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Landslides induced vulnerability and risk assessment in Muzaffarabad and Balakot, Pakistan

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Abstract

The 8th October 2005 Kashmir earthquake (7.6 Mw) triggered thousands of landslides in the Muzaffarabad and Balakot, Pakistan. This study aims to evaluate landslide induced vulnerability and risk to the buildings. Building footprint maps were developed from satellite image (SPOT-5) and required attributes such as construction material, roof material, building use, building height and household's data were collected from field visits. Quantitative method was used to assess the landslide induced vulnerability and risk in the area. The number of buildings located in high, moderate and low susceptibility zone were estimated by crossing the landslide susceptibility map and building footprint map. Landslide hazard probability was calculated as a result of combining landslide susceptibility map and landslide return period map. Spatial probability was determined by calculating cumulative landslide area in each susceptibility class. Absolute vulnerability of the buildings was multiplied with landslide spatial probability to derive the total loss for different return-period scenarios and shown in a risk curve. The study shall help the concern agencies to mitigate the devastating impacts of landslides.

Keywords: Landslides; Vulnerability; Risk buildings; Muzaffarabad; Balakot.

1. Introduction

Landslides are one of the frequent and devastating natural hazard in mountainous regions around the world (Gaurav, 2009). Followed by floods and earthquakes, landslides are recognized as the third most devastating natural disaster (Castellanos Abella, 2008). The spatial distributions of landslides are strongly controlled by the causative factors including tectonic features, lithology, geomorphology, topography, temperature, infiltration, runoff, deforestation and anthropogenic activities (Kamp et al., 2008; Owen et al., 2008). The temporal distributions of landslides are determined mainly by the triggering factors including earthquake and rainfall (Shafique et al., 2016).

The 2005 Kashmir earthquake with a magnitude of 7.6 Mw, has triggered thousands of landslides in the affected area. Assessing and evaluating landslide induced vulnerability is of significant importance to develop and implement landslide mitigation strategies (Gaurav, 2009). However, assessing landslide induced vulnerability and risk is a complex process and requires knowledge on the building characteristics, landslide nature, frequency and return period which is often difficult to acquire over a regional scale. Therefore, often the landslide vulnerability of building is simply taken as 1, assuming complete destruction of the elements at risk (Van Westen, 2012). Whereas, quantitative risk assessment requires data related to the probability of landslide occurrence, characteristics of the elements at risk, and expected degree of loss to these elements at the given magnitude of the landslide (Jaiswal et al., 2011).

Remote Sensing and GIS are effectively used to assess the landslide induced hazard, vulnerability and risk at a regional scale (Van Westen, 2004). The availability of landslide hazard and risk map is essential to demarcate the potential areas of landslide losses and to minimize their societal impact. The prerequisite of the landslide vulnerability and risk assessment is the preparation of landslide susceptibility map, when combined with temporal information, this can be converted into a landslide hazard map. The landslide hazard map can be used in combination with elements at risk information for estimating potential losses due to landslides (Martha et al., 2013).

Many researchers have worked at different aspects of Kashmir earthquake induced landslides using satellite imageries and GIS techniques to evaluate landslide hazard in Muzaffarabad and Balakot (Sato et al., 2007; Owen et al., 2008; Kamp et al., 2008; Kamp et al., 2010; Khattak et al., 2010; Saba et al., 2010; Lodhi, 2011; Basharat et al., 2012; Khan et al., 2013; Basharat et al., 2014). All these studies have mainly focused on the landslide mapping, evaluating their spatial and temporal distribution and susceptibility analysis; however, the landslide induced vulnerability to the elements at risk (buildings) and risk assessment is being ignored so far. The aim of this study is to utilize GIS and remote sensing to evaluate landslide induced vulnerability and risk to the buildings.

2. Study area

The study area is comprised of Balakot and Muzaffarabad, which were severally devastated by the Kashmir earthquake. Three rivers drain the study area; the Kunhar, the Jhelum and Neelum Rivers. Balakot is situated at the bank of river Kunhar in the lower contact of Himalayan Ranges and Muzaffarabad is located at the confluence of Jhelum and Neelum Rivers (Fig.1).

The study area has a monsoonal climate and rainy season starts from late June till August. These rains often cause floods and landslides. During the winter, precipitation falls as snow at elevations above 1500 m asl. Some of the active landslides in the study area are shown the figure 2.

