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Rapid Mass Movement Simulations Based Analysis of Landslides along National Highway 205 in Himachal Pradesh, India

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Abstract

This study investigates the application of the Rapid Mass Movement Simulation (RAMMS) tool in assessing and mitigating various types of landslides. The research encompasses comprehensive field visits to diverse landslide-prone areas, capturing detailed photographic evidence to document pre- and post-landslide conditions. Utilizing the field data, RAMMS simulations were conducted to model the dynamics of different landslide scenarios, including rockfalls, debris flows, and avalanches. The simulations provided insights into the potential impact zones, flow velocities, and deposition patterns of landslides under varying environmental conditions. The results highlight the efficacy of RAMMS in predicting landslide behavior and guiding mitigation strategies. By comparing the simulation outputs with field observations, we validated the accuracy of RAMMS models, demonstrating their utility in real-world applications. Furthermore, the study identifies key factors influencing landslide susceptibility and proposes targeted mitigation measures to enhance community flexibility. This research underscores the importance of integrating advanced simulation tools like RAMMS with empirical field data to develop strong landslide risk management frameworks.

1. Introduction

Debris flow, sometimes referred to as mudflow or debris avalanche, is a kind of swiftly moving landslip that consists of a mixture of water, rock, soil, and plants. These flows usually happen in steep or mountainous places, and they are frequently caused by sudden or intense snowmelt that saturates the soil and causes the slope to become unstable [1, 26]. They generate seismic, sonic, and infrasound waves as they travel downslope along the channel. The most effective way for constructing barriers against debris flows is affected by an insufficient comprehension of the interactions between barriers or retaining wall and debris flows. Debris flows are related geo-hydro-mechanical phenomena that entail rapid flow via a narrow channel and deposition in level areas. The vibrations induced by these waves (in the surface or in the air) are produced by solid particle impacts on the channel bed and by flow turbulence. They begin on steep slopes. Creating numerical models for debris flows involves choosing a rheological model, considering the entrainment process, and integrating 3D terrain features [1]. Since debris flows occur frequently in a variety of morphologic settings and with high velocity and large volumes, they pose a serious natural hazard in mountainous areas [2]. Although there are many potential reasons for debris flows, impact water and the ensuing rise in pore-water pressure are often suggested as initiators. The event often includes a series of surges characterized by maximum flow depth and peak discharge. The landslide susceptibility mapping techniques can be broadly classified into two categories: qualitative and quantitative approaches. The qualitative approaches are inventory based and knowledge-driven methods such as distribution models, geomorphic mapping and map integration models. On the other hand, the quantitative approaches are

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data-driven methods and physically based models [3].

Debris flows not only lead to recurrent blockages of National Highways and rivers but also result in the loss of life and property. Further, they contribute to annual environmental damage in mountainous regions. The fast urbanization and expansion of hill roads increase the hazardous status of debris flows by disturbing sensitive Himalayan tectonics and natural drainage systems. As a result, researchers are focusing more on hazard and risk assessment in context of debris flows in mountainous areas [4]. Debris flow runout studies aim to define the affected regions and assess the intensity of the flow after the mobilization of debris materials. The primary objectives of these studies involve spatially delineating potential impacted areas and determining the parameters of flow intensity. Various factors which trigger the nature of flow of debris, which include the initial volume of debris which has flown downstream, slope topography, properties of the downstream path, lithology, failure mechanism and the rheology of the debris along with the water [5]. Hill slope debris move down valley slopes as tracks or sheets along their own paths, while channelized debris flows follow predetermined channels in mountain valleys.

