

Assessment of social vulnerability of landslides in the Darjeeling district using MCDA-based GIS techniques

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Abstract

The consequences or the result of any disaster or hazard's impact on society or nature is considered a vulnerability. In terms of landslide hazards, it causes many losses to the community such as the death of people, damage to property and damage to nature. Social vulnerability is measured with different scales depending on the area of the occurrence. In this study, a social vulnerability was conducted to identify the socially vulnerable zones such as people and property. The study was conducted in the Darjeeling district, West Bengal (26°27" N to 27°13" N latitudes and 87°59" E to 88°53" E longitudes). The main objective of this study is to find out the area under vulnerable zones. With the help of the GIS platform and Data available from the DDMA handbook and Census 2011, the social vulnerable map was created. In this study, Analytic Hierarchy Process (AHP)¹⁷ was applied to determine the weighted values of each factor i.e. Population Distribution, Literacy Rate, Non-working population etc.

All the parameters were put into Arc GIS based on each parameter's weighted values and the final output of social vulnerability was prepared. The result showed that 26% area comes under high vulnerable zones and 4% are in very high vulnerable zones. The southern part of the district comes under high to very high vulnerable zones due to the high population density and high settlement density.

Keywords: Social Vulnerable, Landslide, GIS, Remote sensing, Hazard, MCDA, AHP Model, Impact Assessment, Vulnerable Zones.

Introduction

The frequency and intensity of natural disasters increase because of human and environmental conflict. Climate change with high anthropogenic activities increases the vulnerability of hazards to society and the environment.¹ "A landslide is the movement of a mass of rock, debris, or earth down a slope under the influence of gravity."¹³

A landslide is a natural event mainly occurring in a hilly area or on an elevated surface due to natural agents i.e. rainfall, seismic activity, weathering etc. also triggered by anthropogenic activity. Landslides are geophysical phenomenon that can change the formation of the

landscape.²² Landslide hazards cannot be entirely prevented, but the intensity and impact severity can be minimized if the problem is recognized.

Social Vulnerability: Social vulnerability refers to the potential threat or loss; this includes people exposed to damages, places of hazard occurrences, the structural vulnerability of buildings and the economy.^{3,9} The definition of social vulnerability for natural disasters was introduced in the early 1980s to understand socio-economic elements affecting resilience. Social vulnerability generally represents the age of the population, health, infrastructure, economy, literacy rate and working and non-working population.¹⁹ Social imbalance and social inequalities are generally understood as social vulnerabilities. The condition of social instabilities is knowledge understanding of hazard, experience, social economy, technological availabilities, communication, building structure, the density of population and buildings structure.⁶

Social vulnerabilities influencing factors: There are some significant elements affecting or influencing social vulnerability like less access to the resource, limited political power and communication, religious belief and social custom, types of building and structure, age group structure and population density distribution.⁷ These elements that influence social vulnerability are discussed in table 1. Other elements are also significant for measuring social vulnerabilities such as special needs populations, physical or mental challenged populations, tourists, homeless, or immigrants. The structure and settlement density and built environment are also necessary to measure social vulnerabilities as these are directly related to economic losses, injuries and deaths.

Material and Methods

Study area: The study area is situated in the north part of West Bengal state and the southern part of the east Himalayan range. The Darjeeling district is 2034 sq. km. Earlier in 2014, it was 3300 sq. km. in 2014, Kalingpong was divided from Darjeeling district. There are 9 C.D blocks and 92 gram-panchayat. The research site is bound within the 26°27" N to 27°13" N latitudes and 87°59" E to 88°53" E longitudes. This district can be divided into the northern hilly and southern plain areas. As a result, the elevation ranges from 15m. to 3603 m. Due to this region's southwest and northeast Indian monsoon, a vast rainfall occurs from June to August.

Problems of the study area: The main problem of the study area is high elevation and high rainfall during monsoon. The

Darjeeling district mainly covers undulating surfaces with the northern high Himalayan ranges, making this northern part highly vulnerable to landslides. Besides this,

unscientific activity in the slope area and erosional work by rivers also caused the landslide.

