

August, 2019 Landslide Events in Kinnaur, H.P.—An Assessment of Earthquake and Landslide Consequences Using Satellite Data



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Abstract On August 18, 2019, the Kinnaur region in the Indian state of Himachal Pradesh experienced many landslides due to heavy rains. In H.P.'s Kinnaur district, National Highway 5 was blocked, heavy rainfall triggered many landslides in isolated regions of Himachal Pradesh, blocking large number of roads, it was blocked near Ribba village of Kinnaur district causing heavy traffic jam. According to reports, this event resulted in the death of 22 people and a significant loss of property. This study presents the results of the Kinnaur landslide damage assessment derived from the analysis of very high-resolution images (VHR) received from different satellites. These datasets were obtained through a coordinated effort by the government organisation major disasters. The damage is mainly attributed to rock slides from the area of the slope that later became debris flows by sanding the material along the exit zone.

Keywords Landslides · Heavy rainfall · VHR · Earthquake · Damage assessment

1 Introduction

Topographical, meteorological, physical and anthropogenic factors are the major causes of slope failures. Topographical factors include terrain, curvature, drainage, slope, elevation, landslide spatial distribution and frequency control. Meteorological factors consist of rainfall intensity, rainfall magnitude and climatic conditions. Physical factors consist of type of soil, structure, texture, roughness and its underlying geology. Anthropogenic factors include human activities like over grazing of animals, cutting of trees, forest fires, excavation of slopes for construction of

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roads, mineral mining, laying of pipelines, etc. [11]. There are many records kept regarding occurrence of earthquake and rainfall data causing heavy destruction in Kinnaur district. Due to the development in urbanisation, construction of roads and dams, environmental changes and global warming, the terrain condition is changing leading to landslides. So, to take preventive measures and reduce risk Landslide Hazard Zonation is prepared with the help of very high-resolution images (VHR) taken from different satellites. Landslide Hazard Zonation is the process in which an area is selected and it is divided into different subclasses based on the landslide susceptibility which consists of different parameters and doing the assessment of earthquake induced landslides. Since it consists of lot of factors to be considered, the analysis of the Landslide Hazard Zonation becomes a complex work and requires skilled and experienced person. Landslide Hazard Zonation can be done in both qualitative and quantitative approach [14]. The quantitative approach includes logistic regression, linear regression and discriminant regression and qualitative approach includes parameter weighted method, site visitation and recording, landslide hazard mapping, soil testing.

The objective of the study is

- To investigate and understand the impact of landslides in Ribba region which lead to economic and physical loss by using landslide susceptible mapping.
- To evaluate the hazard associated with Ribba landslide by using very high-resolution images, rainfall and earthquake data.
- To determine the geotechnical properties of the soil sample collected from Ribba landslide region.
- To suggest slope stability analysis and its frequency by using kinematic and finite element analysis.

2 Area and Location

Kinnaur is a Trans-Himalayan region which is located in the bank of Sutlej and tributary of Baspa. It is the east frontier district of Himachal Pradesh. The total area of Kinnaur is about 6401 km². Ribba is a village panchayat located in Kinnaur district, Himachal Pradesh, India. The coordinates of Ribba are longitude 78.364 and latitude 31.584. In eastern part of Kinnaur lies Ngari region located in Tibet. In southern region, Douladhar ranges which separates Shimla district of Himachal Pradesh and Uttarkashi district of Uttar Pradesh. Srikhand Dhar makes boundary between Kuku and Kinnaur in the western region. In norther region Spiti is located which shares Indo-Tibetan border (2017) (Fig. 1).

The elevation of Kinnaur varies between 1220 and 3050 m. But in mountainous region the average height of the peaks is 5500 m which consist of ice and snow throughout the year. Kinnaur district consists of rivers, glaciers, deep valleys gorges and very high mountains.