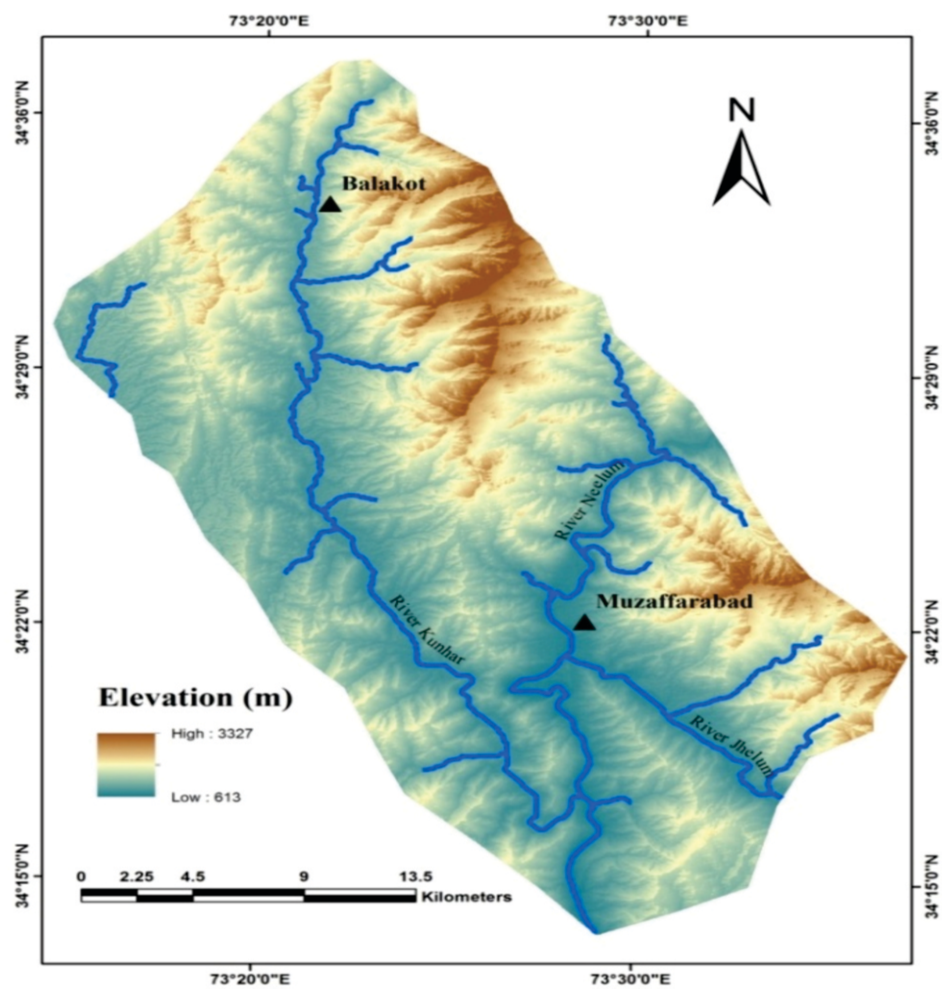

Fig.1. Location map of the study area.

3. Materials and methods

3.1. Preparation of building footprint maps

Satellite image of SPOT 5 (spatial resolution 2.5 m, acquisition date 9th October 2014) was used to develop buildings footprint maps of Balakot and Muzaffarabad using ArcGIS software. Individual buildings were digitized as polygons. In the study area, a total of 20007 buildings were digitized from the satellite image with 9915 buildings in Balakot and Garhi Habibullah (Fig. 3) and 10488 buildings in Muzaffarabad (Fig. 4). The mapped building foot prints were subsequently verified in the field and modified accordingly. In the field, random buildings were visited to collect information about their construction materials, roof materials, building use and number of floors.

Fig. 2. Settlements on landslide prone areas (a) Balakot (b) Lower Shiwai (C) Muzaffarabad and (d) Shagai village.

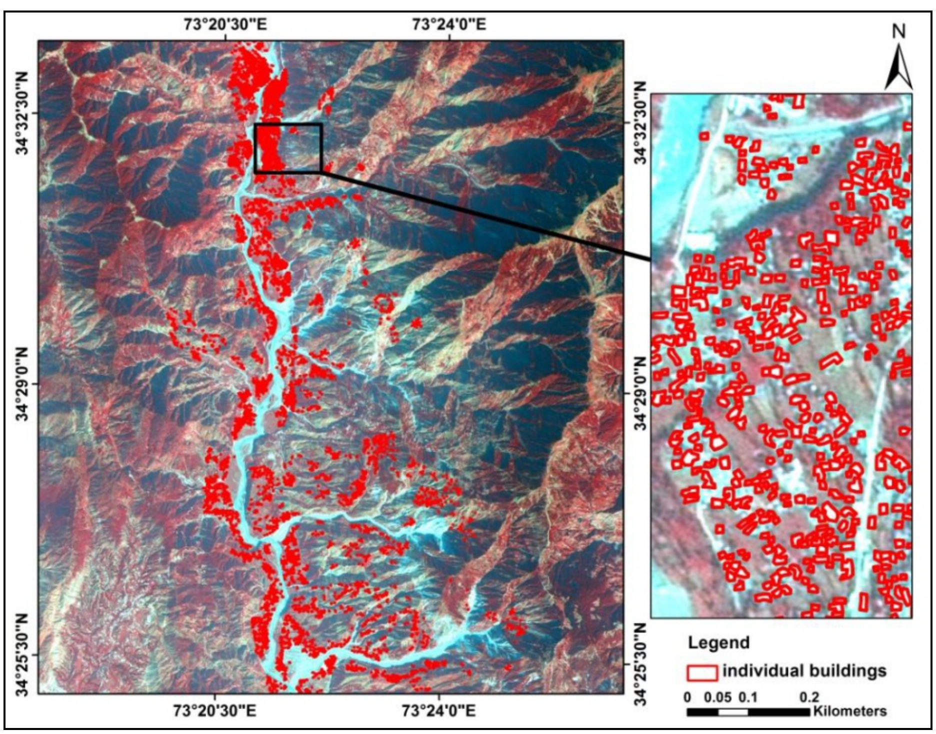

Fig. 3. Buildings foot print map in Balakot and Gari Habibullah.

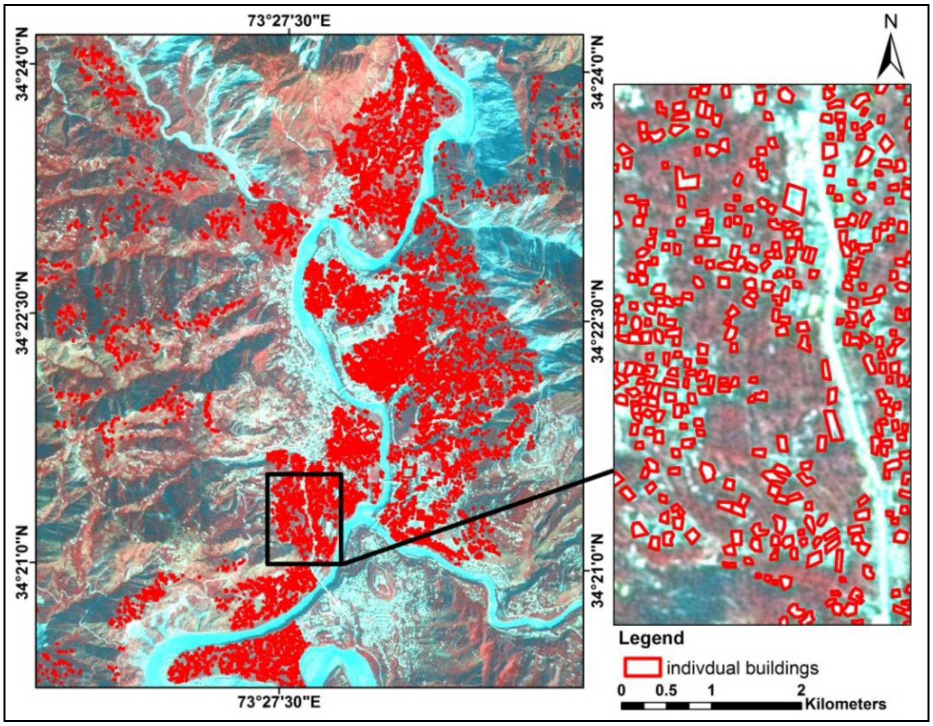

Fig. 4. Buildings foot print map in Muzaffarabad.

