.16	0.41	0.13
11	0.80	0.22	0.50	0.15	0.77	0.28	0.57	0.11	0.95	0.00	0.58	0.18	0.93	0.00	0.36	0.22	0.68	0.26	0.45	0.10
12	0.65	0.10	0.26	0.16	0.56	0.21	0.43	0.13	0.62	0.16	0.40	0.15	0.70	0.07	0.29	0.20	0.54	0.07	0.26	0.12
13	0.46	0.00	0.18	0.13	0.61	0.14	0.30	0.13	0.72	0.25	0.46	0.14	0.52	0.06	0.23	0.15	0.46	0.01	0.18	0.14

Note: 1. Poshyore area, 2. Nassey gaon, 3. Mangal Dara and Chibo Basti, 4. Narseregaon (Mangal Basti), 5. Dhobi dhara, 6. Topkhana and Gattekhola, 7. Lower Echhey, 8. Khasgaon (Sidepong), 9. Bhamay Gaon (Sidepong), 10. Dungra, 11. Gairigaon (Lower Bong Basti), 12. Adikari Gaon (Bong Basti), 13. Subba gaon and Tairigaon (Bong Basti).

households have high physical resilience value and about 16% of households have the lowest resilience value relatively.

4.5. *Overall resilience index value*

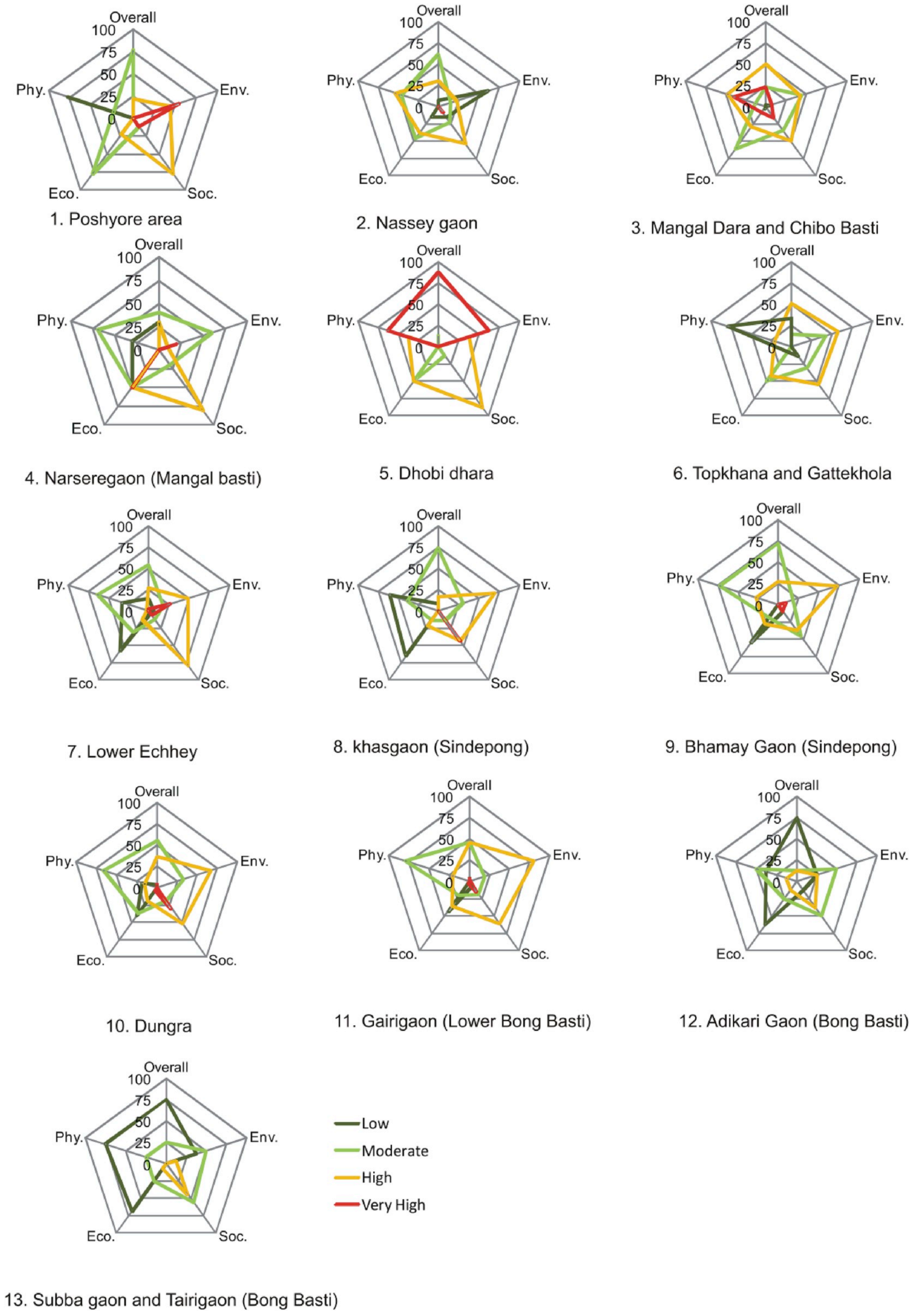
The overall resilience value is composed of the environmental, social, economic, and physical dimension. Most of the households (76%) belong to the low and moderate category of overall resilience. About 14% of households and 10% of households concentrate under high and low resilience category (Fig. 5). The result shows that the level of resilience is highly varied in the eastern, central, and western portion of the ridge (Fig. 4). The overall resilience value is higher in the central part of the ridge where the mean value of resilience in Dhobidhara and Topkhana and Gattekhola are consequently 0.77 and 0.67 respectively. On the contrary, the resilience level is significantly low in Adikari Gaon (Bong Basti) ($M = 0.26$), Subba gaon and Tairigaon (Bong Basti) area ($M = 0.18$) which are located in the eastern part of the ridge. The resilience level is also relatively low such as 0.41 (Khasgaon - Sidepong), 0.42 (Bhamay Gaon-Sidepong). In the western part, the resilience level is low to moderate, such as 0.42 (Narseregaon - Mangal Basti, Nassey gaon), 0.47 (Poshyore area) (Table 3). The high environmental risk of landslide, poor economy and poor accessibility are major causes of low resilience value in the eastern part of the ridge.

