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ORIGINAL PAPER

Use of GIS in assessing building vulnerability for landslide hazard in The Nilgiris, Western Ghats, India

Edison Thennavan[1] · Ganapathy Pattukandan Ganapathy[1] · S. S. Chandra Sekaran[2] · Ajay S. Rajawat[3]

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Abstract The present paper aims at to produce the building vulnerability and its spatial distribution in mountainous regions of the Nilgiris District in the Western Ghats, India. The landslide-susceptible areas were identified based on the existing landslide-susceptible maps. The landslide-prone slope was identified based on the historical and recent landslide information's collected from various authenticated sources as well as the field investigations made on the recent landslides. The high-to-severe landslide hazard-prone areas were selected for the present study of building vulnerability analysis. The areas were divided into ten segments based on the landslide inventory, built-up areas, and transportation corridors in the vicinity of landslide locations. Building foot print map was prepared for each segments using ArcGIS software visual interpretation for 1627 buildings and infrastructures. Different thematic layers viz, building type/material, surrounding wall, sloping side details, warning, and number of floors which contribute to landslide vulnerability in vector formats are used for the present study. Using the formula proposed by Papathoma-Köhle et al. (Nat Hazards Earth Syst Sci 7:765–779, 2007) the vulnerability score were calculated by scripting in ArcGIS software. Based on the vulnerability score, the buildings were grouped under three categories viz, low, medium, and high

✉ Ganapathy Pattukandan Ganapathy
seismogans@yahoo.com

Edison Thennavan
edison.gis@gmail.com

S. S. Chandra Sekaran
chandrasekaran.ss@vit.ac.in

Ajay S. Rajawat
asrajawat@sac.isro.gov.in

[1] Centre for Disaster Mitigating and Management, VIT University, Vellore, Tamil Nadu 632 014, India

[2] School of Civil and Chemical Engineering, VIT University, Vellore, Tamil Nadu 632 014, India

[3] Space Application Centre, Indian Space Research Organisation (ISRO), Ahmedabad, Gujarat 380015, India

vulnerability. The spatial distribution of vulnerability of buildings was prepared and presented. The present study can be useful data for preparation of regional landuse plan as well as evacuation plans and warning systems to safeguard measure for population living in the vulnerable buildings in The Nilgiris District of Western Ghats in India.

Keywords Landslide · Susceptibility · Vulnerability · Mapping · The Nilgiris

1 Introduction

According to one estimate, nature takes nearly 1000 years to produce a few centimeter of top soil, but destabilizing forces of nature in the mountainous areas wipe millions of cubic meters in just a second (Bhandari 2006). Mountains are more frequently affected than other environments by destructive natural processes including earthquakes, volcanic eruptions, dam bursts, or glacial lake out bursts. Moreover, other hazards such as avalanches and landslides occur almost exclusively in mountains (Marty 2003). Landslides are recognized altogether continents, within the seas and within the oceans. On Earth, the realm of a landslide spans nine orders of magnitude, from a little soil slide involving few square meters to giant submarine landslides covering hundreds of square kilometers of land and ocean floor (Guzzetti et al. 2005). The ultimate goal of many landslide studies is the determination of risk posed by existing or future slope failures either population and or the infrastructure (Ardizzone et al. 2008). Assessing building damage in a geological landslide is a dynamic process in which the event can be regarded as the combined effect of the landslide impact and the building's response (Chong Shi et al. 2013).

The vulnerability may be expressed in terms of damage states varying from non-structural damage to extensive collapse. Damage may be structural or non-structural with being damage caused to utility systems (Corominas et al. 2014). The vulnerability is expressed as degree of expected damage. By establishing degree of vulnerability of buildings and lifelines, one can obtain an estimate of risk. Vulnerability analysis is therefore as intrinsic aspect of disaster mitigation and of linkages in the assessment process. The vulnerability of a structure is a quality of that structure, irrespective of where it is built (UNDRO 1991). Little is known about vulnerability to landslides, despite landslides causing frequent, widespread damage to the built-up environment and population in many areas of the world (Galli and Guzzetti 2007). Vulnerability assessment involves the understanding of the contact between a given landslide and the affected elements. Practices in the field of landslides indicate that the extent of damage to buildings due to landslides varies considerably according to the building characteristics, the mechanism of movement, and the magnitude and intensity (Dai et al. 2002). No theory has been elaborated up to now to model the damaging effects due to all types of landslides, with the exception of the sudden impact of a block on a wall (Imiriland 2000). In the last decades, methods of vulnerability assessment have been developed and tested within the framework of risk analysis; most of them are designed for a specific hazard. Research has demonstrated that irrespective of the type of assessment (natural—or social science based), there are some key issues related with the definition of the vulnerable system that must be addressed (Ciurean et al. 2013).

Finlay (1996) discussed the various parameters for vulnerability to landslide viz., run out distance, volume and velocity, and element at risk, (buildings, persons and infrastructures). Dai et al. (2002) proposed a structural vulnerability matrix for Hong Kong city to assess the landslide risk. Blöchl and Braun (2005) analyzed the vulnerability of buildings according to the type of damage through landslides. Gilberto (2006) analyzed the linkages between vulnerability and resilience. Neil Adger (2006) reviewed the existing knowledge on analytical approaches to vulnerability to environmental change in order to propose synergies between research on vulnerability and on resilience of social–ecological systems. Akbas et al. (2009) developed an empirical vulnerability function from the data obtained from July 13, 2008, debris flow event in the village of Selvetta located in the Italian Alps. Pascale et al. (2010) developed an approach for the estimation of the consequences of landslide events drawn up by means of the utilization of a territorial model based on a network of influences and an estimation procedure of systemic vulnerability. Van Westen et al. (2011) developed a methodology for landslide inventories and its uses in landslide risk assessment. Erener and Düzgün (2011) used the Geographic Information Systems (GIS) technology for quantitative vulnerability assessment and developed a methodology for damage probability matrix in landslide-prone areas of Turkey for buildings and roads. Silva et al. (2011) carried out a study on vulnerability assessment of buildings and roads to shallow translational landslides in Santa Marta de Penaguiao, Vila Real, Portugal. Rondón and Cho (2012) analyzed the structural vulnerability of masonry buildings for landslide hazard by mathematical modeling using different parameters for 14 buildings in a regional scale. Du et al. (2013) proposed a model for quantitative vulnerability index for landslides. Mavrouli et al. (2014) and Uzielli et al. (2015) discussed different methods employed for vulnerability assessment and derived different vulnerability curves for reinforced concrete buildings prone to landslides. Papathoma-Köhle et al. (2007) produced a simple methodology to analyze the elements at risk posed to landslides using Geographical Information System.