Table 1
Social Vulnerabilities influencing Factors

Influencing factors	Description
Gender	Women can be more vulnerable due to their specific employment nature and family responsibilities and strength compared to men ²¹
Age group	Indeed, two age groups are most vulnerable. The age group below six years or children and elderly population above 60 age group increase load upon care and lack resilience. ⁵
Working status of community	Unemployment or non-working populations always increase society's risk and recovery rates are also slow compared to the working population. ¹⁵
Type of property	Built with higher-cost buildings are more resilient than mobile homes, i.e. cottage huts and tiny houses. Density, quality and area of settlements also influence vulnerability. ¹⁰
Occupation	Those directly involved in service or care-related occupations and mostly labour class people, self-employed persons like fishermen are said to be more vulnerable. ¹⁸
Education	Education is the most critical parameter in social vulnerability assessment. An adequately educated society with knowledge about disasters can increase resilience. ¹⁰

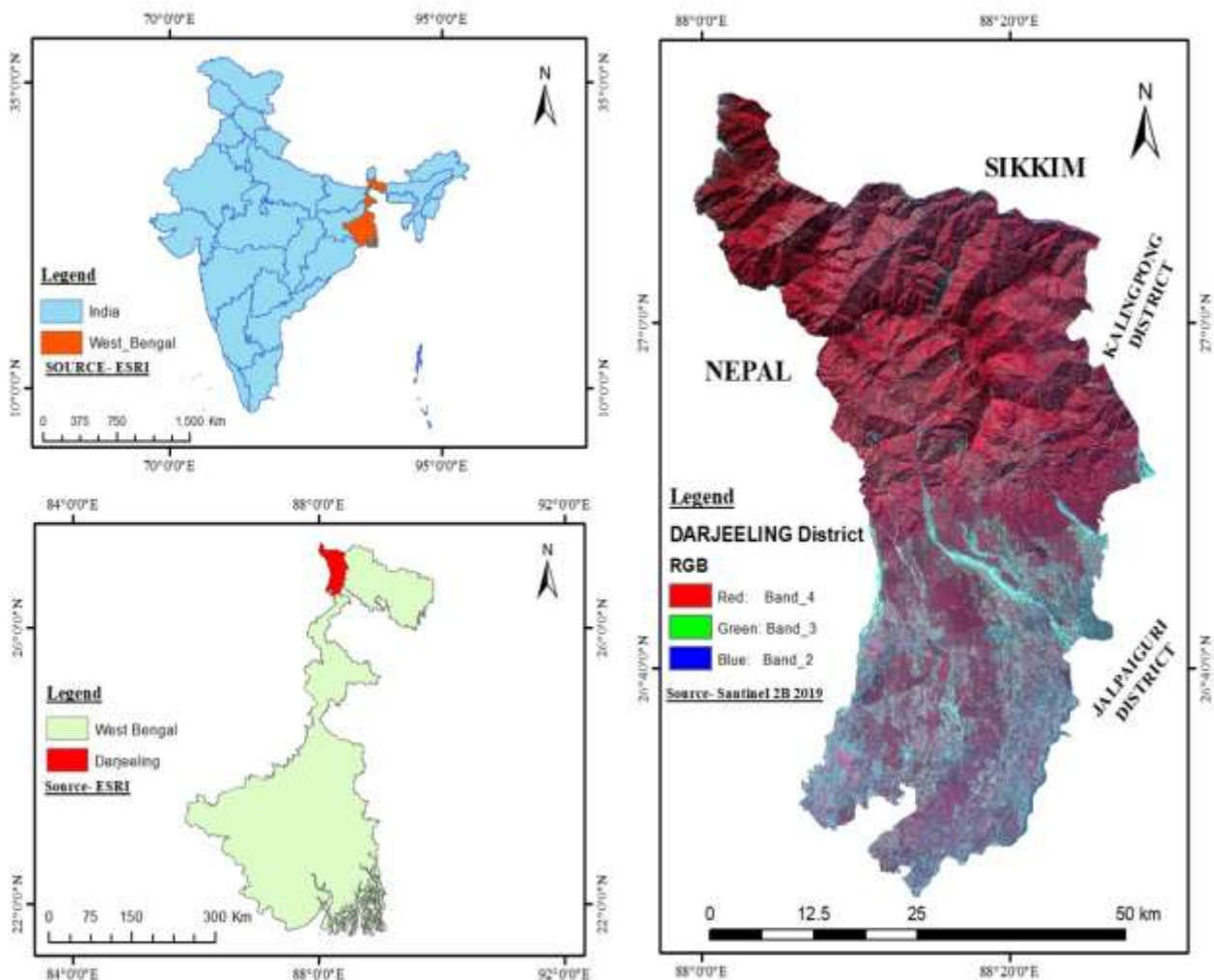


Figure 1: Map of the Study Area

The main aim of this study was to identify the social vulnerability map of the Darjeeling district. Similarly, this study was conducted to understand the social vulnerability parameters.

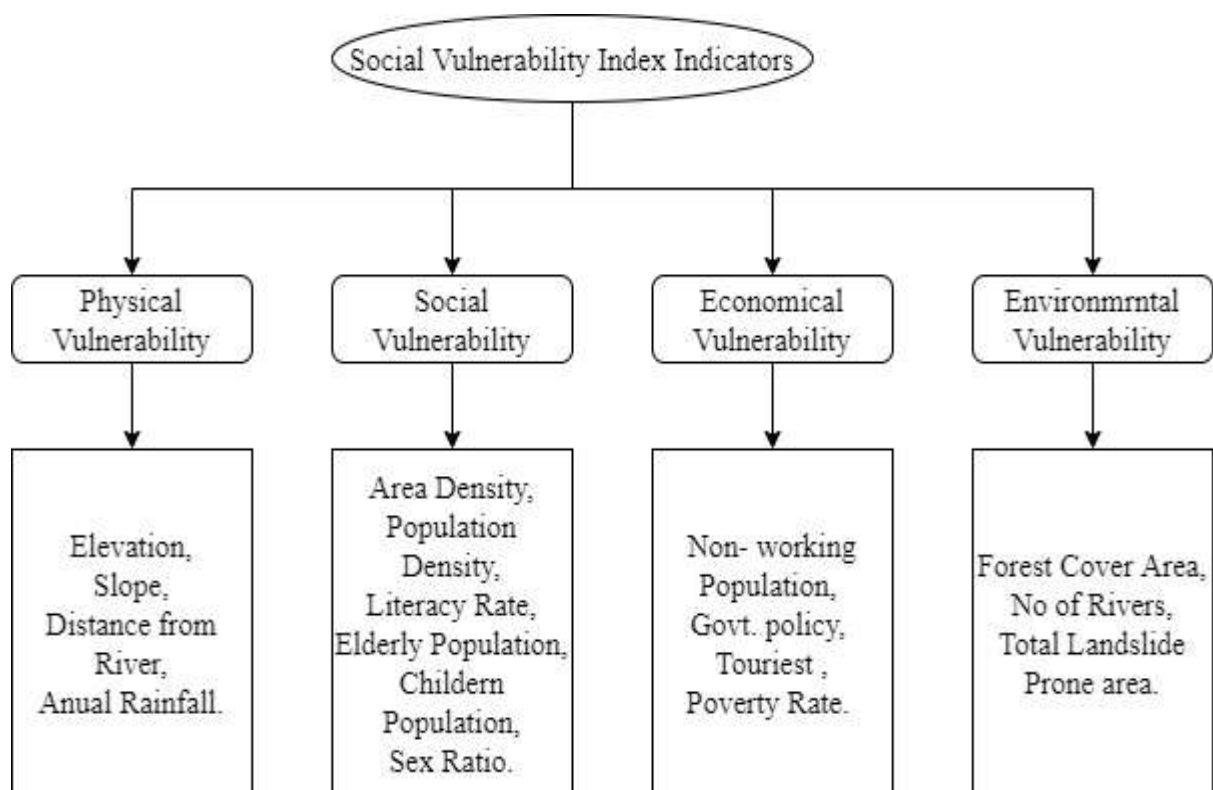
Material and Methods

Components of social vulnerability index: In this study, the social vulnerability was considered as indicator of social, physical, economical and environmental parameters. All these parameters represent resilience, exposure to hazards and coping capacity. Vulnerability assessment is the process of understanding or identifying society's vulnerability or resilience. Social vulnerability indicators depend on data availability, research work and field survey.