4.6. *Resilience in urban and rural areas*

The result demonstrates the variation of resilience level among the households in the urban and rural areas. More than 83% of households in the urban area has moderate to high resilience level. Only 0.89% of households are located in a very low category in an urban area. Whereas more than 65% of households belong to very low to low resilience category and only 6.8% of households have high resilience value in the rural area (Fig. 7). We conducted a MANOVA test to measure the variation of overall resilience and all its dimension in the urban and rural area (Table 4). The result shows that there is a significant difference between the urban and the rural when considered jointly on the variables environmental, social, economic, physical and overall resilience dimension, Wilk's $\lambda = 0.347$, $F(3,326) = 122.651$, $p = 0.000$, partial $\eta^2 = 0.653$. There was significant difference between urban and rural households on environmental dimension, $F(1,330) = 10.419$, $p = 0.001$, partial $\eta 2 = 0.031$, with mean value of urban ($M = 0.549$) being higher than that of the rural ($M = 0.485$).

In the urban area, size of the landslide is small and frequency is also low relative to a rural area. However, in an urban area, exposure of the population in the same unit of area is much higher than the rural area. Based on field observation, it can be concluded if the landslides occur at the same magnitude in both urban and rural area, the loss (human and land value) of the urban area will be many times higher than that of a rural area. In the rural area, the population is less dense, but the frequency of landslide occurrence is higher than the urban area. Hence, although the environmental resilience of urban area is relatively higher than the rural area, the risk of the landslide is not always low. In social dimension, resilience value is relatively higher in urban area ($M = 0.578$) in rural area ($M = 0.591$), although there have no significant difference.