India has a series of record of death and damages due to landslides. The Darjeeling floods of 1968 destroyed vast areas of Sikkim and West Bengal and triggered numerous landslides, causing considerable loss of lives and destruction to buildings. There was a cut off at 92 to places in the mountain highway to Darjeeling, which result the total disruption in communication system and cause loss of lives. In July 1970, the great Alaknanda Tragedy of Uttaranchal State was triggered by the massive floods in the River Alaknandha. The Malpa rock avalanche tragedy of August 18, 1998, killed 220 people and vanished the entire village Malpa in the State of Himachal Pradesh. The southern part of India is quite equally prone to landslides especially the Western Ghats. The Amboori landslide of Kerala killed 23 people on November 2001 (Bhandari 2006, 2013; Sharda 2008). The Nilgiris district in Western Ghats part of Tamil Nadu state is one of the very high-to-severe landslide hazard-prone areas of India (BMTPC 2003), and the district is well known for landslide threat. Unprecedented rains triggered about a 100 landslides within an area of 250 sq. km in the district during 1978. Nearly 200 landslides were recorded during 1979 causing loss of life and severe damage to property. The 1993 Marappalam landslide of The Nilgiris District is a famous one which killed 52 passengers in the bus in the road corridor. As per the State Government record about 1100 small-, medium- and large-size landslides were reported within 5 days time from November 10–15, 2009, and taken away about 45 human lives, also the vast damage reported on houses, roads and railway lines. In the recent times causalities and damage due to landslides have increased in the Nilgiri Hills (Ganapathy et al. 2010, 2013). Some of the notable landslides of India, which cause threat to human lives and property, are compiled and presented in Table 1. The spatial distribution of landslides is presented in Fig. 1.

Table 1 Some of the notable landslide deaths and damages in India since 1867

State	Location	Year	Total deaths	Total affected	Total damage
Uttarakhand	Sher Ka Danda, Nainital	1867	0	0	NA
Assam	Assam	18th September, 1948	500	0	0
Jammu and Kashmir	Nashri	1956	0	0	NA
Bihar, Bengal	Bihar, Bengal	01st October, 1968	1000	0	0
Sikkim	Gangtok–Silugiri Road	July, 1966	NA	NA	NA
Uttar Pradesh	Alaknandha, Uttaranchal	20th July, 1970	NA	NA	NA
Himachal Pradesh	Snowdon, Shimla, Lower Himalayas	February, 1971	0	0	NA
Northeastern States	Northeastern	5th November, 1978	64	0	0
Punjab	Lahaul	March, 1979	230	5000	0
Uttar Pradesh	Uttar Pradesh	19th August, 1979	42	112	0
Uttar Pradesh	Uttar Pradesh	25th June 1980	150	0	0
Sikkim	Sikkim	01st September 1983	67	0	0
Jammu and Kashmir	Jammu and Kashmir	16th November, 1986	65	200	0
Himachal Pradesh, Uttar Pradesh	Himachal Pradesh, Uttar Pradesh	1st July, 1986	88	2,500,000	0
Himachal Pradesh	Kaliasaur	August, 1986	0	0	NA
Jammu and Kashmir	Ladakh	15th March, 1988	250	0	0
Uttar Pradesh, Haryana, Himachal Pradesh, Punjab	Uttar Pradesh, Haryana, Himachal Pradesh, Punjab states	1st July, 1988	255	0	0
Sikkim	Sikkim	16th September, 1990	30	0	0
Mizoram	Aizawl	9th August, 1992	60	0	0
Maharashtra	Bombay	23rd September, 1993	20	25	0
Tamil Nadu	Marappalam, The Nilgiris	11th November, 1993	52	0	15
Jammu and Kashmir	Kashmir province	16th January, 1995	200	5250	0

Table 1 continued

State	Location	Year	Total deaths	Total affected	Total damage
Mizoram	Mizoram State	3rd June, 1995	40	14,285	4500
Himachal Pradesh	Kullu, Himachal Pradesh	12th September, 1995	400	1100000	0
Karnataka, Andhra Pradesh, Maharashtra	Karnataka, Andhra Pradesh, Maharashtra	30th September, 1996	48	0	0
Sikkim	Gangtok	9th June, 1997	28	30	0
West Bengal	Darjeeling Hills	6th August, 1997	23	2000	0
Himachal Pradesh	Himachal Pradesh	5th March, 1998	26	0	0
Assam	Assam	6th March, 1998	48	150	0
Uttar Pradesh	Malpa village, Pithoragrah District	18th August, 1998	210	200,000	0
Uttar Pradesh	Mansuna village	19th August, 1998	37	0	0
Sikkim	Sikkim	31st March, 1998	24	6	0
Uttar Pradesh	Moradabad, Bijnor districts	June, 2000	43	0	0
Maharashtra	Ghatkopar, Mumbai	12th July, 2000	58	7038	0
Himalayas	Himalayan Foothills	11th August, 2000	86	0	0
Uttarakhand	Rudraprayag district	16th July, 2001	27	0	0
Himachal Pradesh	Chamba district	14th August, 2001	16	0	0
Kerala	Amboori, Trivandrum district	9th November, 2001	55	0	0
Himalayas	Himalayas	3rd March, 2003	25	0	0
Jammu and Kashmir	Verinag, Qazigund, Ramsu, Anantnag, Poonch	15th February, 2005	250	5000	50,000
Assam	Assam	24th August, 2005	12	20	0
Jammu	Panthal, Jammu–Srinagar Highway	27th February, 2007	0	0	Highway blocked

Table 1 continued

State	Location	Year	Total deaths	Total affected	Total damage
Jammu and Kashmir	Doda	18th March, 2007	2	5	3 houses damaged
Maharashtra	Chembur, Mumbai	24th June, 2007	2	0	0
West Bengal	Kurseong and Darjeeling	15th July, 2007	0	0	Two Houses Damaged
Assam	Katahbari, Guwahati	16th July, 2007	2	0	0
West Bengal	Siliguri, Darjeeling	16th July, 2007	0	0	Damaged Road
Sikkim	Bardang near Singtam, Gangtok	17th July, 2007	0	0	Damaged National Highway 31A
Assam	Guwahati 7	20th July, 2007	7	0	0
Meghalaya	Tura, West Garo Hills	28th July, 2007	9	0	3 houses damaged
Himachal Pradesh	Kinnaur	30th July, 2007	4	Many	0
Himachal Pradesh	Chamba	30th July, 2007	3	0	0
Himachal Pradesh	Chattru, Lahaul-Spiti	11th August, 2007	1	2	0
Himachal Pradesh	Kanga	12th August, 2007	8	0	0
Himachal Pradesh	Dharla	15th August, 2007	At least 62	0	14 houses and a primary health care centre damaged
Gujarat, Maharashtra	Nivsur, Ratangiri	2nd September, 2007	0	0	Konkan Railway Route
Uttarakhand	Pithoragarh	6th September, 2007	5 (9 others Feared Dead)	0	0
West Bengal	Kalimpong, Darjeeling	7th September, 2007	6	0	80 Houses Damaged
Assam	Guwahati	16th September, 2007	3	0	0
Uttar Pradesh	Loharkhet, Almora	29th September, 2007	4	0	0
Nagaland	Lalmati near Kohima	19th October, 2007	0	0	Road Damaged
Tamil Nadu	Udhagamandalam-Coonoor, Near Nilgiris	27th October, 2007	1	2	Many Houses Damaged