Data used: This study used a satellite image, Sentinel 2B (2019), to prepare the district map. ESRI and Bharat maps were used to create a base map for the study area. Landslide vulnerability map was prepared with various data i.e. Population Distribution, Density, Children population, Elderly population, Disabled population and Settlement distribution collected from India Census 2011 data. For the complete map preparation, ArcGIS 10.3 was used.

Processing: This study used various parameters such as Population distribution, Density, Children population, Elderly population, Disabled population and Settlement distribution to determine the social vulnerability map.¹⁴ All these parameters were created using ArcGIS shapefile, then the data was input into the attribute table. The shapefile was then converted into Raster data set with a 30*30 cell size and reclassified into five classes using ArcGIS. Using the AHP¹⁷ technique, a final vulnerability map was created with the help of the ArcGIS Weighted Overlay tool.

Data analysis: In MCDA (multi-criteria decision analysis), AHP (Analytic hierarchy process) is commonly used for weighted analysis. In this study, AHP¹⁷ was used to calculate the weighted value of each parameter. The relative value for each factor has been given according to the vulnerability for the subclasses, 0-9 value was assigned. After that, using the AHP pair-wise matrix, the weights were calculated. Each factor is co-related with other factors; in a pairwise matrix, each row follows the inverse value of all the factors. To validate the weighted value, CR (consistency ratio) was calculated.¹² According to Saaty,¹⁷ if the consistency ratio is < 0.10 %, the weighted values are accurate or more consistent.



Flow chart 1: Different types of Vulnerability Index

Table 2
Random index (RI)¹⁷

n	1	2	3	4	5	6	7	8	9	10
RI	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

$$\text{Consistency Ratio (C.R.)} = \frac{\text{Consistency index (CI)}}{\text{Random Consistency Index (RI)}}$$

$$\text{Consistency index (CI)} = \frac{(\lambda_{\max} - n)}{n - 1}$$

where $\lambda_{\max}$ is principle Eigen value and n is no. of factors.

In this study, the consistency ratio was 0.071% indicating that the weighted values were appropriate for Landslide social vulnerability map preparation. Furthermore, after calculating the weighted value rating of sub-classes, each