The mountains of Kinnaur are full of craggy rocks of massive heights perilous gradients in spurs. The mountains are covered with huge boulders and cliffs which



Fig. 1 Physical and satellite map of Kinnaur district [8]

makes a dangerous location during landslides. Rainfall occurs throughout the year in this region. As the district is located in the higher region, it has temperate climate with longer winters from October to May compared to remaining parts of India (2017).

From 2011 census records of India, Kinnaur district population is 84,121, with population growth rate of 7.61%. The district consists of 65 panchayats with 12,503 households. Due to tourism and verity of culture tourist from different parts of the world are attracted to this region (2017).

2.1 Zone of Landslide in Ribba Village

The landslide of Ribba village is located at $31^{\circ}59'20''N$ and $78^{\circ}36'49''E$, along which another landslide zone is located called Pawari landslide zone where the landslides are common. These two zones are located near the bank of Sutlej River. Recently on August 18, 2019 due to heavy rainfall a massive landslide was occurred in Ribba landslide zone due to which National Highway 5 was blocked. The width and length of landslide zone are 2.58 km and 859 m, respectively, and has an area of about 2.21 km^2 . [9] (Fig. 2).

The landslide occurred at MSL of 1993 m and at an altitude of 2850 m. The surrounding villages are Rarang, Akpa, Panah and Purbani. In this landslide zone the northern part is a cliff with debris flow and rock boulders. In the southern zone there is a valley of Sutlej river. By geomorphic characteristics, this zone has steep angle of slope with a difference of 50° and 65° in the northern region and 40° and 55° in the southern region [1].

3 Frequency of Earthquake and Rainfall

The rainfall data can be obtained from meteorological centre, Shimla which can be used to observe the pattern of rainfall occurring in Kinnaur district. With this data



Fig. 2 Ribba village landslide zone [9]

the affected area of landslide is accessed. The earthquake data is compiled from ‘The tribune’ [13].

The largest earthquake occurred in Kinnaur district is ‘1975 Kinnaur Earthquake’ with a magnitude of 6.8 and causing extensive damage in whole Himachal Pradesh. Its epicentre was in Kinnaur district in the southern east of Himachal Pradesh. Earthquakes are common in Himachal Pradesh which can be varied from low intensity to high intensity. Since the state of Himachal Pradesh lies toward the southern boundary of Himalayan region belt, the collision between Eurasian plate and Indian plate causes ground movements. There are a lot of incidents of earthquake recorded in this region by Indian meteorological department.

The district receives rainfall from the month of June till September. The marginal shift in the monsoon pattern has been noticed over the period of years. The average annual rainfall in the district is 816 mm. However much of the rainfall is received in parts of lower Kinnaur. There is a progressive decrease in rainfall as one goes from west to east. The parts of upper Kinnaur receive more snowfall than the rainfall. The district receives heavy snowfall from November end or early December till March or sometimes April. During this period, the area remains totally cut off from rest of the area. The higher peaks of Kinnaur district are completely covered with snow throughout the year (Tables 1 and 2).

4 Data Preparation for Landslide Hazard Zonation

The required data of landslide can be obtained from Geological Survey of India, National Remote Sensing Centre which gives the satellite images. By using GPS and Google Earth the present situation of landslide can be obtained for mapping. With

Table 1 Earthquake data of past 10 years [7]

S.no	Date	Intensity	Epicenter	Casualty	Remarks
1	28, May 2010	4.8	Shimla dist	No	
2	02, Oct 2012	4.5	Border of districts of Chamba, Lahaul and Spiti	No	
3	12, Nov 2012	4.1	Bajjnath in Douladhar ranges	No	
4	05, Jun 2013	4.8	Border of the districts of Chamba and Lahaul-Spiti	No	The region falls in seismic zone-IV
5	26, Apr 2015	7.9	Nepal	Killed-36 Injuries-200	
6	27, Aug 2016	4.6	Kullu Region	No	
7	27, Oct 2017	4.4	Mandi Region	No	
8	25, May 2018	3.6	Kinnaur Dist	No	
9	03, Feb 2019	3.5	Kangra Dist	No	
10	03, May 2019	4.2	North east of Mandi	No	