The result shows that all the indicators are not significantly influenced by resilience value. In the urban area, social resilience is high due to high education level, high ratio of literate person among the household. However, in the rural area, people are more adjusted to the landslide. The duration of residence of the people is much higher in the rural area than in an urban area. The residents of Dhobidhara, Topkhana, and Gattekhana mainly came after 1968 disaster, which is the most catastrophic event in the history of the area. Similarly, urban area ($M = 0.497$) has higher economic resilience value than rural area ($M = 0.326$) and there was significant difference between these two areas, $F(1,330) = 61.490$, $p = 0.000$, partial $\eta 2 = 0.157$. In both rural and urban



1. Poshyore area

2. Nassey gaon

3. Mangal Dara and Chibo Basti

4. Narseregaon (Mangal basti)

5. Dhobi dhara

6. Topkhana and Gattekhola

7. Lower Echhey

8. khasgaon (Sindepong)

9. Bhamay Gaon (Sindepong)

10. Dungra

11. Gairigaon (Lower Bong Basti)

12. Adikari Gaon (Bong Basti)

13. Subba gaon and Tairigaon (Bong Basti)

Fig. 6. Percentage of the households in the categories of overall resilience and its environmental, social, economic and physical dimension in each site of the study area (Note: Env. = Environmental resilience, Soc. = Social Resilience, Eco. = Economic Resilience, Phy. = Physical Resilience).

area, monthly income highly impacts the overall resilience value. In the rural area, people have a lower income and lesser livelihood diversity than in an urban area. Most of the people in the rural area are dependent on agricultural activity which is highly damaged by the landslide during the rainy season. All these factors contribute to making economic resilience in the rural area weak. The most significant difference is found on physical dimension between the areas, F (1,330) = 485.136, p = 0.000, partial $\eta 2 = 0.595$ with urban ($M = 0.788$) value higher than rural ($M = 0.375$). The results sharply indicate that the difference in the physical dimension is mainly due to the concentric development of infrastructure in an urban area. Longer distance from the location of the service area increases the problems related to road blockage incidence that reduces accessibility during the rainy season. Hence, geographic location is the independent factor to determine the physical resilience of

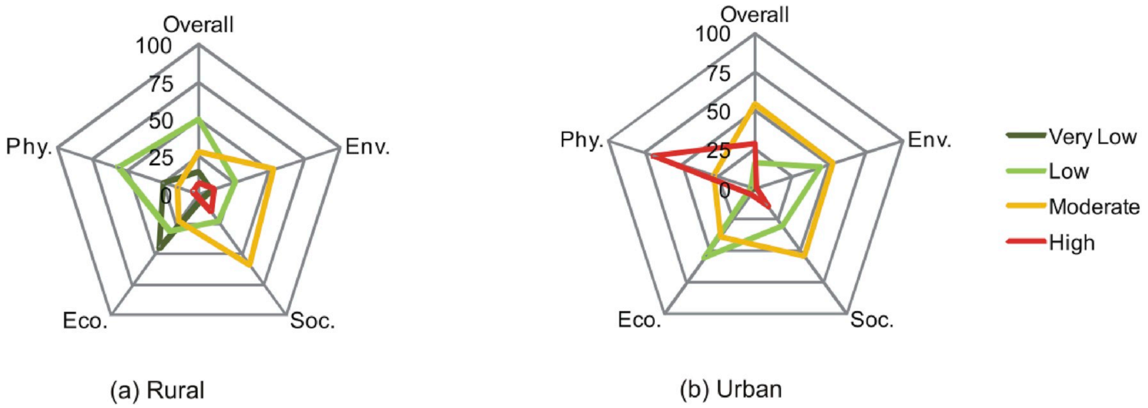


Fig. 7. Percentage of all households in the categories of resilience and its dimension in the urban and rural areas.