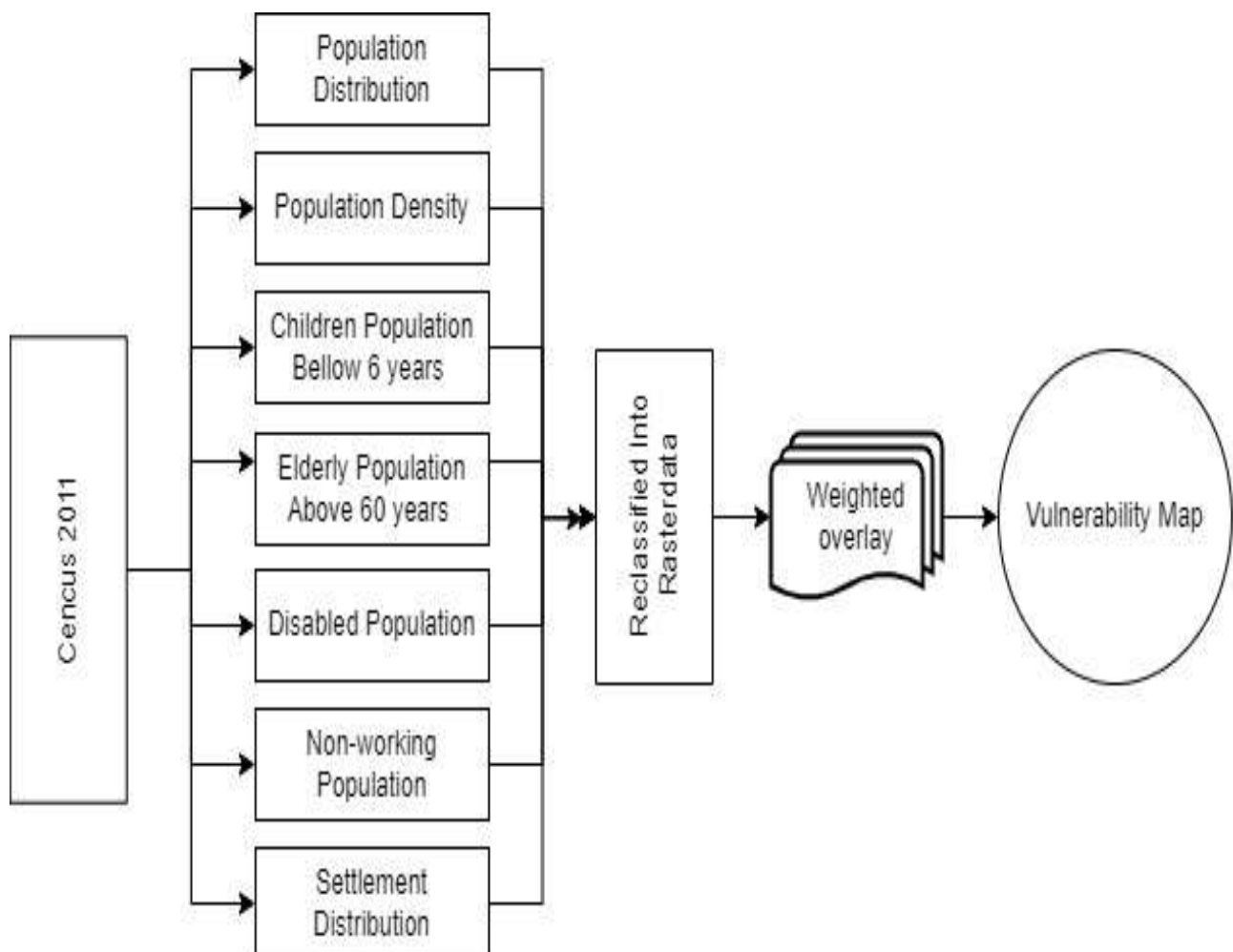
factor has a scale of 0 to 9. 0 representing less vulnerable and 9 represents the highest vulnerability.

Results and Discussion

Population Distribution: Population distributions are the most susceptible to social vulnerability in any disaster. Populations mainly in the hilly region are constantly exposed to landslide hazards and thus making them more vulnerable. In the study area, there are a total of 1595181 population living. With the help the of AHP¹⁷ technique, the whole district has been reclassified into 5 subclasses in ArcGIS (fig. 2a) according to their vulnerability (table 4).

Table 3
Pair-wise matrix Comparisons using the AHP technique

	TP	PD	CP	EP	DP	NP	SP	WEIGHT
Total Population (TP)	0.2	0.25	0.17	0.23	0.21	0.22	0.16	0.205
Population Density (PD)	0.08	0.1	0.08	0.12	0.11	0.1	0.13	0.103
Children Population (CP)	0.21	0.22	0.18	0.17	0.18	0.15	0.16	0.181
Elderly Population (EP)	0.11	0.1	0.13	0.12	0.13	0.15	0.13	0.123
Disabled Population (DP)	0.12	0.11	0.13	0.12	0.13	0.14	0.14	0.127
Non-Working Population (NP)	0.11	0.11	0.14	0.1	0.11	0.12	0.14	0.121
Settlement Distribution (SD)	0.18	0.11	0.16	0.14	0.13	0.12	0.14	0.139



Flowchart 2: Methodology of the study

Population Density: It is another critical parameter for social vulnerability assessment. Highly dense populated areas are always highly prone to any disaster like landslides. Population growth and high density always increase vulnerability to disaster.¹⁶ Nearly 40 percent of the total population comes under a highly dense group resulting in increasing population concentration in the urban and landslide-prone areas.