Table 2 Rainfall data of Kinnaur district of past six years [4]

Year	2014	2015	2016	2017	2018	2019
Jan	78.1	67.2	16.1	135	1.8	81.8
Feb	140.7	166.7	44.3	38.6	36.8	154.6
Mar	69.5	228.2	79.2	69.5	74.6	102.2
Apr	52.9	32.7	105.2	121.1	40.1	9.4
May	25.6	44.1	15.2	17.4	36.0	69.4
Jun	7.3	44.1	10.1	39.4	24.9	38.2
July	25.9	35	29.8	41.9	51.9	19
Aug	8.6	23.3	49.2	27.5	24.5	53.7
Sep	10.2	37.8	27.2	51.6	78.8	9.5
Oct	1.4	4.5	1.7	0.1	0.0	0
Nov	0.2	8.9	0.0	21.5	35.7	74
Dec	39.3	18.0	5.0	29.9	13.3	0
Total	426.5	710.5	383	593.5	645.1	611.8

the collected information, by using a software called ARC GIS 10 a thematic layer of the landslide can be developed by considering the factors of land cover, slope angle, type of soil, curvature, density of drainage, geological features and relief. By using previous records of landslides occurred in the Kinnaur district with different properties like landslide pattern, geological characteristics, runoff distribution and earthquake pattern an inventory is prepared. In Kinnaur District a total of 6322

landslides have been occurred in the entire district. Using the image processing techniques and field investigations in detail gives the type of landslide, its mechanism, failure pattern and its causes. There are two main aspects of hazard analysis, Aspect and Slope [6]. As the distance of change in slope increases the slope value varies, if the slope value is more then it represents the steeper terrain and vice versa. The slope value can be calculated by

$$\text{Slope (In degrees)} = 57.3 \tan^{-1} \sqrt{(dz/dx)^2 + (dz/dy)^2}$$

The slopes which have been modified is classified into five zones with different land use pattern. Now the steepest slope direction gives the aspect and can be calculated by

$$\text{Aspect} = 57.3 \tan^{-1} 2[(dx/dx) + (dz/dy)]$$

x and y are the direction of slope which are represented by dz/dx and dz/dy [6].

5 Stability Analysis

Since the landslide zone of Ribba village consist of rock mass and boulders the stability analysis is done to determine the slope deformation and rock failure mode. Now the rock failure mode can be determined by using kinematic analysis based on stereonet and slope deformation is obtained by using shear strength reduction technique and plain strain (FEM).

5.1 Rock Failure Mode by Kinematic Analysis

With the help of stereographical projection method, the rock exposure, joint orientation data and stereo plot can be obtained in the northern part. The kinematic analysis gives the possible failure mode and direction in a rock mass by using angular relationship data between slope surface and discontinuities [14].

5.2 Finite Element Analysis

In the finite element analysis, a two slope model is used to determine the failure criteria of slope. Generalised Hooke brown model gives the failure criteria for slope 1 by using the following formula

$$\sigma_1 = \sigma_3 + \sigma_{ci} [m_b (\sigma_3 / \sigma_{ci}) + s] \Delta(a)$$

- σ_1 Maximum principal stress.
 σ_3 Minimum principal stress.
 σ_{ci} Intact compressive strength (mpa).
 m_b, s and a Hoek–Brown parameters.

Now Generalised Hooke brown model is dependent on a parameter called Geological Strength Index (GSI) of rock mass. The GSI can be obtained by correlating discontinuity condition and rock mass blocky nature which has a standard chart proposed by Cai [3].