3.2. Methodology

Quantitative approach was used for landslide risk assessment. The concept of risk that has been applied to landslide studies, can be expressed by the following general equation proposed by Van Westen (2012).

$$\text{Landslide risk} = H \times V \times A \qquad (1)$$

Where, H is Hazard, V is Vulnerability and A is the amount. The term hazard represents spatial and temporal probability of landslide event. Therefore, we introduce spatial and temporal probability in the equation.

$$\text{Landslide risk} = Pt \times Ps \times V \times A \qquad (2)$$

In this research using the equation 2, a semi quantitative approach is applied for the calculation of amount of buildings in different susceptibility zones. The landslide susceptibility map is crossed with the building footprint map and the number of houses according to the building types were calculated in high, moderate and low susceptibility zones. The second part of the analysis deal with a quantitative approach for landslide risk assessment. To calculate the landslide hazard probability, spatial and temporal probabilities of landslides were derived using the following equations.

$$\text{Spatial probability} = \text{cumulative landslide area / class area} \qquad (3)$$

$$\text{Temporal Probability} = 1/ \text{return period} \qquad (4)$$

For this purpose, the susceptibility map was crossed with the landslides return period map. The following queries were used for the calculation of landslide area in low, moderate and high susceptibility class.

Area_low= iff(susceptibility = “low”, area, 0)

Area_moderate=iff (susceptibility = “moderate”, area, 0)

Area_high= iff(susceptibility=“high”, area, 0)

3.2.1. Estimating vulnerability

Vulnerability values were assigned to each building according to the building type and floor space. Floor space of each building was calculated using equation 5.

Floor space area of building × number of floors (5)

To assign vulnerability values, the floor space values of the buildings were classified in five classes (very small, small, medium, large and very large) according to their cumulative percentages. Using the histogram of the floor space map, cumulative percentages of the floor space were calculated using equation 6, after Van Westen (2012).

$$Perc\_cum = npixcum / total\ number\ of\ pixels\ (area) \times 100 \quad (6)$$

Vulnerability values were assigned to each class after classification of the building floor space. A 2D table was created and the vulnerability values were applied for each class. In the table 3, the damage percentages are given as a function of the building type and size.

4. Results and discussions

4.1. Types of building structure

Building material in the study area is given in table 4 and shown in figures 5 and 6.

Table 1. Classification of floor space values in Muzaffarabad.

Floor space class	Cumulative percentage	Floor space value (upper boundary)
Very small	20%	174
Small	40%	312
Medium	60%	456
Large	80%	682
Very large	100%	12830

Table 2. Classification of floor space values in Balakot.

Floor space class	Cumulative percentage	Floor space value (upper boundary)
Very small	20%	138
Small	40%	205
Medium	60%	560
Large	80%	804
Very large	100%	20790

Table 3. Building categories in the study area and their vulnerability values.

Building type	Very small	Small	Medium	Large	Very large
Concrete block	1.0	1	0.9	0.7	0.6
Field stone	1.0	1.0	1.0	0.9	0.9
Mud	1.0	1.0	1.0	1.0	1.0
Corrugated iron sheets	1.0	1.0	1.0	0.9	0.9
Wooden	1.0	1.0	1.0	0.9	0.8
Pre-fabricated houses	1	1	1	0.9	0.7
Brick	1.0	0.9	0.8	0.6	0.5

Table 4. Building material in the study area.

Building material	**Total**	**percentage**
Concrete blocks	18424	92.09%
Wooden (shops)	28	0.14%
Mud	490	2.45%
Field stone	772	3.86%
Corrugated iron sheets (shops)	21	0.11%
Pre-fabricated houses	95	0.47%
Mud in brick	209	1.04%
Total buildings	20007	

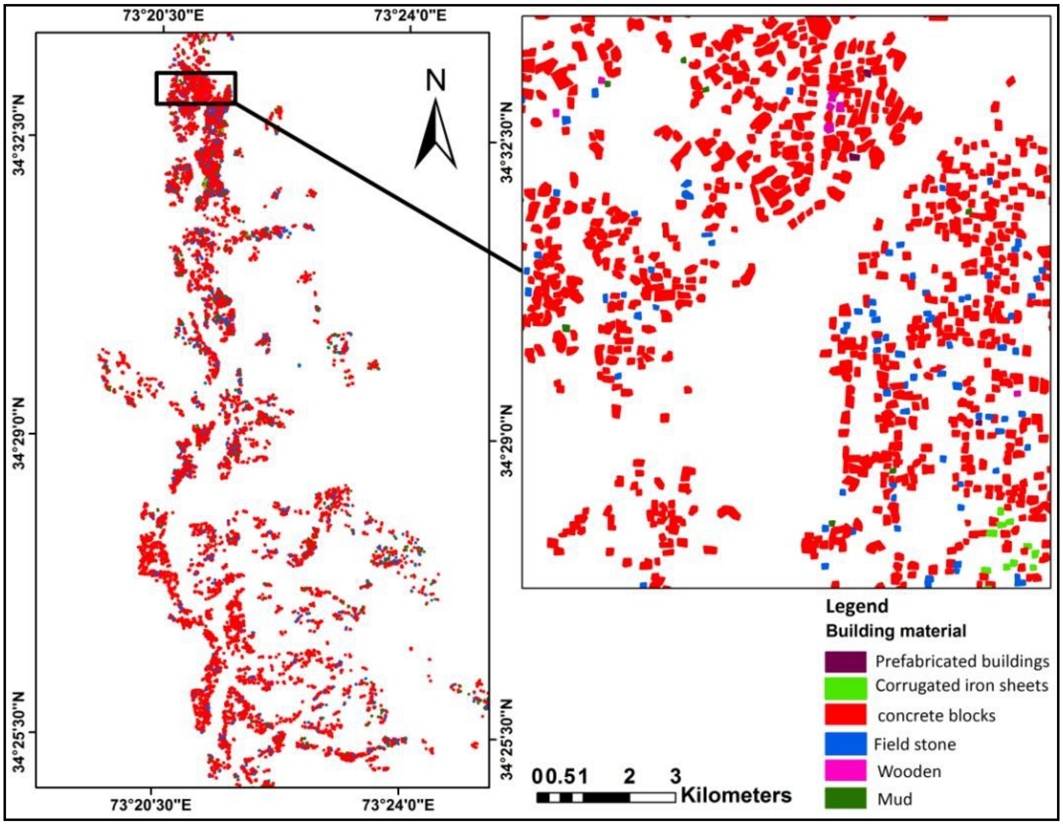

Fig. 5. Spatial distribution of building material in Balakot.