Table 4
MANOVA results of the various dimension of the resilience of the households of the urban and rural area.

Resilience Dimension	F	Sig. (p)	Partial Eta Squared
Environmental Dimension	10.419	0.001	0.031
Social Dimension	**0.398**	**0.529**	0.001
Economic Dimension	61.490	0.000	0.157
Physical Dimension	**485.136**	0.000	0.595
Overall Resilience	115.283	0.000	0.259

Between the areas, F (1,330) = 0.398, p = 0.529, partial η2 = 0.001.

any area. The sites of rural area are relatively highly affected by landslides. Therefore, the limited stable place is one of the challenges to decentralize services in the rural area. Since, the environmental, economic and physical resilience is high in the urban area, the overall resilience value is significantly higher in the urban area ($M = 0.657$) than in the rural area ($M = 0.443$).

4.7. Limitation and future studies

The resilience of an area is complex and interlinked with many factors which exist within a certain space and beyond. Considering the difficulties in bringing up the actual figure of resilience, the task of measurement is challenging and complicated. In this section, we discuss three aspects of the paper: first, resilience indicators; second, a variation of resilience index; third scale of the study.

In the case of resilience indicators, land stability, landslide magnitude, landslide susceptibility were not considered due to inadequacy of micro-level data. In the future, the study can be improved to analyze slope stability at the local scale and land movement information by the installation of ground-based instruments. We did not consider also the caste-based and religious identity of the household in social dimension although it is considered as indicators in the context of India. We have observed in the field that the society of Kalimpong is a combination of multiple religious groups of people within a small area and there is no discrimination among the different religions and caste. Insurance is one of the important indicators to enhance the resilience of a household. In the study area, surveyed households do not have any insurances. Therefore, the study did not consider the indicator to measure resilience like housing and health insurance. The indicator like the road is difficult to evaluate resilience in the perspective of landslide hazard. Development of roads increases the connectivity and enhances accessibility. Hence, we considered road as an important indicator for positive resilience building of an area. The physical resilience is improved in many remote places of Kalimpong region like Khasgaon (Sindepong), Bhamay Gaon (Sindepong) due to the construction of roads. However, our field observation depicts that impact of the road on resilience is heterogeneous, multidimensional and very site-specific. According to the residents of Narseregaon (Mangal Basti), roads reduce the risk of the landslide as they dissect the runoff water and enhance mobility during an emergency situation. On the other, roads altered the natural flow of the stream, which enhances the erosion activity in terms of losing agricultural land and houses. This problem is acute in Gairigaon (Lower Bong Basti). Hence, the practice of road construction in mountainous ecology is still a question for sustainability. Secondly, the variation of resilience index is analyzed in the context of only landslide hazard, although the region is affected by multi-hazards in the forms of landslide, earthquake, flood, and forest fire. The degree of resilience to different hazards may be different in different places. However, many indicators are not suitable for the case of other hazards. In the future, the study can be improved, incorporating other hazards to measure the resilience capacity of the region. In this study, the different places, urban and rural area are treated as a discrete entity. However, in this complex man-environment system, often different places are intertwined each other in the same domain of region. The methods can be improved, incorporating interrelationship between places in the frame of resilience measurement.

Third, in disaster studies majority of resilience studies is based on regional scale [29,38,66–68]. The regional-scale studies are effective in assigning resilience to the different administrative unit. It can also reflect the role of institutions or government in disaster risk mitigation. In the household-based studies, it is difficult to measure the variation of governance efficiency. However, an effective disaster risk reduction plan depends on both the macro and micro level study. In the mountainous region, exposure of households to natural hazards like landslide are highly varied within the small administrative unit. Our field survey shows different households are exposed in different degrees to different problems like active landslide, drainage and degree of slope. The accessibility of basic infrastructure is highly varied due to variation of distance and local event like road blockage event due to landslide during the rainy season. We can reflect on this kind of issue through indicators at the micro-scale (household) but it is difficult to bring it at the resilience framework of regional scale.