Interestingly, contemporary theoretical formulations of snow avalanche dynamics closely resemble, albeit with slightly less complexity, the proposed models for debris flows [6]. A review of existing literature on debris flow models indicates that only a limited number are constructed using continuum mechanical principles [7]. This often makes it challenging to compare models, as the underlying physical assumptions are obscured. Most models in the literature treat debris flows as single-constituent materials, overlooking their inherently mixed nature. The role of water, crucial for debris flow initiation, is usually included parametrically rather than dynamically. Acknowledging the significant contribution of water, any realistic mathematical model describing debris flow initiation should incorporate it as a distinct constituent. Debris flows are composed of grains with variations in size, shape, composition, and other attributes. The segregation of particles within a debris flow refers to the phenomenon where particles of different sizes undergo redistribution during motion. Notably, over extended periods, larger particles tend to migrate towards the top, while smaller particles tend to accumulate towards the bottom of a debris flow [8]. A comprehensive model of a debris flow should account for the spatio-temporal evolution of particle size distribution, especially considering phenomena like inverse grading. However, as of now, there is no existing model that addresses this aspect [9].

1.1. Rapid Mass Movement Simulation (RAMMS)

The debris flow simulation using RAMMS, a flow simulation model (version 1.8.0, January 2024) based on the Voellmy (MuXi) model. The study aims to provide a comprehensive approach to debris flow modeling, drawing on research conducted by various researchers in the field. Authors have taken the specific aspects of debris flow modelling within the RAMMS model, to evaluate the model’s application that is the input parameters, methodology used to collect and analyze the past data from various authors were taken into consideration. The manuscript will serve as a valuable resource for the scientific community, providing a consolidated understanding of the model's applications, performance, and potential avenues for future research and improvement. The Swiss Federal Institute for Forest, Snow, and Landscape Research and the WSL Institute for Snow and Avalanche Research SLF produced this model and the corresponding code [5]. Numerical methods offer a significant advantage to calculate the flow's movement across uneven topographic terrains. Computation of parameters related to intensity, such as flow depth, and impact pressure at each point along the flow path can be performed using numerical methods which can be integrated with vulnerability functions to facilitate quantitative risk assessment [10].