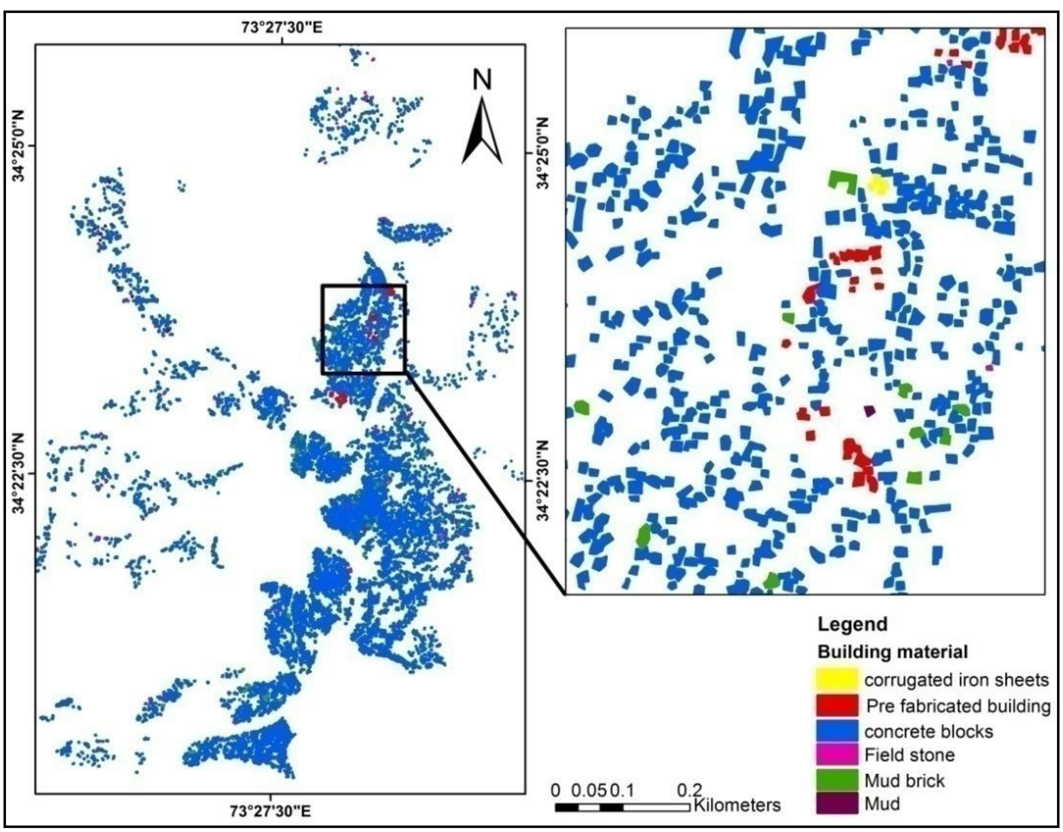

Fig. 6. Spatial distribution of building material in Muzaffarabad.

4.2. Roof material

In the area, 43.17% of the buildings have roof material of cemented reinforced concrete, 50% buildings have corrugated iron sheets and 6.94% have poor roof material made of mud and wood. The results are shown in Table 5 and Figure 7.

4.3. Building heights

In the Balakot, single storey buildings occupy about 79% of the buildings, 21% are double storey buildings, and 0.31% of the buildings are triple storey (Table 6 and Fig. 8).

In Muzaffarabad, the number of building story are shown in Table 7 and Figure 9.

4.4. Building susceptibility assessment

The results achieved through crossing of landslide susceptibility map (Shah, 2015) and buildings foot print map of the shows that in the Muzaffarabad, 7400 buildings are located in the moderate susceptibility class, 1400 buildings are located in the low susceptibility class and 1292 buildings in the high susceptibility class. Their distribution according to their building material in different susceptibility classes is shown in Table 8 and Figure 10.

Table 5. Types of roof material in Balakot and Muzaffarabad.

Roof material	Total	Percentages
Cemented reinforced concrete	8638	43.17%
Corrugated iron sheets	9916	50%
Mud + wooden	1389	6.942%
Pre-fabricated material	95	0.47%
Total	20007	