Table 1 continued

State	Location	Year	Total deaths	Total affected	Total damage
Jammu and Kashmir	Kapran village, Gurez district	8th February, 2008	37	0	0
Himachal Pradesh	Manali	17th March, 2008	25	0	0
Jammu and Kashmir	Kishtwar	1st May, 2008	20	0	0
Jharkhand	Ranchi	14th June, 2008	15	0	0
Arunachal Pradesh	Itanagar	14th June, 2008	14	More than 50 injured	0
Himachal Pradesh	Mandi	2nd July, 2008	2	1	0
Uttrakhand	Dehra Dun	18th July, 2008	10	12	0
Uttrakhand	Chamoli	26th July, 2008	8	2	0
Himachal Pradesh	Nahan	21st September, 2008	6	0	0
Arunachal Pradesh	Itanagar	30th October, 2008	12	0	Many houses damaged in flash flood
Assam	Lakhimpur, Sontipur	30th October, 2008	7	0	0
Jammu and Kashmir	Jammu and Kashmir	30th December, 2008	0	6	0
Uttarakhand	Pithoragarh district	8th August, 2009	45	0	0
Maharashtra	Mumbai	3rd September, 2009	10	0	0
Tamil Nadu	Nilgiris	10th November, 2009	45	More than 1000 people affected	Hut Damage 3785, Road Breaches 7, Road Structures Damaged – 145, Affected Length 201
Jammu and Kashmir	Khelenmarg mountains	8th February, 2010	14	0	0
Maharashtra	Malin, Pune	30th July, 2014	209	0	95

Table 1 continued

State	Location	Year	Total deaths	Total affected	Total damage
West Bengal, Himachal Pradesh	Darjeeling, Himachal Pradesh	1st July, 2015	38	500	Extensive damage to road NH 10 and NH 15

Source: Compiled from various sources (EMDAT 2015; SAARC 2010)

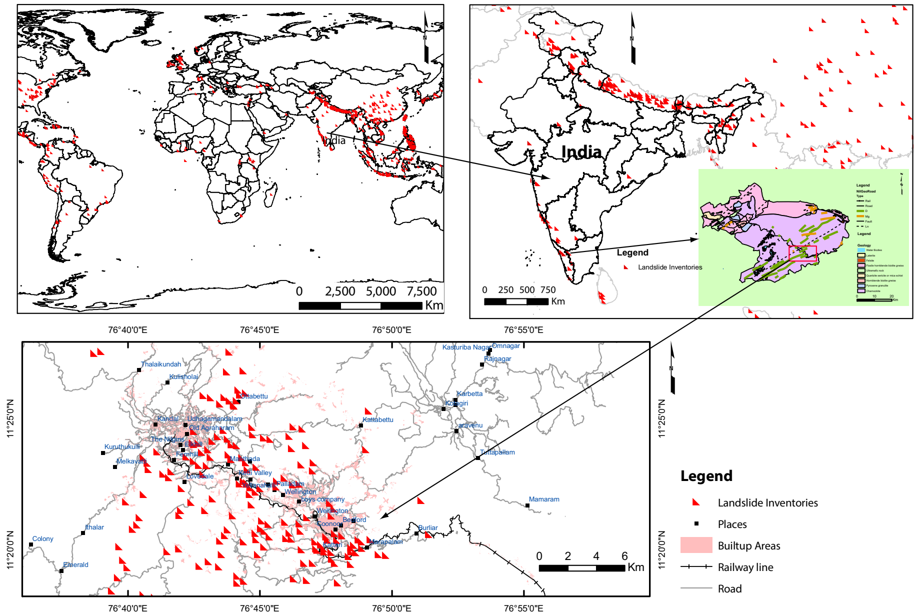

Fig. 1 Location of the study area with landslide inventory over built-up area

Many researchers carried out landslide hazard studies in The Nilgiris District (Seshagiri et al. 1982; Ramakrishnan et al. 2002; Rajarathnam and Ganapathy 2006; Rajakumar et al. 2007; Vasantha Kumar and Bhagavanulu 2007; Thanavelu and Chandrasekaran 2008; Ganapathy and Jothimani 2009; Jaiswal et al. 2009, Jaiswal et al. 2010a, b, 2011a, b; Naveen Raj et al. 2011; Antony Ravindran and Mohd Abdul Kadar Prabhu 2012; Ganapathy and Hada 2012; Manimaran et al. 2012; Prabu and Ramakrishnan 2012; Pradeep Kishore et al. 2012; Vaani and Sekar 2012; Gurugnanam et al. 2013; Sunandana Reddy and Lakshmikanta Reddy 2013; Gomathi et al. 2013; Chandrasekaran et al. 2012; Muthukumar 2013; Bairavi et al. 2014; Nalina et al. 2014; Ganapathy and Rajawat 2015). However, there is not much work carried out on landslide vulnerability analysis of buildings in The Nilgiris District of Western Ghats, India. Since the landslide occurrence in The Nilgiris quite a common phenomenon, it is necessary to study the physical vulnerability of buildings under landslide threat. The present study aims to produce the spatial distribution of vulnerability of buildings under landslide hazard-prone slopes of The Nilgiris district of India. The main focus on the study is on the physical environment especially on the impact of landslide hazard on built environment.

2 Study area

The Nilgiris district is part of Western Ghats hill ranges in the State of Tamil Nadu, India. The district has an area of 2552.50 sq. km with a population of 0.735 million with female–male ratio of 1:1 as per Census of India 2011, and the district headquarter is Ooty (Udhagamandalam). The elevation varies from 1000 to 2633 m above mean sea level. The highest peak is in the district is Doddabetta with a height of 2663 m. The topography of the district is undulating with steep escarpment and about 60 % of the cultivable land slopes ranging from 16° to 30° slope. The district regularly receives rain during both the southwest monsoon and the northeast monsoon. Administratively, the district is divided into six taluks. The taluks are further divided into four blocks, which is further divided into 55 revenue villages. The entire Gudalur and Pandalur and Kundah taluks and parts of Udhagamandalam taluk get rain from the southwest monsoon, while part of Udhagamandalam taluk and the entire Coonoor and Kotagiri taluks get rains of the northeast monsoon. Tourism is an important source of revenue in the district and is home to a number of beautiful hill stations trendy with tourists who flock to them during summer (Nilgiris 2015).

Geologically the district exposes charnockite group of rocks with associated migmatites and Bhavani group along with the enclaves of Sathyamangalam schist complex. The charnockite group is represented by charnockite and pyroxene granulite and covers a major part of the district in the southern part, which is popularly known as "Nilgiri Massif." The Bhavani group (peninsular gneissic complex) comprises fissile hornblende biotite gneiss and occurs in the northern part of the district. The Sathyamangalam schist complex is represented by quartz–sericite/mica schist, ultramafics, and banded magnetite quartzite. The Nilgiri massif is capped by aluminous laterite at a number of places, indicating the deep zone of weathering. Most of the area in the district is deeply weathered, and the development of a thick soil profile attaining a thickness up to 40 m with lithomarge is a common feature. The low gradient of slope in Ooty promotes stagnation of surface water as bogs and swamps. The major soils of Nilgiri district are lateritic soil, red sandy soil, red loam, black soil, and alluvial and colluvial soil (GSI 2000; CGWB 2008).