Disabled population: Disable populations are the most vulnerable factors close to any disasters. Special needs populations are always more exposed than the normal population, causing high numbers of casualties. Therefore, disability is a major factor in accessing social vulnerability.² In the study area, total of 40136 populations were found according to the Census 2011 Data of India. Among the blocks in Darjeeling District, Phansidewa and Darjeeling

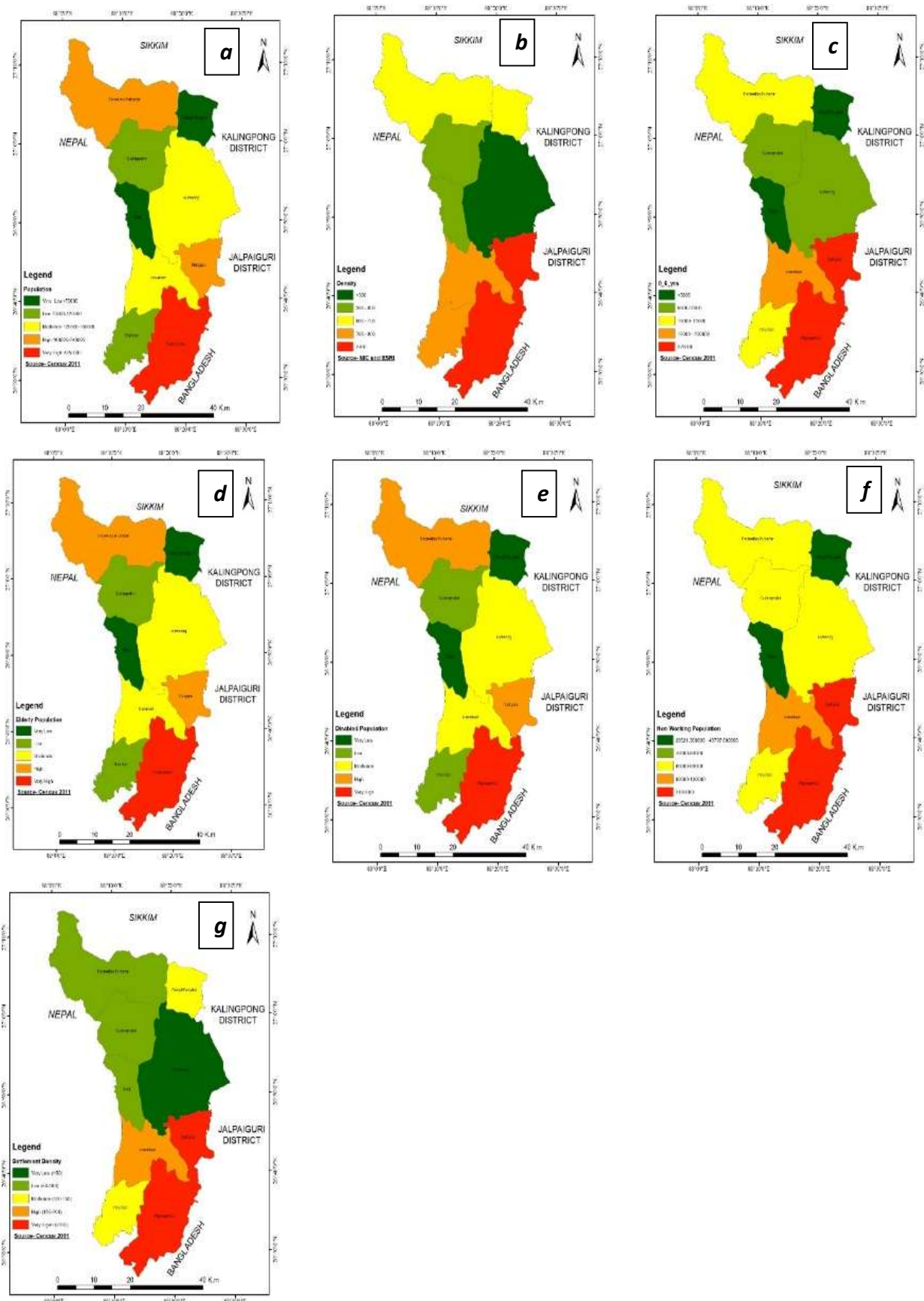
Pulbazar are having the highest number of disabled populations (Fig. 2 e).