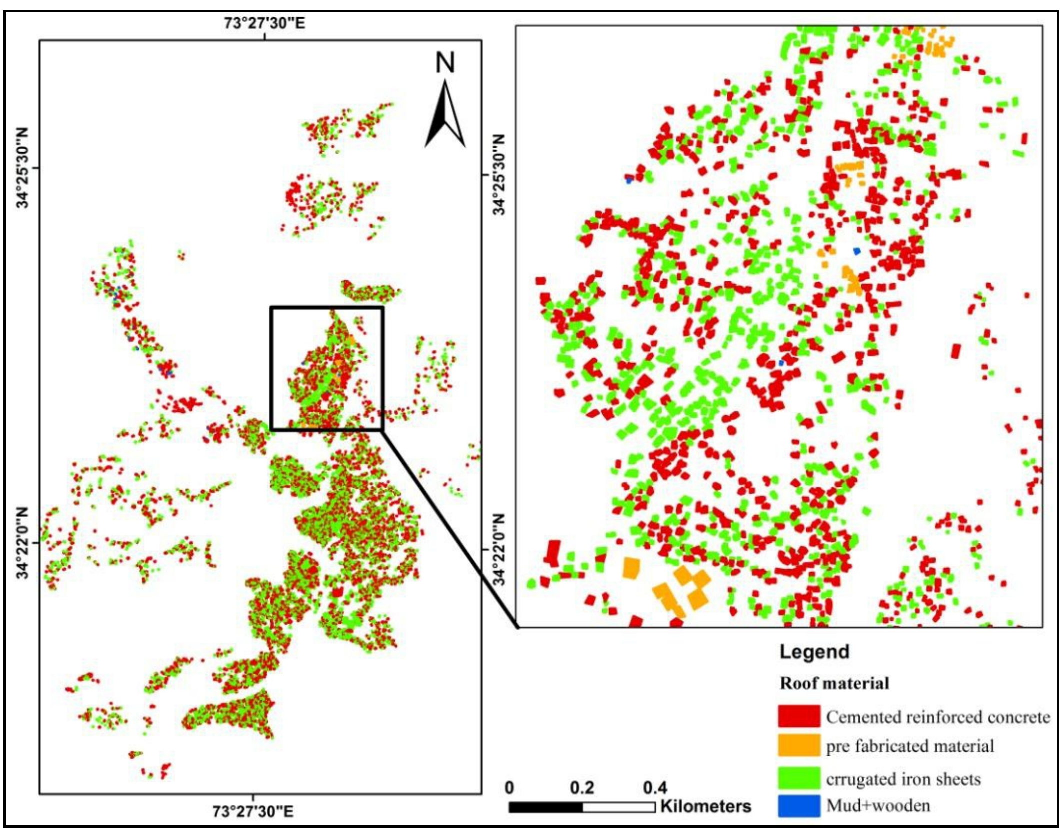

Fig. 7. Spatial distribution of roof material in Muzaffarabad.

Table 6. Number of building storey in Balakot.

Storey	No of buildings	Percentage
Single	7816	79%
Double	2068	21%
Triple	31	0.31%

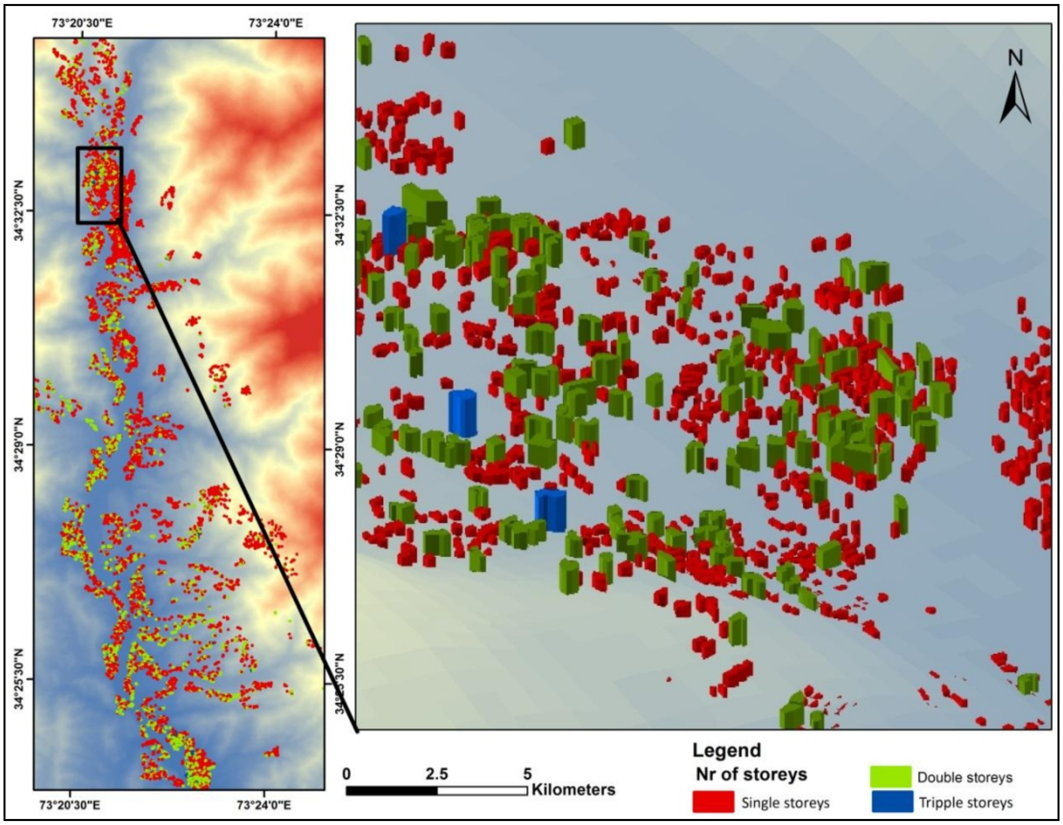

Fig. 8. Spatial distribution of building story in Balakot.

Table 7. Number of building story in Muzaffarabad.

S.No	Storey	No of buildings	Percentage
1	Single	3839	38%
2	Double	5667	56%
3	Triple	584	6%
4	Four	24	0.24%
5	Five	9	0.09%
6	Six	3	0.03%
7	Seven	1	0.01%