Although the study has a limitation, the study has also merits. The method of the study is flexible to store the numerous information on resilience in a single spatial dataset and can be easily compared to monitor different dimensions of resilience of the households. Since our method is based on field and satellite image-derived data, the indicators can also be applicable in the other data scarcity region of India and the world.

5. Conclusion and recommendation

The paper measured and compared the overall resilience and the resilience of environmental, social, economic, and physical dimension of the households in the urban and rural areas of Kalimpong district. The key findings of the study are as follows:

1. About 49% of surveyed household falls under the low category of overall resilience. The maximum number of households has low economic and physical resilience than environmental and social resilience. More than 50% of households have economic and physical resilience value under the value of the low category. The sites in the eastern part of the ridge are less resilient, and therefore, it requires essential risk reduction strategy for further improvement of resilience.
2. The resilience level of the households in the urban area is significantly higher than the households of rural area. High exposure of households to landslide risk and the weaker economy make the rural area lesser environmental and physical resilient than the urban area. The variation of resilience level between urban and rural area is higher in the physical dimension than in any other dimensions. It signifies that the concentric developments of infrastructure like roads, hospital, market in the urban area are one of the causes of the degree of variation of resilience.

In a developing country like India, almost 12.6% of the landmass is prone to landslide and substantially damaging properties and infrastructure in the entire Himalayan region, western ghat region and Nilgiri hills. Numerous settlement area is growing in this mountainous area without concerning the risk of landslide. Many hill station in India like Darjeeling, Sikkim, Kurseong, Kohima, Aizawl are experiencing the risk of the landslide in a similar way of Kalimpong. Comprehensive understanding of socio-ecological system within the places is important to reveal the variation of resilience on space. In the context, the study can apply to these places considering the internal factor of the places. Based on our finding, we can suggest a plan should consider the interaction of household and landslide at the micro level to the broader frame of resilience building.

Acknowledgement

The research is the part of Ph.D. work of the first author supported by Junior Research Fellowship of University Grant Commission (India) (UGC-Ref. No.: 3181/(NET-DEC. 2014) and grants from the Digital Globe Foundation (Sales Order Number: 0057506095), USA. The authors are grateful to Mr. Uttam Sahoo, Dr. Pankaj Jaiswal (GSI office, India), Mr. Praful Rao (Save The Hills, India) for their help. The authors sincerely thank the local government officers and above all the local people of Kalimpong for supporting this study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2019.101456.

Annexure.

Table A1
Average mean weight of each indicator among the households of different sites.