Settlement Distribution: Congestion, limited escape plan and dense infrastructure add to the increase of vulnerability. Urban areas and cities in the entire world face the same problem. For example, in the country of China, urban earthquakes are more severe than other disasters because of highly congested settlements.⁸ In the study area, settlement distribution is divided into 5 classes (table 4) (fig. 2 g) and it is observed that the southern part of the district is highly dense because of urbanization.

Children below 6 years of population: In terms of vulnerability to any disaster, children below 6 years of age group are always more vulnerable. Particularly this age group faces more death than other age groups.

Table 4
Weights of subclasses for Landslide Vulnerability Parameters

FACTORS	CLASSES	RATING	Weighted (%)
Population	Very Low <70000	1	20.5
	Low 70000-120000	3	
	Moderate 120000-160000	5	
	High 160000-240000	7	
	Very High >240000	9	
Density	Very Low <300	1	10.3
	Low 300-600	3	
	Moderate 600-700	5	
	High 700-900	7	
	Very High >900	9	
Settlement Distribution	Very Low <50.0	1	14
	Low 51-100	3	
	Moderate 101-150	5	
	High 151-200	7	
	Very High >200.0	9	
Children Below 6 Years Population	Very Low <5000	1	18.1
	Low 5000-10000	3	
	Moderate 10000-150000	5	
	High 15000-20000	7	
	Very High >20000	9	
Disabled Population	Very Low	1	12.7
	Low	3	
	Moderate	5	
	High	7	
	Very High	9	
Elderly Population above 60 years	Very Low <70000	1	12.3
	Low 70000-120000	3	
	Moderate 120000-160000	5	
	High 160000-240000	7	
	Very High >240000	9	
Non-working Population	Very Low <40000	1	12.1
	Low 40000-60000	3	
	Moderate 60000-80000	5	
	High 80000-100000	7	
	Very High >100000	9	



**Figure 2: Social vulnerability Parameter map-
 (a) Population Distribution, (b) Population Density, (c) 0–6-year children Population, (d) Elderly Population,
 (e) Disabled Population, (f) Non-working Population, (g) Settlement Distribution**