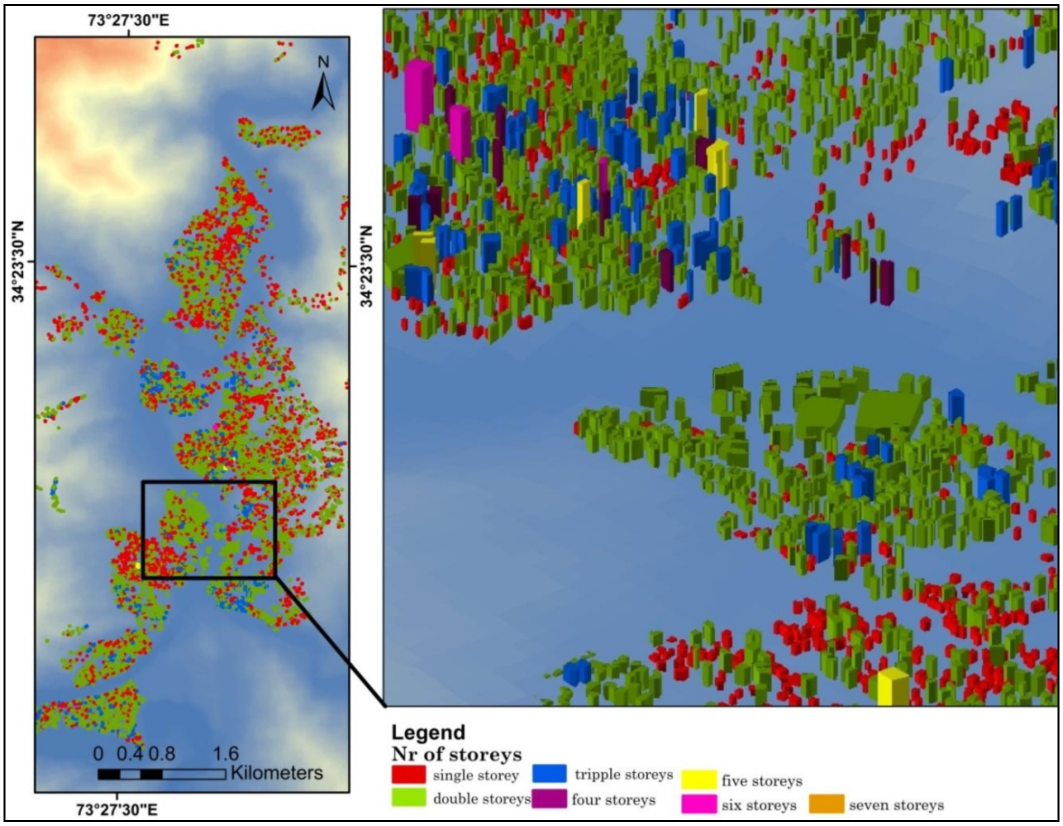

Fig. 9. Spatial distribution of building storey in Balakot in Muzaffarabad.

Table 8. Shows number of buildings in low, moderate and high susceptibility classes in Muzaffarabad.

Susceptibility classes							
Building type	Low	% of building type	Moderate	% of building type	high	% of building type	total per type
Field stone	15	13%	75	65.22%	25	22%	115
Concrete blocks	1366	14%	7112	73.45%	1204	12%	9682
Corrugated iron sheets	0	0%	1	20%	4	80%	5
Mud	5	18.52%	11	40.74%	11	40.70%	27
Pre-fabricated houses	0	0%	39	72%	15	28%	54
Mud brick	14	7%	162	78%	33	16%	209
Total per class	1400		7400		1292		10092
Perc. of total	14%		73%		13%		

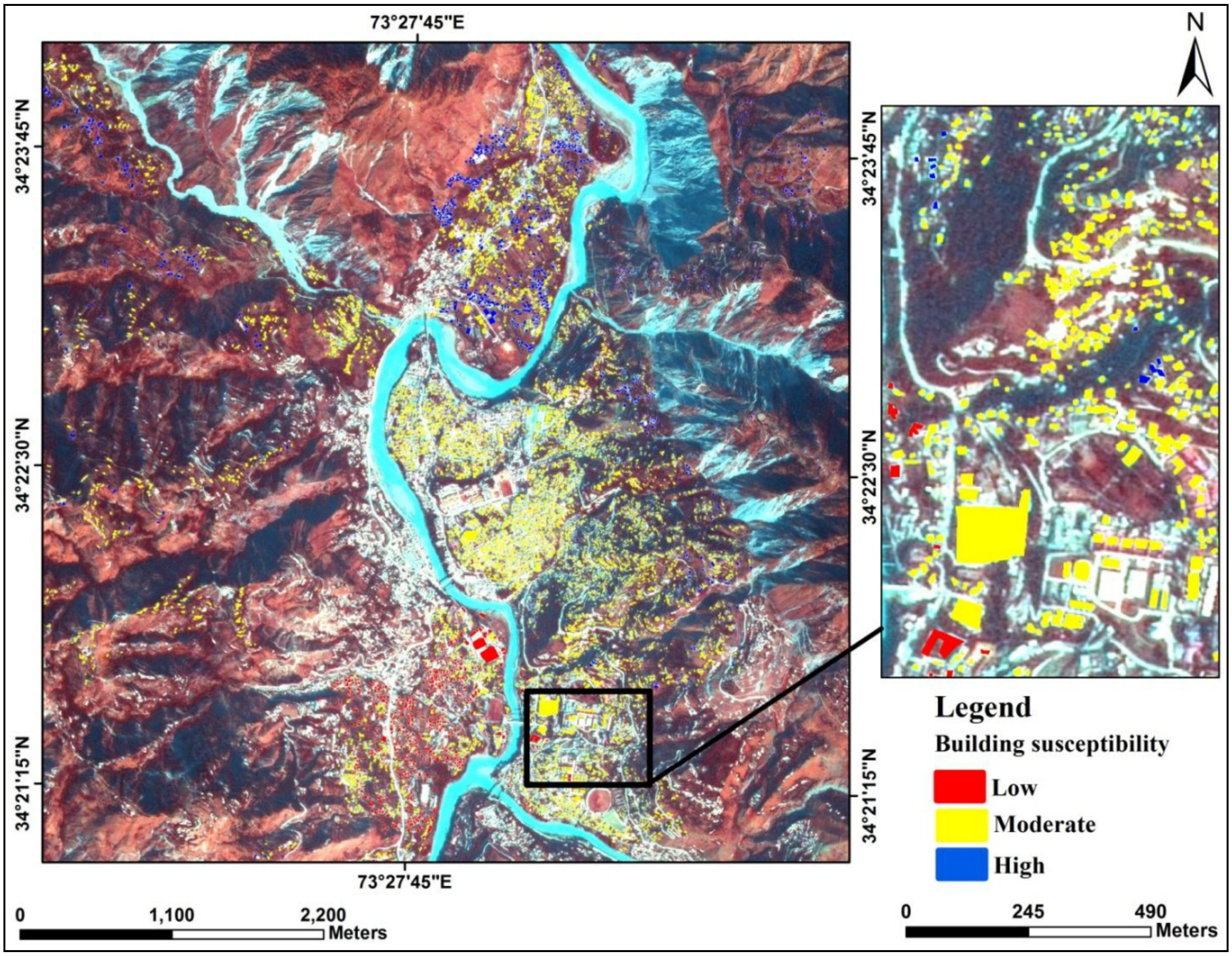

Fig. 10. Building susceptibility to landslides in Muzaffarabad.

Whereas, in Balakot, majority (5417) of the buildings are located in moderate susceptibility class as compared to high (3002) and low (1496) classes. Their distribution according to their building material in different susceptibility classes is shown in Table 9 and Figure 11.

Table 9. Number of buildings in low, moderate and high susceptibility classes in Balakot.