Geomorphologically, Nilgiri hills rise abruptly from the surrounding plains to an elevation of 1370 m above mean sea level (m.s.l). They are surrounded by the Coimbatore plains in the southeast, Bhavani plains in the northeast, Moyar valley in the north, and Gudalur plateau in the northwest. The prominent hills are Ooty hills, Doddabetta, Kodaibetta, Bhavani Betta, and Devabetta. Doddabetta is the highest peak in Tamil Nadu. Moyar is a prominent river in the district and flows in an easterly direction, along the northern boundary of the district. The drainage is dendritic to radial at places with prominent rapids, cascades, and waterfalls.

The erosional surfaces such as Dodabetta, Ooty, Coonoor, and Moyar are recorded in the district. All these erosional surfaces are capped by residual laterite. The Dodabetta surface includes landform such as high peaks, structural hills, and rocky escarpments with or without soil cover around which prominent radial drainage is developed. The Ooty and Coonoor surfaces include gentle mounds, with soil cover, stream meanderings, and gentle smoothening of the hills. The latter abutts against the former at many places with break in slope. Ground water occurs under discontinuous, unconfined to semi-confined aquifers, down to 200 meter below ground level (m.b.g.l) in the charnockitic terrain and 150 m.b.g.l in the gneissic country rock, restricted to weathered mantle and fractures (GSI 2000).

In Nilgiris the major built-up areas are distributed along the road corridors from Coonoor to Ooty (Udhagamandam). The densely populated placed in this sector are Coonoor, Aruvankadu, Bicketty, Ooty, and Kotagiri (Fig. 1). Landslide Hazard Zonation Atlas of India classified the Nilgiris district from high to severe landslide-prone areas. The landslide activity in the district is almost seasonal during every year.

3 Approach

The present study carried out in three steps: (1) Identification of landslide-susceptible areas using existing data. (2) Superimposing spatial distribution of historical/recent landslide inventories on hazard-prone slopes. (3) Calculation of building vulnerability using different thematic layers derived for the maps in GIS platform.

To identify the landslide hazard-prone areas, the readily available authenticated information from Geological Survey of India (GSI) is used for the present study. GSI produces the Landslide Hazard Zonation Map on macroscale, and this is predominantly a numerical superimposition technique. In this methodology, the following six numbers of major causative factors (lithology, structure, slope morphometry, relative relief, landuse/landcover, and hydrogeological conditions) inducing slope instability independently or interdependently have been taken into consideration. The landslide susceptibility index (LSI) of each area was calculated, and the areas were graded according to the aggregate LSI values (Ganapathy and Rajawat 2015). The area was divided into zones with five grades I to V with increasing susceptibility to landslides (Seshagiri et al. 1982). Zone I is considered to be the least susceptible and zone V the most susceptible (Fig. 2). Since the map was produced in 1982, the occurrences of historical and recent landslides were collected from Geotechnical Cell, Coonoor, Risk Assessment Cell of Chennai with limited field checks. The Geological Survey of India landslide hazard map was further revised by additional landslide information's for the present study.

Built-up areas, road and railways network were digitized from Google Maps (Google 2015) by visual interpretation techniques to identify the preliminary vulnerable areas and infrastructure under high and severe landslide hazard-prone areas (Fig. 2). A detailed

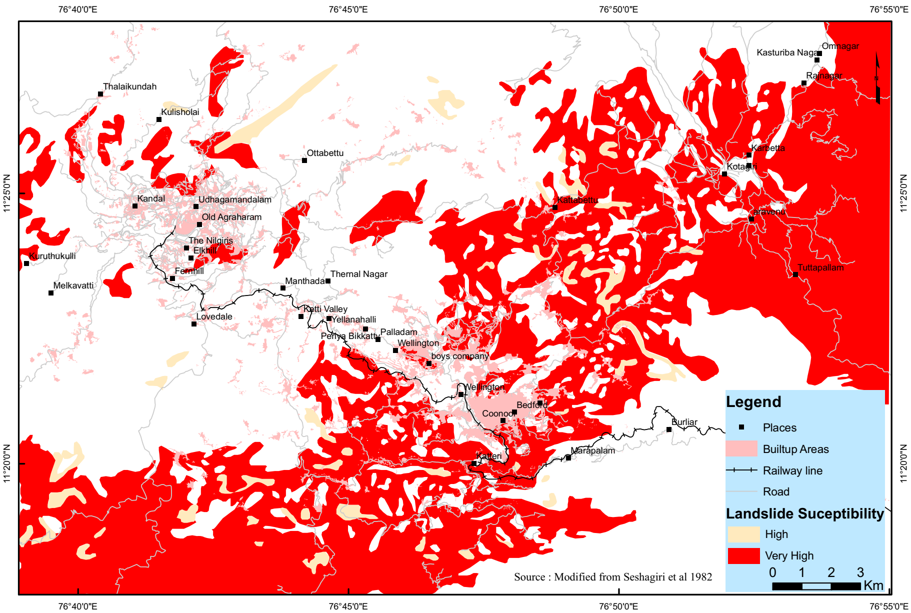

Fig. 2 Landslide hazard and built-up areas

landslide inventory data collected from various sources as well as by limited field investigations used in GIS platform for the study to locate the vulnerable slopes.

For the detailed vulnerability analysis, areas from Burliar to West of Wellington are taken into consideration. The map consists of landslide inventories prepared in a GIS platform to understand the spatial distribution of landslides in the study area. The individual buildings were digitized from Google Maps 2014 data for preparation of building data base. Contour map was prepared by using CartoDEM satellite data for 30-m resolution to understand the slope gradients (Earth Explorer Aster Global 2011). By superimposing the buildings, infrastructure, and landslide inventories, totally 10 segments (Segment A to J) were identified for the detailed vulnerability analysis in the present study area (Fig. 3). Each segments were decided based on the building density, infrastructure, and location of landslide.

Vulnerability assessment includes the user-friendliness of the method, the selection of all the relevant indicators, the transferability of the method, the inclusion of information concerning the hazard itself, the use of GIS technology and the provision of products such as vulnerability maps and the consideration of the temporal pattern of vulnerability (Papathoma-Köhle et al. 2011). To identify the element at risk in landslide-prone areas, first an inventory must be made of the different types of the construction (concrete, masonry, etc.). Secondly, a distinction must be made between elements with special design requirements (e.g., hospitals) and elements for which vulnerability analysis is feasible such as housing. Thirdly, an inventory must be made of prevalent types of buildings and the vulnerable elements like strong high wall, medium high wall, sloping side, number of floors (Papathoma-Köhle et al. 2007).