After the finding out the failure criteria of slope 1, Mohr coulomb criteria is used to determine debris flow in slope 2 with the formula

$$\tau = c + \sigma \tan \theta$$

- τ shear stress or shear strength of material.
 c cohesion of material.
 θ angle of internal friction.

By using these two failure criteria, a model is prepared in CartoSat-1 Digital Elevation Model which is used for execution of the slope parameters for finite element analysis.

6 Soil Properties

By performing soil experiments on the soil sample collected from the Ribba landslide it is found that the soil is poorly graded with coarse and very fine grade category.

- The average specific gravity of the soil is 2.47.
- By performing sieve analysis, the following graph is plotted in which the value of coefficient of uniformity is 16.84 and coefficient of curvature is 0.31.
- In Atterberg limits, Liquid Limit (LL) is 23.339%, Plastic Limit (PL) is 19.67% and shrinkage limit (SL) is 17.05%.
- From standard proctor test, a compaction curve is plotted to obtained optimum moisture content (OMC) of 25.1% and maximum dry density (MDD) of 1.744 gm/cc (Figs. 3, 4 and 5).

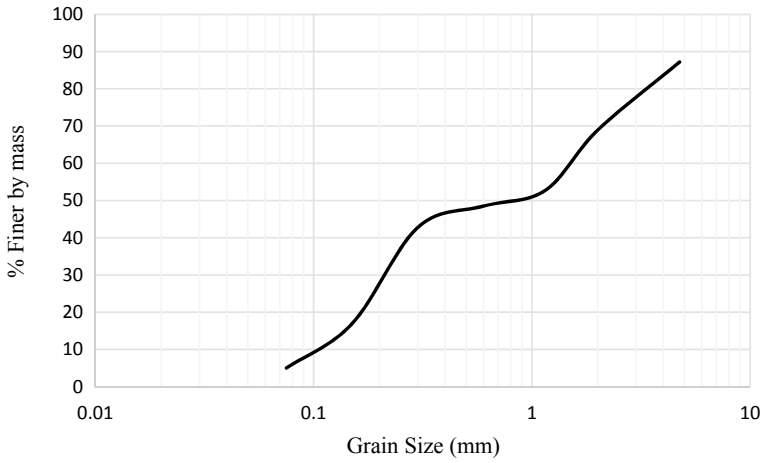


Fig. 3 Particle size distribution

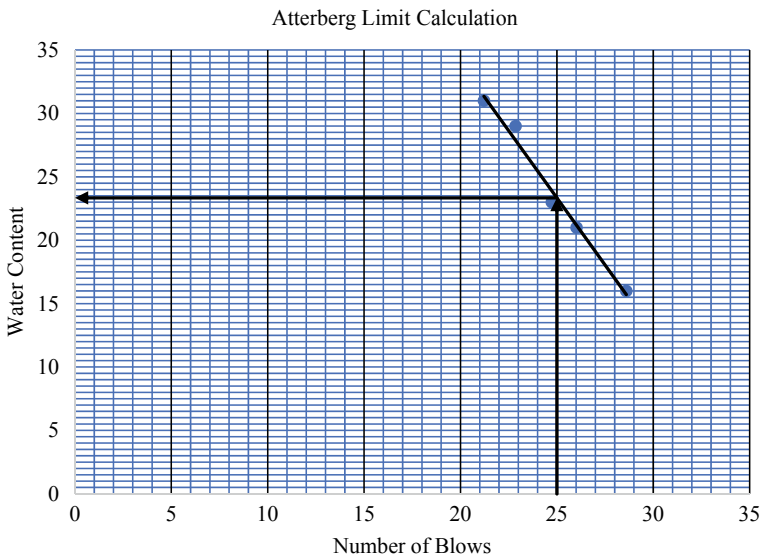


Fig. 4 Atterberg limit calculation

7 Landslide Susceptibility Mapping

There are different factors of mapping which are responsible for landslide susceptibility. The previous landslides data and information are accessed so that these can be used for future analysis of landslides to be occurred. A landslide inventory is used to prepare a whole map showing the old and currently active landslides and