Susceptibility classes							
Building type	Low	% of building type	Moderate	% of building type	High	% of building type	total per type
Concrete blocks	1378	16%	4758	54.62%	2575	30%	8711
Field stone	89	14%	373	56.77%	195	30%	657
Pre-fabricated houses	0	0%	20	50%	20	50%	40
Mud	29	6.26%	237	51.19%	197	42.55%	463
Corrugated iron sheets	0	0%	11	69%	5	31%	16
Wooden	0	0%	18	64%	10	36%	28
total per class	1496		5417		3002		9915
Perc. of total	15%		55%		30%		

4.5. Landslide hazard assessment

Return period scenarios taken for the landslides are 5, 10, 15 and 20 years. The spatial probability of landslide occurrence was estimated for the three susceptibility classes using Equation 3. Spatial probability was determined by calculating cumulative landslide area in each susceptibility class (Table 10 for Muzaffarabad and Table 11 for Balakot).

4.6. Estimating the spatial probabilities

The results show that the landslides with a return period of 1/15 years and 1/20 years have the highest spatial probabilities in high hazard class. In moderate hazard class, 1/20 years return period landslides also have the highest spatial probability. The results are given in table 12.

The analysis done for the estimation of highest spatial probabilities in each hazard class for the study area of Balakot shows that the landslides having 1/15 and 1/20 years return period have the highest spatial probabilities in high hazard class. With increase in return period the landslide induced risk also increases.

4.7. Estimating losses and generating a risk curve

Total building losses have been estimated for different return period scenarios. The required results were achieved by multiplication of spatial probability of landslide occurrence (return period) with the building vulnerability. The total building losses computed for different return periods is shown in Figures 12 and 13.

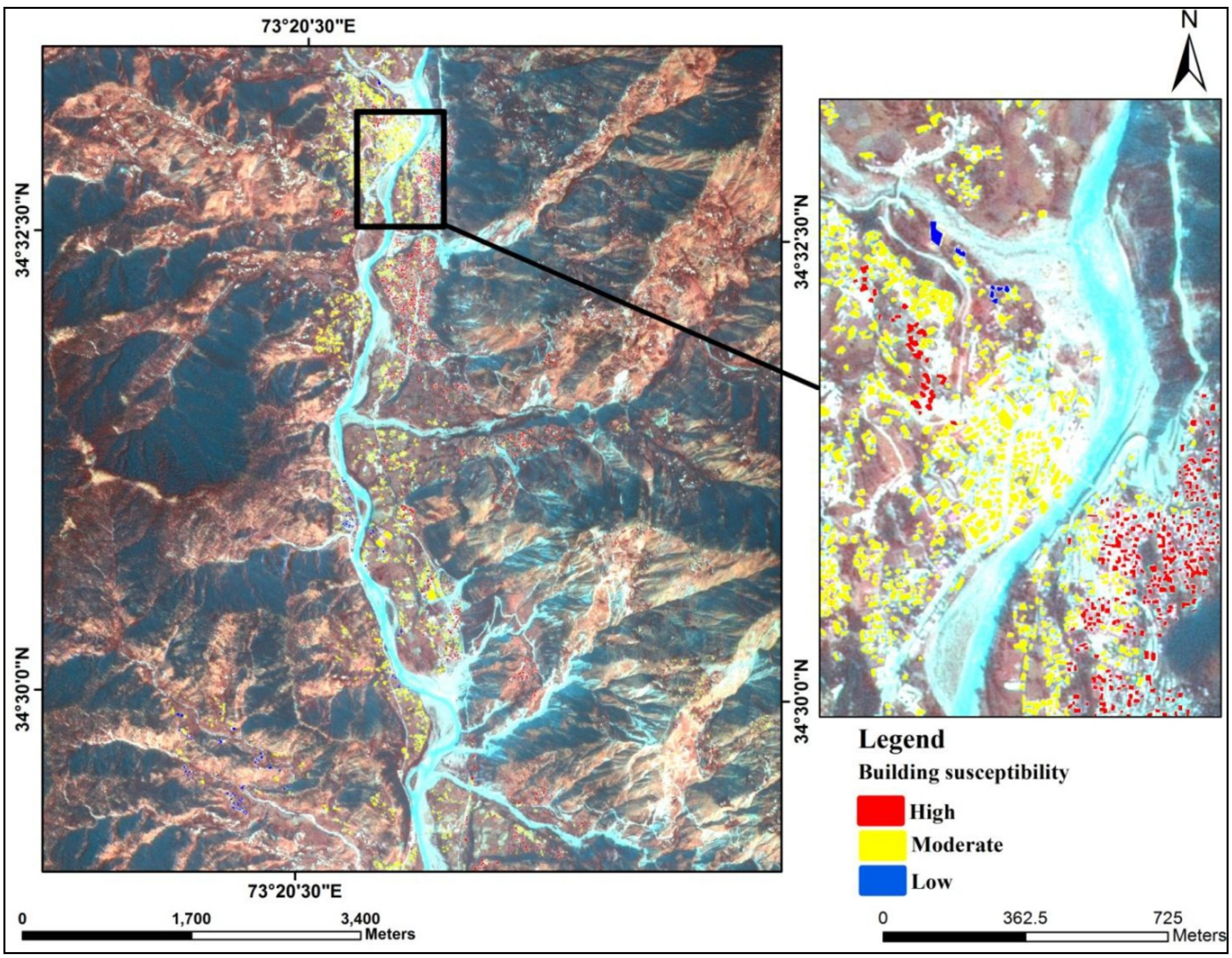

Fig. 11. Building susceptibility to landslides in Balakot.

Table 10. Calculation of high, moderate, and low hazard class in Muzaffarabad.