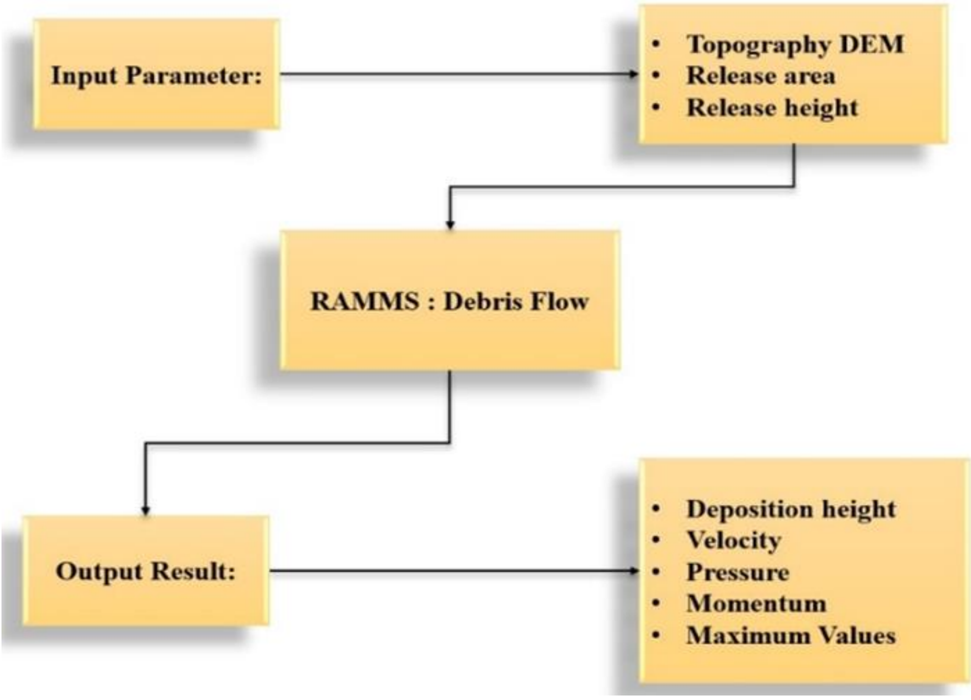

Figure 1. Work flow of RAMMS simulation

In the realm of natural hazards, there is a major need for process models that initiates the runout behaviour of avalanches, debris flows, hill slope and rockfalls. These models are frequently utilized to assess how a specific process interacts with mitigation strategies, such as forests or deflecting dams, as well as for hazard mapping. Traditionally, separate software tools are employed for each distinct process. A brief overview of a consolidated software package designed to simulate avalanches debris flows, hillslope debris flows, and rockfalls has been done [11]. The software package, known as RAMMS, integrates these four process modules within a user-friendly graphical interface. The subsequent discussion delves into the software engineering challenges associated with amalgamating diverse process models into a single tool. These models have undergone testing and calibration using WSL's real-scale test as well as data derived from meticulously documented case studies. By consolidating various physical models into one tool, engineering offices can utilize a singular solution to address various natural hazards. The unified interface facilitates a comprehensive assessment of mitigation measures, supporting holistic risk management [4].

1.2. RAMMS: Avalanche

The RAMMS: Avalanche module addresses the two-dimensional depth-averaged mass and momentum equations across three-dimensional terrain, employing both first and second-order finite volume methods. This model is designed to predict avalanche velocities and flow heights. The initiation of avalanches is determined by specifying initial conditions through defining a slab area with a fixed fracture height. Multiple slab areas with distinct fracture heights may be defined to accommodate diverse release conditions, including instances such as wind-blown snow near mountain crests [7]. These parameters can be chosen as constants across the entire problem domain or allowed to vary spatially to consider differences in terrain characteristics, roughness, or vegetation. The calculations automatically stop when the total mass flux drops below a specified fraction of the maximum mass flux.

1.3. RAMMS: Debris flow

The module can compute impact pressures and flow heights for engineering mitigation measure design. Similar to the avalanche module, the model generates results presented in three-dimensional digital elevation models. Researchers have the option to select single or multiple block-release areas, or define a hydrograph input to specify discharge and velocity over time. Presently, RAMMS: DEBRIS FLOW does not account for erosion and entrainment, but work on "bulking" algorithms is underway. Regarding the input hydrograph, researchers can input flow discharge based on measurements or estimates [8]. This enables a more efficient calculation process by limiting the computational domain area, or it allows for increased grid resolution by initiating the model at a location further downslope from the initiation zone, such as at the apex of the fan [19].

1.4. RAMMS: Hillslope

Landslides exhibit various downslope movements, including small slumps and slides, with the potential to transform into rapidly advancing flows that share characteristics with debris flows on hillslopes lacking well-defined channels [6]. The challenge of hillslope debris flows is prevalent in many countries, prompting the optimization of the debris flow model to accurately simulate their runout. Rapid shallow landslides, like hillslope debris flows, display greater geomorphic diversity compared to channelized debris flows. While the Voellmy-fluid friction relation and block release initiation can successfully model many of these flows, their typically smaller volumes (ranging from hundreds to thousands of m^3) and shorter runout distances necessitate higher-resolution DEMs and computational grids. Careful consideration of the landslide release location is crucial due to the influence of local microtopography, such as channels and constrictions, on flow direction [16]. Unlike channelized debris flows, the runout surfaces of hillslope debris flows often extend onto pastures or agricultural land. Consequently, friction coefficients in RAMMS: HILLSLOPE are frequently distinct from those used for channelized debris flows. The RAMMS: HILLSLOPE package leverages the functionalities of RAMMS: DEBRIS FLOW without the input hydrograph. Moreover, an adapted version of the Voellmy friction relation, accounting for friction reduction due to granular fluctuations, is available. This modification enhances the realism of simulations of on-slope deposits in certain scenarios. The model is currently undergoing beta testing, involving several engineering offices sponsored by the Federal Office for the Environment (FOEN) [8].