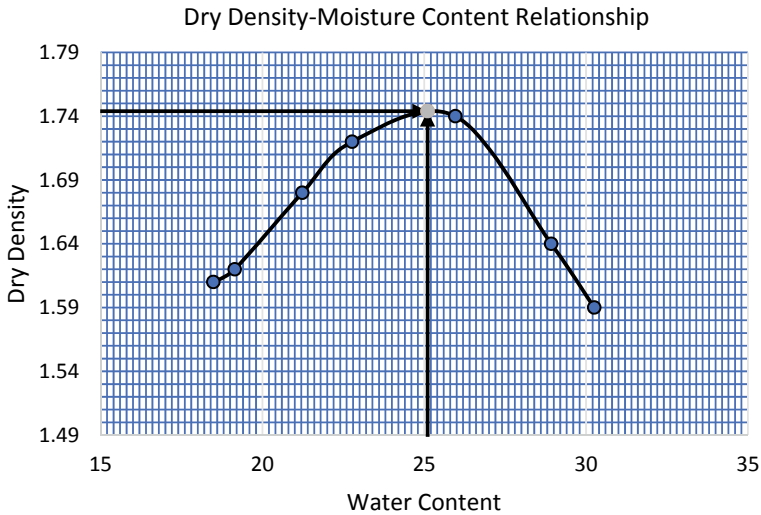


Fig. 5 Determination of optimum moisture content and maximum dry density

to perform further investigation in those regions. Thematic layers of these map are prepared by overlaying the different factors showing geological, morphological and land use conditions [5]. Finally, a model is prepared on the landslide susceptibility for assessment which can be qualitative or quantitative approach. Landslide vulnerability includes different aspects based on physical, land use and land cover, people perception, comprehensive vulnerability (Fig. 6).

7.1 Morphometric Properties

Due to heavy rainfall in this region, a high amount of volume of water is discharged with greater velocity which leads to erosion of soil. As the slope has steeper gradient the flow of water along with debris is high and this flow washes away the pavement constructed and finally into the Sutlej river. The bifurcation ratio is defined as the ratio of number of streams of given order to number of streams to next order. The bifurcation ratio gives us the physical loss of the soil mass (Fig. 7).

Here the Sutlej River has a low bifurcation value which says that it has a controlled bedrock. Many streams are formed from higher ridge, and due to continuous flow, the boulders and soil gets washed away into Sutlej basin.