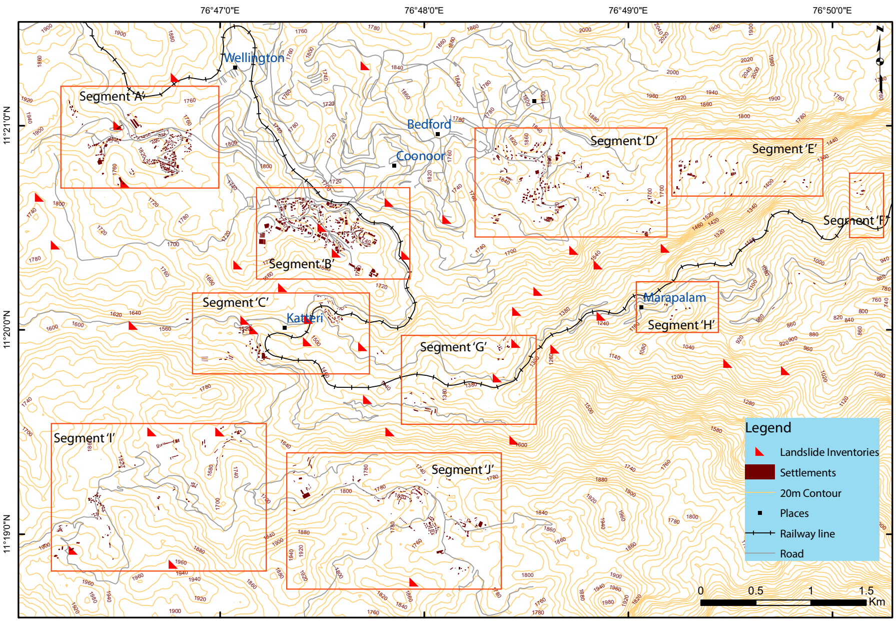

Fig. 3 Segment-wise area considered for vulnerability analysis

A foot print map was prepared from Google Maps to create a digital database for vulnerability study. The thematic layers which contribute to landslide vulnerability are prepared viz. material of the building (concrete/masonry/other), surrounding material (strong high wall/medium wall/no wall), slope side facing buildings (only wall/small windows/large windows), warning signs (yes/no), and floor details (more than 1 floor/one floor). Qualitative and descriptive data were collected on the buildings using limited field checks. The standardization scores (0–1) were determined by using the following formula proposed by Voogd (1983).

$$\text{Standardization score I} = \text{Raw score I/Maximum raw score} \quad (1)$$

For each identity the raw score was assigned and the standardized score was calculated from Eq. 1 and entered in the GIS data base. The different weights were assigned based on the severity contribution to vulnerability assigned for the themes viz., Material—5, Surrounding—4, Slope side 3, Warning—2, Floors—1. The details of the building category, raw score, standardized score, number of building in each category, and their percentage are presented in Table 2.

Papathoma-Köhle et al. (2007) developed a simple methodology (applied for the present study) to calculate the building vulnerability based on the local knowledge parameters, which affect the built environment such as material and age of building, existence of protection wall, existence of facing windows toward slope side, the total number of floors, closeness to transportation corridors, and lifelines. The vulnerability of each building in the landslide inundation zone is calculated from Eq. 2.

$$\text{Vb} = (5 \times a) + (4 \times b) + (3 \times c) + (2 \times d) + (1 \times e) \quad (2)$$

where Vb is vulnerability of the building, (a related to the material of the building; b related to the surroundings of the building; c related to the description of the building's side facing the slope; d related to the existence of warning signs; and e related to the number of floors of the building).

Table 2 Number of buildings in different thematic factors

Factor (weight)	Categories	Raw score	Standardized score	Number of buildings	Percentage
Material (5)	Concrete	1	0.33	842	51.75
	Masonry	2	0.66	785	48.25
	Other (poor)	3	1	0	0.00
Surround (4)	Strong high wall	1	0.33	0	0.00
	Medium wall	2	0.66	380	23.36
	No/low Surrounding wall	3	1	1247	76.64
Slope side (3)	Only wall	1	0.33	1086	66.75
	Small windows	2	0.66	541	33.25
	Large widows	3	1	0	0.00
Warning (2)	No	2	0.5	411	25.26
	Yes	1	1	1216	74.74
Floors (1)	More than one Floor	1	0.5	0	0.00
	One Floor	2	1	1627	100.00

A separate field is created in the attribute table of the GIS file and calculated the vulnerability Vb using field calculator by coding the Eq. 2 and the weight and score used from Table 2. The vulnerability Vb values ranges between 8.28 and 12.28.

4 Discussion

Continuous rainfall from November 7–13, 2009, triggered a total of 1150 landslides in Ooty, Coonoor, and Kotagiri regions of the Nilgiris District and killed 42 people within 48 h, and the total death is 45. Heavy downpour of 36 cm on November 8 and the night of November 9 on the upper slope of the Burliar Reserved Forest and Tiger Hill areas cause extensive damage in the district (Ganapathy and Hada 2012). The approach road to Ooty from Tamil Nadu via Mettupalayam has been severely damaged. Communication and infrastructure came down, and roads and rail lines fell apart. Most of the landslides occurred on the upslopes of the National Highways. From Burliar to Ooty and few of them occurred on the way to Coonoor to Kundah road. The reported deaths were 13, 23, 9 in Ooty, Coonoor, and Kotagiri taluk, respectively. About Indian Rupees 4.5 million was disbursed toward relief amount in these taluks. A total number of 3785 houses were affected, among these 3721 house were partially damaged and 64 houses were fully damaged due to the intense rainfall and landslides in the Nilgiri district. An amount of USD 0.15 million was released by the government toward the relief activity. Totally 32 cattle loss was reported during this activity. About 740 hectares of crops were damaged due to the rain and landslides. A total length of 201 km road, 235 water supply areas, 124 power supplies, and 3082 street lights were affected during this event. The total estimated losses are worth about USD 6 million by a government report (The Hindu 2009).

Chandrasekaran et al. (2012) carried out investigation on infrastructural damages by the November 2009 landslides in two locations Coonoor and Chinnabikkatty of the Nilgiris District. He concluded that the combined effect of surcharge load of building and high pore pressure leads to intense shearing behind retaining walls at Coonoor site. His inferences indicate that occurrence of large displacements along the face and at toe of the slope at Chinnabikatty site. From the field investigations made by the corresponding author in the year 2009, it is clearly revealed that most of the concrete structures with stand the force; however, the masonry structures failed during landslides (Fig. 4).

Fig. 4 Damaged buildings due to 2009 November landslides

The landslide hazard distributed along the road and railway corridors. The areas between Mettupalayam–Coonoor–Ooty are prone to landslide hazard. The present study area lies between Mettupalayam and Coonoor where 90 % of the area under high landslide hazard.

Totally 1627 buildings were identified in different segments for the present study. Out of 1627 buildings, 51.75 % buildings are concrete buildings and 48.25 % of buildings are masonry constructions. A total number of 1247 buildings have no or low surrounding walls, and only 23.36 % of buildings, i.e., 380 buildings, are having medium wall, and there is no strong wall construction in the study area. Totally 1086 buildings have slope side wall and 541 buildings have slope side windows. Among all, a total of 75 % buildings will have landslide-warning sign. Almost all the buildings in the study area have only one floor.

The segment-wise buildings considered for the study are segment A (373), Segment B (313), Segment C (111), Segment D (281), Segment E (58), Segment F (27), Segment G (59), Segment H (23), Segment I (162), and Segment J (220) depicted in Fig. 5. Among all, segments A, B and D are highly congested areas. The estimated vulnerability values ranges from 8.28 to 12.28, and it has been grouped into three categories viz., low, medium, and high vulnerability. Segment 'A' have total 373 buildings, and all these building come under moderate vulnerability. In Segment 'B' 298 buildings falls under moderate category, and only 8 buildings falls in high vulnerability category. The Segment 'C' will totally fall in high vulnerability category (111 buildings). In segment 'D' 179 buildings fall in high and 102 buildings in moderate category. The segments E, F, G, H, I, J have high vulnerability buildings viz, 58, 27, 59, 23, 162, and 220, respectively. Segments E, I, and J have 5, 4, and 19 buildings under moderate. There were only seven and one building under low vulnerability category in Segment B and Segment J. The spatial distribution of vulnerability in the different segments is presented in Fig. 6.