Indicators	Overall Sites	1	2	3	4	5	6	7	8	9	10	11	12	13
Distance from active slide(+)	.29	.54	.17	.09	.21	.78	.14	.45	.59	.30	.38	.37	.25	.13
Distance from drainage (+)	.25	0.25	.14	.25	.37	.53	.37	.14	.34	.42	.12	.11	.22	.27
Degree of slope (−)	.48	0.30	.35	.48	.82	.72	.69	.38	.47	.20	.33	.31	.45	.48
Temporal probability of landslide (−)	.35	0.39	.20	.25	.19	.00	.35	.22	.26	.40	.37	.32	.33	.34
Density of landslide (−)	.3	0.72	.64	.45	.29	.03	.03	.44	.58	.39	.30	.13	.64	.49
Degree of threat from landslide (−)	.34	0.05	.88	.42	.80	.00	.51	.24	.17	.18	.04	.14	.25	.88
Built-up area density (−)	.3	.04	.16	.69	.12	.62	.58	.06	.06	.21	.17	.13	.03	.04
Subsidence activity (−)	.54	0	.62	.03	.40	.38	.00	.70	1.00	1.00	1.00	1.00	1.00	1.00
Ratio of dependent Population (−)	.21	.08	0.32	.24	.12	.17	.18	.31	.15	.27	.22	.18	.39	.30
Ratio of female population (−)	.48	.49	.49	.49	.44	.46	.49	.49	.47	.46	.45	.48	.51	.49
Ratio of disable population n (−)	0	0	.00	.00	.00	.00	.01	.00	.00	.00	.00	.00	.00	.00
Ratio of literate population (+)	.63	.65	.46	.65	.61	.52	.79	.53	.69	.58	.63	.57	.47	.50
Level of education(+)	.12	.13	.10	.14	.09	.11	.15	.12	.11	.14	.12	.11	.11	.07
Years of residence (+)	.34	.62	.58	.59	.54	.53	.31	.79	.87	.27	.76	.66	.43	.50
Distance from nearest house	.05	.1	.08	.03	.08	.01	.01	.09	.09	.06	.03	.06	.20	.17
Monthly income (+)	.47	.44	.56	.53	.33	.58	.54	.43	.46	.45	.42	.42	.37	.37
Ratio of employed population (+)	.3	.26	.30	.34	.27	.27	.35	.24	.33	.21	.33	.28	.34	.18
Livelihood diversity (+)	.48	.55	.56	.37	.65	.34	.37	.56	.55	.43	.54	.59	.56	.58
Occupation affected by landslides (−)	.37	.55	.46	.05	.70	.00	.02	.70	.70	.45	.63	.48	.75	.69
Damaged houses or properties due to disaster within last five year (−)	.54	.44	.54	.45	.50	.63	.38	.79	.74	.73	.41	.59	.50	.81
Assets for emergency time (−)	.45	.5	.46	.44	.70	.31	.30	.64	.74	.36	.57	.48	.31	.25
Construction type of houses (+)	.41	.22	.46	.45	.10	.50	.85	.24	.30	.55	.30	.15	.25	.00
Existence of cracks in house (−)	.36	.16	.27	.47	.55	.44	.39	.48	.24	.64	.19	.25	.25	.56
Distance from metalized road (−)	.21	.34	.27	.02	.40	.06	.08	.23	.25	.22	.37	.26	.82	.46
Road density (+)	.51	.36	.76	.93	.44	.57	.56	.16	.06	.43	.52	.65	.33	.32
Accessibility of roads during rainy season (−)	.31	1.00	.43	.32	.21	.00	.32	.36	.33	.21	.17	.23	.27	.49
Distance from market (−)	.31	.57	.41	.26	.40	.18	.13	.68	.45	.22	.23	.26	.42	.36
Distance from hospital (−)	.3	.31	.48	.34	.41	.22	.12	.26	.48	.26	.33	.31	.44	.49
Distance from health centre (−)	.51	.91	.74	.85	.56	.05	.68	.26	.44	.49	.41	.19	.43	.40
Distance from nearest emergency shelter (−)	.29	0.3	.12	.28	.30	.18	.15	.29	.84	.21	.42	.30	.27	.43
Accessibility of water (+)	.41	.00	.50	.95	.50	1.00	1.00	.00	.00	.00	.00	.00	.00	.00
Accessibility of electricity (+)	.39	.00	.50	.93	.00	1.00	1.00	.00	.00	.00	.00	.00	.00	.00

Note: 1. Poshyore area, 2. Nassey gaon, 3. Mangal Dara and Chibo Basti, 4. Narseregaon (Mangal Basti), 5. Dhobi dhara, 6. Topkhana and Gattekhola, 7. Lower Echhey, 8. Khasgaon (Sidepong), 9. Bhamay Gaon (Sidepong), 10. Dungra, 11. Gairigaon (Lower Bong Basti), 12. Adikari Gaon (Bong Basti), 13. Subba gaon and Tairigaon (Bong Basti).

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