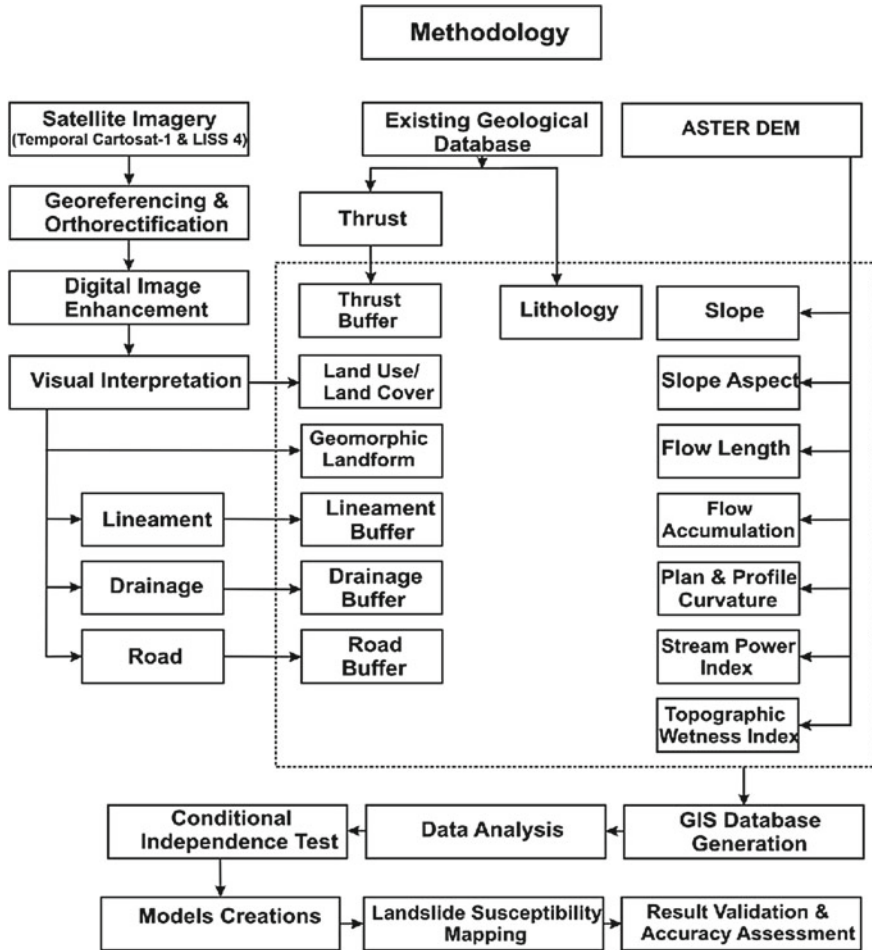


Fig. 6 Landslide susceptibility mapping

Fig. 7 Flow of rainwater along with debris and soil blocking NH 5



Fig. 8 Positive curvature of landslide



7.2 Curvature of Landslide

The deceleration and acceleration of the flow due to profile curvature affect the nature of the landslide. If the curvature has a negative value then it shows that the surface is upward convex and the flow will be decelerated. If positive then the surface is upward concave with accelerated flow (Fig. 8).

Here the landslide occurred at Ribba has a positive curvature due to which high amount of movement of soil mass, boulders and debris took place.

7.3 Lithology of the Location

The lithology of the location is obtained from the geological survey of India and google maps. It is found that the area of Kinnaur district is mostly covered with type of peat with the mixture of limestone, phosphate, quartzite, greenish grey sandstone with area of 29%. The affected area was about 1.2% which consists of boulders, peat, sediments of sandstone and clay. The area of forest covers with limestone, shale which are highly vulnerable to floods, soil erosion and landslides [1].

7.4 Hydroelectric Projects

Construction of hydroelectric project is a major issue which finally leads to slope failures and landslides. If surrounding of the Sutlej is considered it is observed that slope instability is common causing sliding of soil mass and boulders. There are four hydroelectric projects constructed in Sutlej basin and are different in type which were under investigation, clearance, one was commissioned and another was under construction. It was found that the maximum number of landslides were occurred due to under construction type and were causing risk. As the continuity of construction

Fig. 9 Hydroelectric project [10]



activities, the chances of landslides in the surrounding region are increasing. The wildlife sanctuary, forestland and topsoil and many villages were threatened under hydroelectric projects [2] (Fig. 9).

When these hydroelectric projects are constructed blasting technique and tunnelling is done which will cause ground disturbances and finally causing landslides.

7.5 Occurrences of Earthquake

Land movements due to earthquake in Kinnaur region have an intensity between 4.0 and 6.1. The average magnitude recorded is 4.5 and low intensity earthquakes commonly occur in this region. By comparing with the Mercalli intensity scale Kinnaur district falls under IV to V. Every time when a low intensity earthquake is occurred, the tremors can be felt in the surrounding region, with cracks developed in buildings, pavement failure, spalling, settlement, utility disturbances. People living in the surrounding also explained about how they experienced those tremors (Fig. 10).

Even due to blasting operations and tunnelling construction they felt those vibrations. Due to these conditions every village in Kinnaur district comes under earthquake vulnerability zone.