Hazard		1/05	1/10	1/15	1/20
High	Landslide area	3.22E+06	4.63E+05	3.80E+05	3.88E+05
	cumulative landslide area	3.22E+06	3.68E+06	4.06E+06	4.45E+06
	class area	5.37E+07	5.37E+07	5.37E+07	5.37E+07
	spatial probability Ps (density)	5.99E-02	6.84E-02	7.55E-02	8.28E-02
	Temporal probability Pt	2.00E-01	1.00E-01	6.60E-02	5.00E-02
	Hazard: Pt*Ps	1.19E-02	6.84E-03	4.98E-03	4.14E-03
Moderate	Landslide area	1.80E+05	4.71E+04	1.19E+05	8.28E+05
	cumulative landslide area	1.80E+05	2.27E+05	3.46E+05	1.17E+06
	class area	1.31E+08	1.31E+08	1.31E+08	1.31E+08
	Spatial probability Ps (density)	1.37E-03	1.73E-03	2.63E-03	8.94E-03
	Temporal probability Pt	2.00E-01	1.00E-01	6.60E-02	5.00E-02
	Hazard: Pt*Ps	2.74E-04	1.73E-04	1.74E-04	4.47E-04
Low	Landslide area	0.00E+00	1.46E+04	1.59E+04	1.01E+05
	cumulative landslide area	0.00E+00	1.46E+04	3.05E+04	1.32E+05
	class area	3.27E+07	3.27E+07	3.27E+07	3.27E+07
	spatial probability Ps (density)	0.00E+00	4.44E-04	9.30E-04	4.02E-03
	Temporal probability Pt	2.00E-01	1.00E-01	6.60E-02	5.00E-02
	Hazard: Pt*Ps	0	4.44E-05	6.14E-05	2.01E-04

Table 11. Calculation of high, moderate, and low hazard class in Balakot.

Hazard		1/05	1/10	1/15	1/20
High	Landslide area	2.66E+06	7.54E+05	4.30E+05	1.37E+05
	cumulative landslide area	2.66E+06	3.41E+06	3.84E+06	3.98E+06
	class area	5.94E+07	5.94E+07	5.94E+07	5.94E+07
	spatial probability P_s (density)	4.48E-02	5.74E-02	6.47E-02	6.70E-02
	Temporal probability P_t	2.00E-01	1.00E-01	6.60E-02	5.00E-02
	Hazard= P_t*P_s	8.95E-03	5.74E-03	4.27E-03	3.35E-03
Moderate	Landslide area	1.16E+05	3.56E+05	1.94E+05	5.15E+05
	cumulative landslide area	1.16E+05	4.72E+05	6.66E+05	1.18E+06
	class area	2.64E+08	2.64E+08	2.64E+08	2.64E+08
	spatial probability Ps (density)	4.38E-04	1.79E-03	2.52E-03	4.48E-03
	Temporal probability P_t	2.00E-01	1.00E-01	6.60E-02	5.00E-02
	Hazard= P_t*P_s	8.76E-05	1.79E-04	1.66E-04	2.24E-04
Low	Landslide area	0.00E+00	4.16E+04	7.22E+04	1.84E+04
	cumulative landslide area	0.00E+00	4.16E+04	1.14E+05	1.32E+05
	class area	7.00E+07	7.00E+07	7.00E+07	7.00E+07
	Spatial probability P_s (density)	0.00E+00	5.94E-04	1.63E-03	1.89E-03
	Temporal probability P_t	2.00E-01	1.00E-01	6.60E-02	5.00E-02
	Hazard= P_t*P_s	0	5.94E-05	1.07E-04	9.44E-05

Table 12. Showing the spatial probability of different return periods in each hazard class in Muzaffarabad.

Hazard classes	Spatial probability				
		Spat_prob_5Y	Spat_prob_10Y	Spat_prob_15Y	Spat_prob_20Y
	High	5.99E-02	6.84E-02	7.55E-02	8.28E-02
	Moderate	1.37E-03	1.73E-03	2.63E-03	8.94E-03
	Low	0.00E+00	4.44E-04	9.30E-04	4.02E-03

Table 13. Showing the spatial probability of different return periods in each hazard class in Balakot.

Hazard classes	Spatial probability				
		Spat_prob_5Y	Spat_prob_10Y	Spat_prob_15Y	Spat_prob_20Y
	High	4.48E-02	5.74E-02	6.47E-02	6.70E-02
	Moderate	4.38E-04	1.79E-03	2.52E-03	4.48E-03
	Low	0.00E+00	5.94E-04	1.63E-03	1.89E-03

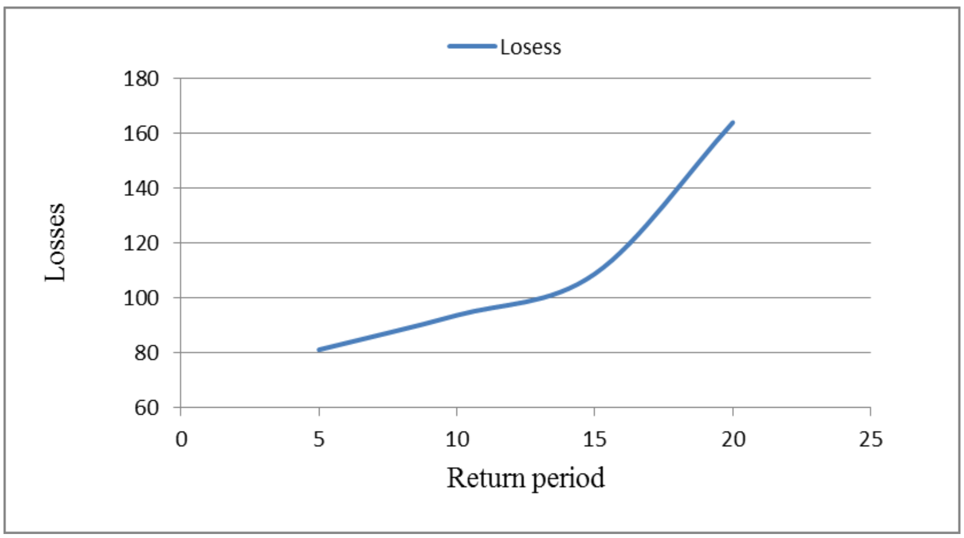

Fig. 12. Landslide induced building losses in different return periods in Muzaffarabad.

Fig. 13. Landslide induced building losses in different return periods in Balakot.

5. Conclusion

Remote sensing and GIS are effectively used to evaluate the landslide induced vulnerability and risk in the northern Pakistan. The study revealed that 14% (1400) of the buildings in Muzaffarabad are located in low susceptibility zone, 73% (7400) in moderate susceptibility zone and 13% (1292) in high susceptibility zone. Whereas, in Balakot 15% (1496) of the buildings are located in low susceptibility zone, 55% (5417) in moderate susceptibility zone and 30% (3002) in high susceptibility zone. The total building losses have been calculated for 5, 10, 15 and 20 years return period scenarios. The results showed that as return period of landslides increases, the total losses of the buildings increases. The vulnerability and risk assessment provides valuable information for the disaster management authorities for drafting and implementing landslide management strategies.

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