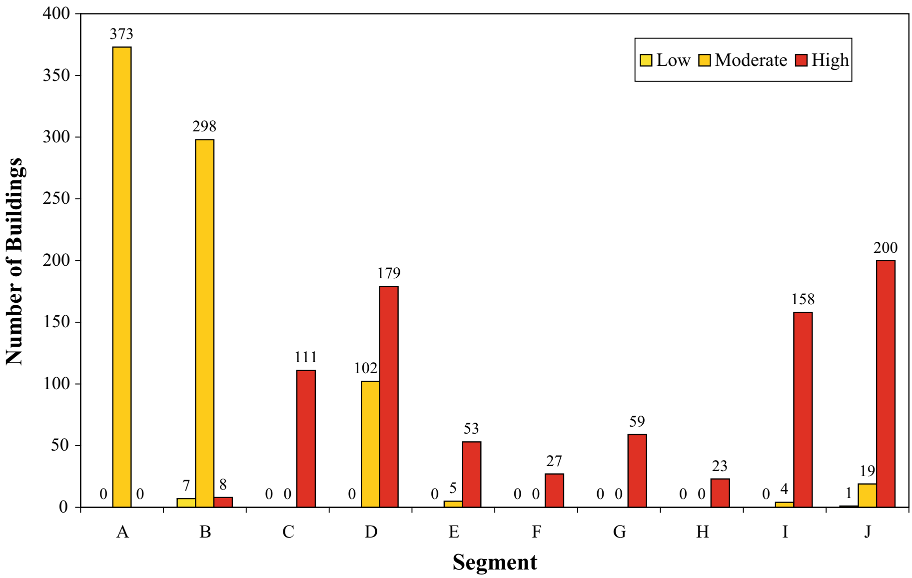

Fig. 5 Segment-wise details of buildings in different vulnerability category

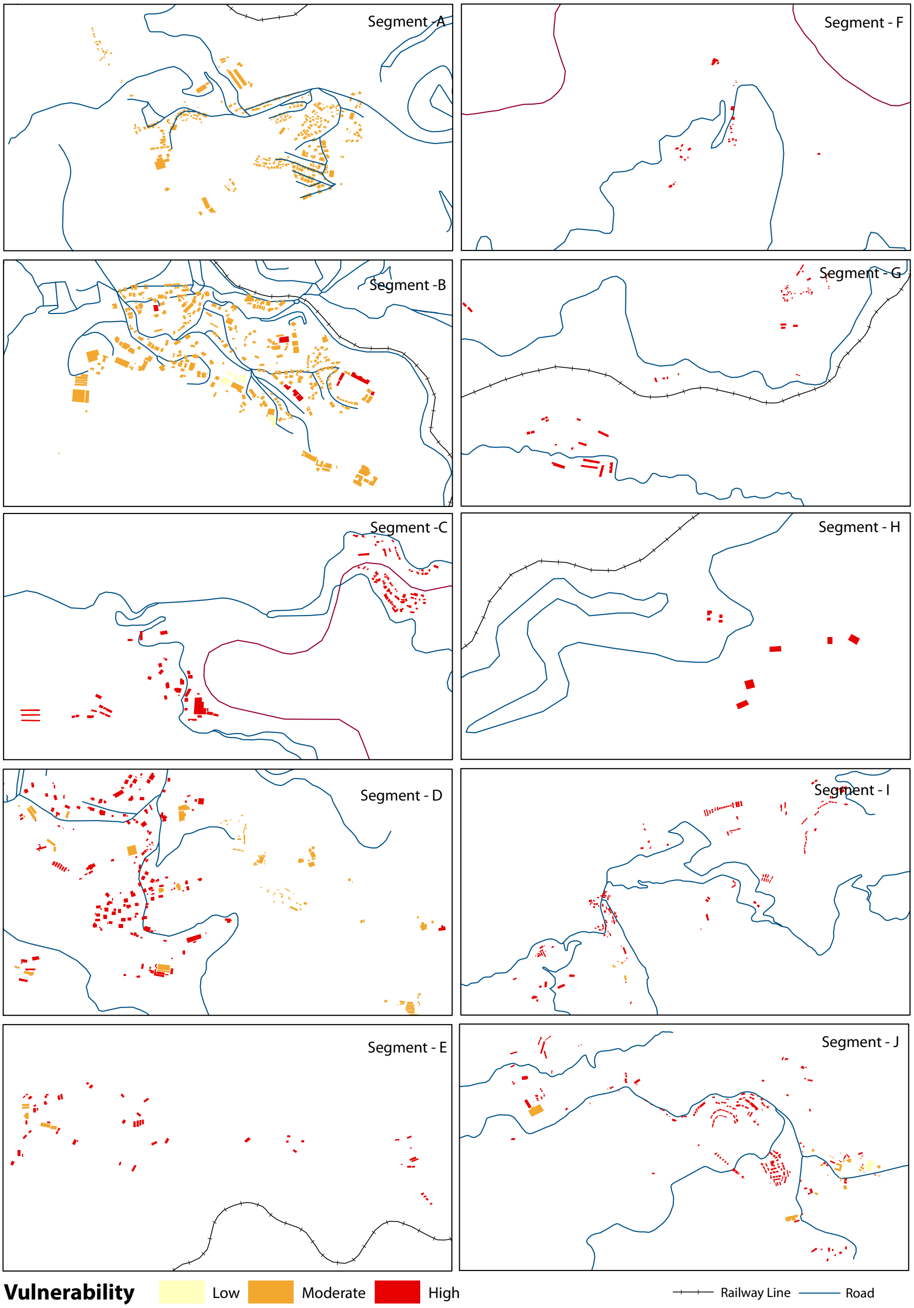

Fig. 6 Spatial distribution of vulnerable buildings in the study area

5 Conclusion

The Mettupalayam to Coonoor sector is identified as one of the high-to-severe landslide-prone areas of the Nilgiris district, Western Ghats of India. The slopes prone to landslides in this sector were identified. The built-up areas were demarcated in hazard-prone areas. About 70 % of the buildings in the study area are in high-to-severe landslide-susceptible areas. Totally 1627 buildings were considered for the vulnerability analysis study. 50 % of the buildings in the study area are prone to high vulnerability, 49 % of buildings are in moderate vulnerability, and only 1 % is in low vulnerability. Out of all, buildings in segment 'J' are more vulnerable, which have 200 buildings; then the segment 'D' has 179 buildings in high vulnerability followed by Segment 'I' having 158 building, and in Segment 'C' all buildings (111) are under high vulnerability. Even though the number of buildings is less in segments F, G, H, however, all buildings in these segments have high vulnerability (Fig. 5).