8 Questionnaire Survey

A questionnaire survey was constructed in Ribba landslide zone to gather the information about the landslide occurred based on different parameters. Out of 70 people 50 people told that the vibrations which they observe are due to blasting operations



Fig. 10 Small range seismic waves due to blasting and tunnelling operations

and tunnelling activities. When heavy rainfall occurs and a huge amount of water is released through dam causing heavy flow of river finally leads to slope failure told by 43 people. All 70 people told that the loss of property and life were common in this region. 27 people told that most of the landslides are both overburden and boulders sliding. Some of them also stated that there are no dumping site and the waste materials were dumped near river or beside roads. Some told that due to deforestation activities, the soil in this region is getting eroded.

9 Conclusion and Discussions

From the study it was found that the Ribba village zone is highly vulnerable to landslide because of its clumsy geophysical nature. Most of the landslides in this region are occurring due to blasting operations as the slopes are steeper so failure occurs easily. By considering morphological factors it can be stated that this region comes under highly vulnerable region. The use of hydropower plant was causing disturbances in soil and also ecological imbalance in Sutlej valley. Further construction activities near the steeper region should be avoided. The recent landslide occurred in Ribba village lead to 22 persons death, and many households got destroyed. The Ribba landslide zone comes under high vulnerability with an impact of 70% failures if any disaster occurs. For further studies it is necessary to consider detailed study of slope stabilisation and rock mechanics and these research works should be undertaken by experienced institutes and departments. The following pie chart shows the research work done or are to be carried out in different areas by considering previous research papers or review papers. Total of eight papers have been found related to Kinnaur district landslides in which these have been divided into six categories in which further investigation can be carried out (Fig. 11).

It can be seen that most of the work has been done in assessment of impact of landslides causing economic and physical loss and investigation of slope failure, ground movements due to blasting operations. Even a little work was also carried in vulnerability assessment in Kinnaur district but still the proper data has been not

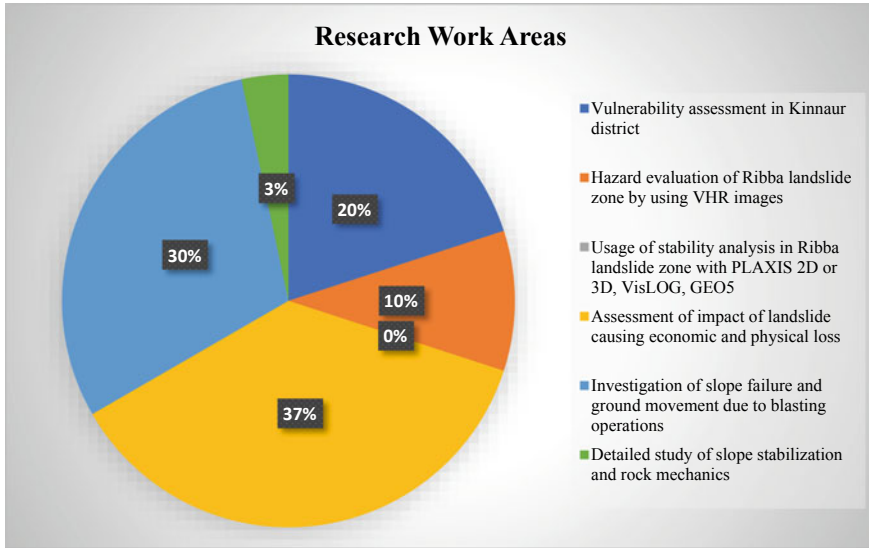


Fig. 11 Pie chart showing research work done or to be carried out in ribba landslide zone [1–3, 5, 6, 10, 12, 14]

provided in any of their research work regarding Ribba landslide zone. So, the main area of work can be carried out in slope stabilisation and rock mechanics analysis. Moreover, no stability analysis has been done in Ribba landslide zone by using PLAXIS 2D or 3D, VisLOG and GEO5 software.

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