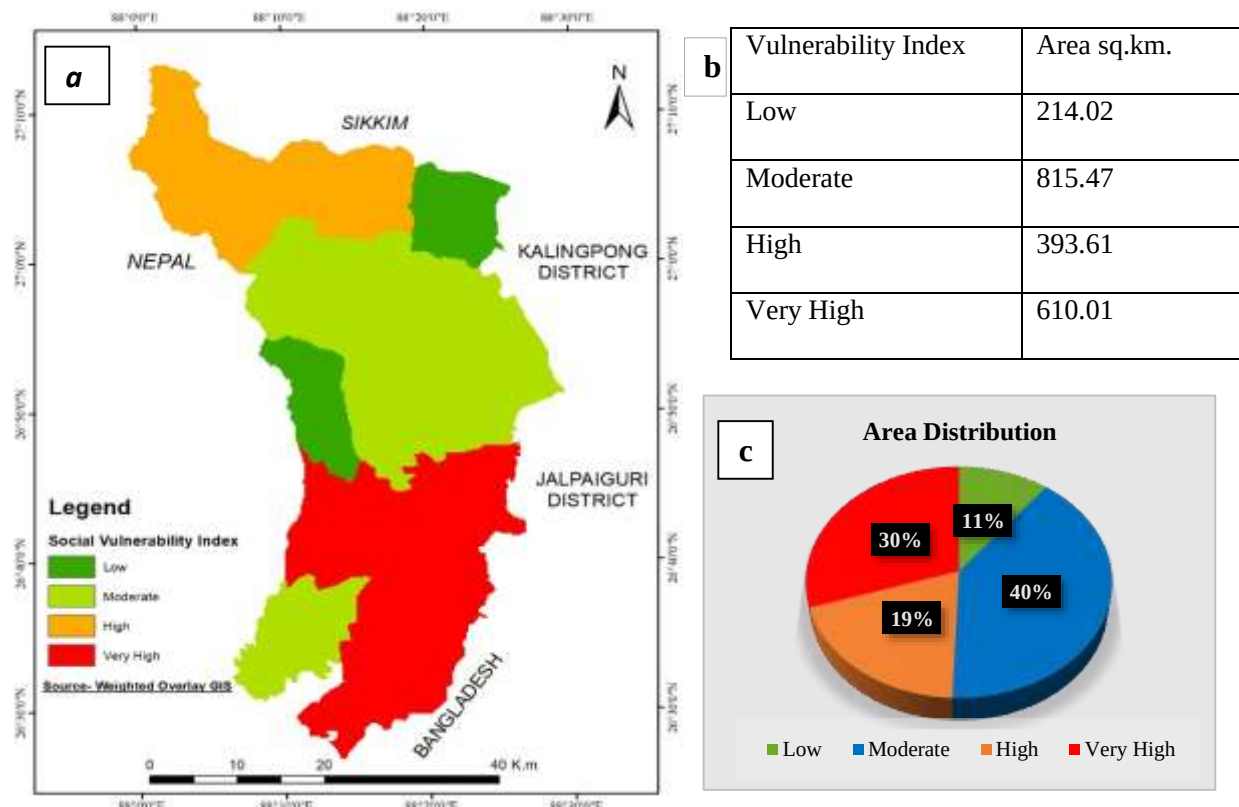


Figure 3: (a) Social Vulnerability Map, (c) Diagram of Area distribution percentage

Due to a lack of understating about emergencies or disasters, this age group comes last in response. With the help of the GIS technique, the district has been divided into 5 vulnerable classes (table 4).

Elderly population above 60 years: The effect of age especially on the elderly population can clearly be seen in kind of emergency or disaster, hence making them more vulnerable.²⁰ In the Darjeeling district, Phansidewa, Darjeeling and Matighara Block are having highest number of elderly populations (fig. 2 d).

Non-working population: The social and economic conditions are also determined by its working population. Thus non-working populations always have a disadvantage in knowledge and response during a disaster.⁴ In the Darjeeling district, majority of the blocks are having moderate non-working population. Total 702667 non-working people are currently living, among them Matighara Block is having highest number.

Conclusion

The study tried to attempt an approach to the assessment of the vulnerability of landslides in the Darjeeling district.¹¹ Landslide in the Darjeeling district has a huge impact on social life as almost every year landslide occurs. A social vulnerability assessment of landslides was conducted based on the social influencing factors to understand the zones of vulnerability. After the final preparation of the vulnerability map of Darjeeling (Figure 3a), the result was showing 30% and 19% of the area (figure 3c) under very high and high

vulnerable zones respectively. Most of the very high vulnerable zones are found in the southern part of the district and the northern block also comes under high vulnerable zones.

Almost 50 percent of the total area around 1000 sq. km. comes under high to very high vulnerable zones. Phansidewa, Naxalbari and Matighara blocks are among the high vulnerable zone and Darjeeling Pullbazar comes under high vulnerable zones. Mirik and Rangli-Rangliot blocks are identified as low social vulnerable zones to landslides. This study will help to identify the potential susceptible zones in the district and also might help in the future projection to increase scientific vulnerability assessment. From this study, it is identified that GIS and Remote Sensing techniques are very important for carrying out vulnerability assessment of landslides.

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