The present study is for first-level analysis to quantify the vulnerable settlements in the landslide-prone slopes to give early warning to the local administrators' as well as the public. The output of the present study can be used for landslide disaster preparedness in the Mettupalayam to Coonoor areas. The buildings of high vulnerability should have a detailed investigation for retrofitting to prevent failure from landslide initiation. Also this can be used as baseline information to prepare guidelines for setback distance and remedial measures to construct retaining wall, etc. The present study is based on limited field checks, and the quality and strength of the buildings are not studied through any instrumental techniques due to the fund constrain. The present study is the first of its kind for the Nilgiris District, and the methodology can be applicable for the whole district and can be a useful document for mitigation planning as well as preparedness to landslides in the district. The people in the high vulnerability areas should be trained for landslide response, and an efficient landslide-monitoring system can be implemented in these areas.

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References

Akbas SO, Blahut J, Stcrlacchini S (2009) Critical assessment of existing physical vulnerability estimation approaches for debris flows. In: Proceedings of the international conference on landslide processes: from geomorphological mapping to dynamic modeling, 6–7, France. Chapter 4, pp 229–233

Antony Ravindran A, Mohd Abdul Kadar Prabhu H (2012) Prediction and control of landslide using W-4 System—2D electrical resistivity imaging technique in Pudukadu, Ooty, Nilgiri. Asian Research Publishing Network, vol 1, no. 2. ISSN 2305-493X

Ardizzone F, Cardinali M, Guzzetti F et al (2008) Landslide hazard assessment, vulnerability estimation, and risk evaluation at the basin scale. In: Proceedings of the first landslide forum, University Nations University, Tokyo, pp 71–74

Bairavi S, Muthukumar M, Gurugnanam B et al (2014) Assessment of influenciable landuse/landcover for landslides study—a remote sensing and GIS approach. Int J Remote Sens Geosci 3(1). ISSN 2319-3484

Bhandari RK (2006) The Indian Landslide Scenario, Strategic Issues and Action Points, (A Key Note address—Technical Session on Landslides) First India Disaster Management Congress, New Delhi, pp 29–30

Bhandari RK (2013) Challenges of the devastating indian landslides. Curr Sci. Guest Editorial, vol 105, no. 510

Blöchl A, Braun B (2005) Economic assessment of landslide risks in the Schwabian Alb, Germany-research framework and first results of homeowners and experts surveys. Nat Hazards Earth Syst Sci 5:389–396

BMTPC (2003) Landslide Hazard Zonation Atlas of India, Published by Building Materials and technology Promotion Council. Government of India and Anna University, Chennai, p 125

CGWB (2008) District Groundwater Brochure Nilgiri District, TAMIL NADU, Technical Report Series. Government of India published by Ministry of Water Resources, Central Ground Water Board, South Eastern Coastal Region, Chennai, p 21

Chandrasekaran SS, Sayed Owaise R, Ashwin S et al (2012) Investigation on infrastructural damages by rainfall-induced landslides during November 2009 in Nilgiris, India. Nat Hazards 65:1535–1557. doi:10.1007/s11069-012-0432-x

Chong Shi, Yu-Long Zhang, Wei-Ya Xu et al (2013) Risk analysis of building damage induced by landslide impact disaster. Eur J Environ Civ Eng, vol 17, Supplement 1. Special Issue: Geotechnical issues in civil and environmental engineering s126–s143. doi:10.1080/19648189.2013.834590

Ciurean RL, Schroter D, Glade T (2013) Conceptual frameworks of vulnerability assessments for natural disasters reduction. doi:10.5772/55538

Corominas J, Van Westen C, Frattini P et al (2014) Recommendations for the quantitative analysis of landslide risk. Bull Eng Geol Environ 73:209–263. doi:10.1007/s10064-013-0538-8

Dai FC, Lee CF, Ngai YY (2002) Landslide risk assessment and management: an overview. Eng Geol 64:65–87

Du J, Yin K, Nadim F et al (2013) Estimation quantitative de la vulnérabilité aux glissements de terrain. Quantitative vulnerability estimation for individual landslides. In: Proceedings of the 18th international conference on soil mechanics and geotechnical engineering, Paris, pp 2181–2184

Earth Explorer Aster Global DEM (2011) ASTER GDEM is a product of METI and NASA. http://earthexplorer.usgs.gov/ (accessed on 02.05.2015)

EM-DAT (2015) The OFDA/CRED International Disaster Database, Summarized Table of Natural Disasters in India from 1900 to 2014. http://www.emdat.be/result-country-profile/

Erener A, Düzgün HSB (2011) A GIS and RS-based quantitative vulnerability assessment for rainfall triggered landslides. In: 34th international symposium on remote sensing of environment. The GEOSS Era: Towards Operational Environmental Monitoring. Sydney, Australia. http://www.isprs.org/proceedings/2011/ISRSE-34/

Finlay PJ (1996) The risk assessment of slopes. School of Civil Engineering, PhD thesis, University of New South Wales, Australia

Galli M, Guzzetti F (2007) Landslide vulnerability criteria: a case study from Umbria, central Italy. Environ Manage 40(4):649–664

Ganapathy GP (2013) Landslide hazard mitigation in the Nilgiris District of Western Ghats, India. Disaster Adv 6(3w):1–3

Ganapathy GP, Hada CL (2012) Landslide hazard mitigation in the Nilgiris District, India. Environ Soc Issues Int J Environ Sci Dev 3(5):497–500

Ganapathy GP, Jothimani P (2009) Hazard estimation and first level landslide risk mapping—a case study, Burliar Area of the Nilgiris District in Western Ghats. In: Abstracts of the "Geomatics 2009" national conference, Dehradun, pp 4–6

Ganapathy GP, Rajawat AS (2015) Use of hazard and vulnerability maps for landslide planning scenarios: a case study of the Nilgiris, India. Nat Hazards 77(1):305–316. doi:10.1007/s11069-015-1587-z

Ganapathy GP, Mahendran K, Sekar SK (2010) Need and urgency of landslide risk planning for Nilgiri District, Tamil Nadu State, India. Int J Geomat Geosci 1(1). ISSN 0976–4380

Gilberto CG (2006) Linkages between vulnerability, resilience, and adaptive capacity. Glob Environ Change 16:293–303

Gomathi R, Ram Mohan V, Backiaraj S (2013) Landslide Susceptibility Zonation in Kavithole and Kukalthurai halla watershed in Northern part of Nilgiris district. Int J Basic Life Sci 1(6):27–33

Google (2015) Google Maps. Google, Imagery @ 2015 CNES/Astrium,DigitalGlobe, Map (data accessed on 05 Mar 2015)

GSI (2000) District Resource Map Series: Nilgiri District Tamil Nadu, published by Geological Survey of India—explanatory Note

Gurugnanam B, Arunkumar M, Venkatraman ATVR et al (2013) Assessment on landslide occurrence: a recent survey in Nilgiri, Tamilnadu, India. Int J Sci Environ Technol 1252–1256

Guzzetti F, Galli M, Reichenbach P et al (2005) Landslide hazard assessment in the Collazzone area, Umbria, Central Italy. Eur Geosci Union Nat Hazards Earth Syst Sci 6:115–131. SRef-ID: 1684-9981/nhess/2006-6-115

Imiriland (2000) Impact of large landslides in the mountain environment: identification and mitigation of risk contract no. EVG1-CT-2000- 00035. Deliverable, D16, Relevant criteria to assess vulnerability and risk, Report, p 10

Jaiswal P, Van Westen CJ (2009) Probabilistic landslide initiation hazard assessment along a transportation corridor in the Nilgiri area, India. Geophys Res Abstr 11. EGU2009-2854, EGU General Assembly

Jaiswal P, Van Westen CJ, Jetten V (2010a) Quantitative assessment of direct and indirect landslide risk along transportation lines in southern India. Nat Hazards Earth Syst Sci 10:1253–1267. doi:10.5194/nhess-10-1253-2010

Jaiswal P, Van Westen CJ, Jetten V (2010b) Quantitative landslide hazard assessment along a transportation corridor in southern India. Eng Geol 116(3–4):236–250

Jaiswal P, Van Westen CJ, Jetten V (2011a) Quantitative assessment of landslide hazard along transportation lines using historical records. J Landslides 8:279–291. doi:10.1007/s10346-011-0252-1

Jaiswal P, Van Westen CJ, Jetten V (2011b) Quantitative estimation of landslide risk from rapid debris slides on natural slopes in the Nilgiri hills, India. Nat Hazards Earth Syst Sci 11:1723–1743. doi:10.5194/nhess-11-1723-2011

Manimaran G, Antony Ravindaran A, Selvam S et al (2012) Characterization and disaster management of landslides in the Nilgiris mountainous terrain of Tamil Nadu, India. Int J Geomat Geosci 3(1):1–12

Marty C (2003) Natural hazards and risk in mountains: the potential impacts of climate change, mountain hazards. WSL Institute for Snow and Avalanche Research SLF Davos, Switzerland, pp 32–35

Mavrouli O, Fotopoulou S, Pitilakis K et al (2014) Vulnerability assessment for reinforced concrete buildings exposed to landslides. Bull Eng Geol Environ. doi:10.1007/s10064-014-0573-0

Muthukumar M (2013) GIS based Geosystem response modeling for landslide vulnerability mapping parts of Nilgiris, South India. Disaster Adv 6(7):58–66

Nalina P, Meenambal T, Sathyanarayan Sridhar R (2014) Slope stability analysis of Kallar–Coonoor hill road stretch of the Nilgiris. J Comput Sci 10(7):1107–1114. doi:10.3844/jcssp.2014.1107.1114

Naveen Raj T, Ram Mohan V, Backiaraj S et al (2011) Landslide Hazard Zonation using the Relative effect method in South Eastern part of Nilgiris, Tamilnadu, India. Int J Eng Sci Technol 3(4):3260–3266

Neil Adger W (2006) Vulnerability. Glob Environ Change 16:268–281

Nilgiris (2015) http://nilgiris.nic.in/disaster.htm

Papathoma-Köhle M, Neuhäuser B, Ratzinger K et al (2007) Elements at risk as a framework for assessing the vulnerability of communities to landslides. Nat Hazards Earth Syst Sci 7:765–779

Papathoma-Köhle M, Kappes M, Keiler M et al (2011) Physical vulnerability assessment for alpine hazards state of the art and future needs state of the art and future needs. Nat Hazards 58:645–680. doi:10.1007/s11069-010-9632-4

Pascale S, Sdao F, Sole A (2010) A model for assessing the systemic vulnerability in landslide prone areas. Nat Hazards Earth Syst Sci 10:1575–1590. doi:10.5194/nhess-10-1575-2010

Prabu S, Ramakrishnan SS (2012) Combined use of socio economic analysis, remote sensing and GIS data for landslide hazard mapping using ANN. J Indian Soc Remote Sens 37(3):409–421. doi:10.1007/s12524-009-0039-1

Pradeep Kishore V, Lakshumanan C, Viveganandan S et al (2012) Evaluation of Limit equilibrium method for Landslide Susceptibility Analysis (LSA)—A case study on Nilgiris district. Int J Adv Remote Sens GIS 1(2):234–243

Rajakumar R, Sanjeevi S, Jayaseelan G et al (2007) Landslide susceptibility Mapping in a Hilly Terrain using Remote Sensing and GIS. J Indian Soc Remote Sens 35(1)

Rajarathnam S, Ganapathy GP (2006) Landslide hazard zonation of India, a GIS approach. In: Proceedings of the first india disaster management congress, New Delhi, pp 29–30

Ramakrishnan SS, Sanjeevi Kumar V, Zaffar Sadiq MGSM et al (2002) Landslide disaster management and planning—a GIS based approach. Indian Cartographer, MFDM-05, pp 193–195

Rondón EM, Cho GC (2012) Structural vulnerability index to the effects of landslides in masonry buildings based on fuzzy sets. Rev Ing Constr 27(1):23–39

SAARC (2010) SAARC Workshop on Landslide, Risk Management in South Asia, Thimpu, Bhutan. SAARC Disaster Management centre, New Delhi

Seshagiri DN, Badrinarayanan S, Upendran R et al (1982) The Nilgiris landslide—miscellaneous publication No. 57. Geological Survey of India

Sharda YP (2008) Landslide studies in India, Glimpses of Geoscience Research in India, The Indian report to IUGS 2004-2008. Indian National Science Academy, Silver jublie, pp 98–101

Silva M, Batcira C, Pcrcira S (2011) Vulnerability Assessment of Buildings and Roads to Shallow Translational Landslides in Santa Marta de Penaguiao, Vila Real, Portugal. Geophys Res Abstr, vol 13. EGU2011-13070-2

Sunandana Reddy M, Lakshmikanta Reddy K (2013) Image processing and DEM of spatial information technology in landslide vulnerable mapping. Int J Electron Commun Comput Eng 4(6). NCRTCST-2013, ISSN 2249-071X

Thanavelu C, Chandrasekaran (2008) Geotechnical assessment of November 2006 landslides in the Nilgiris Tamil Nadu, Abstract Volume. In: Proceedings of the national seminar on challenges in engineering geology, 03rd to 05th December 2008, Hyderabad

The Hindu (2009) Scale of damage in Nilgiris huge, relief work space. http://www.thehindu.com/2009/11/12/stories/2009111258110100.htm (accessed on 12.11.2009)

UNDRO (1991) Mitigating natural disasters, phenomena, effects and options, a manual for policy makers and planners. A publication within the framework of the International Decade for Natural Disaster Reduction (IDNDR), 1990–1999, New York

Uzielli M, Catani F, Tofani V et al (2015) Risk analysis for the Ancona landside-II: estimation of risk to buildings. Landslides (2015) 12:83–100. doi:10.1007/s10346-014-0477-x

Vaani N, Sekar SK (2012) Regional landslide hazard zonation and vulnerability analysis using AHP and GIS—a case study of Nilgiris District, Tamil Nadu, India. J Disaster Adv 5(4):171–176

Van Westen CJ, Saibal Ghosh, Pankaj Jaiswal et al (2011) From landslide inventories to landslide risk assessment; an attempt to support methodological development in India. In: Proceedings of the second world landslide forum, 3–7 Oct 2011, Rome

Vasantha Kumar S, Bhagavanulu DVS (2007) Effect of deforestation on landslides in Nilgiris District—a case study. J Indian Soc Remote Sens 36:105–108

Voogd H (1983) Multi criteria evaluation for urban and regional planning. Pion Limited, London, p 367