1.5. RAMMS: Rockfall - Rigid body simulation with hard unilateral constraints

In this model, the rock is represented as a three-dimensional indestructible polyhedral rigid body that can undergo frictional contact with a tessellated surface. Rockfalls are distinguished from rock avalanches primarily by their size, with rock avalanches typically exceeding 10,000 m^3 and often reaching volumes of around 1 million m^3 [8]. Concepts from rough Dynamics are incorporated to integrate the rigid-body approach with a 'hard' modelling of contacts, involving impenetrability conditions expressed by Signorini and Coulomb's dry friction law. The approach in RAMMS: ROCKFALL differs from the penalty method, commonly employed to predict rockfall runout, which introduces non-physical compliance in contact and comes with various drawbacks. In contrast, the 'hard' modelling of contacts in RAMMS: ROCKFALL offers an accurate depiction of contact behaviour, utilizes fewer parameters, and ensures a consistent mathematical formulation [6].

2. Digital Elevation Model (DEM)

Understanding Earth's surface is crucial due to human-induced changes in natural resources. Digital elevation models (DEM) are key in various fields, such as product development, decision-making, mapping, 3D simulations, river channel estimation, and contour maps. It also plays a vital role in geospatial datasets representing terrain variations, essential for predicting and analyzing topography. DEM analysis involves data collection, modelling, management, and application development. Factors like data collection methods and input data nature affect DEM quality. They are essential for replicating the importance of worldwide, consistent, high-quality digital elevation models. DEMs find applications in various fields like photogrammetry, urban planning, and environmental management. Technological advancements have enhanced DEM accuracy, addressing real-world issues effectively. The scientific community and industry are increasingly aware of the importance of DEM and their applications, with satellite and spaceborne missions launched to provide digital elevation data over the globe using radar interferometry and light detection and ranging (LIDAR). This review covers DEM generation, terminology, types, accuracy assessment, recent advancements, and applications, along with a comparison of traditional and modern methods and future scope [5]. The modern technologies are more appropriate than traditional ones. However, cloud cover is a major drawback of modern technology. Different techniques and patterns, such as contour lines, topographic maps, field surveys, photogrammetry techniques, interpolation techniques, radar interferometry, and laser altimetry, have their advantages and disadvantages.

Various sources for DEM generation include topographic maps, satellite platforms, optical sensors, and radar systems. However, optical satellite sensors face problems with cloud cover, limiting the generation of high-quality and high-resolution DEM. Upcoming satellite missions, scheduled for launch in 2020, are expected to enable high-resolution DEM in the near future. DEM resolution's importance and influence on accuracy are discussed for various applications, such as hydrological models, solar radiation, landslide, soil erosion, and watershed [5].

A Light Detection and Ranging (LiDAR) based DEM for RAMMS will most likely use LiDAR technology to generate high-resolution elevation models of the area where RAMMS is deployed. RAMMS is a technique for rapidly mapping large-scale motions like landslides, debris flows, and rockfalls [5]. LiDAR operates by producing laser pulses from an aircraft or ground-based device and measuring how long it takes for those pulses to bounce back after impacting the Earth's surface. This data is then utilized to create extremely realistic three-dimensional terrain models including elevation information. Integrating LiDAR data into RAMMS might improve its capabilities by giving comprehensive topography information about the region under observation. This information can aid in detecting possible landslide-prone locations, tracking topography changes over time, and measuring the influence of mass movements on the environment. Furthermore, LiDAR derived DEMs can help with the design and execution of mitigation measures to lessen the danger associated with mass movements.

When using ArcGIS to delineate landslides in Google Earth Pro for RAMMS simulations, a symbiotic relationship arises between intuitive visual analysis and advanced geographic modelling. The method begins with accurately identifying landslip borders using Google Earth Pro's user-friendly interface and high-resolution images. This information is then easily incorporated into ArcGIS, where exact elevation data is retrieved and processed to provide DEMs customized to the individual terrain features affected by landslides. This integration not only leverages the capabilities of both platforms, but it also assures that RAMMS simulations are based on comprehensive topographical data, improving the accuracy and dependability of hazard evaluations. This strategy, which combines the capabilities of Google Earth Pro for quick identification and ArcGIS for exact terrain modelling, is a powerful tool for enhancing landslip hazard analysis and mitigation measures.

Using ArcMap to create a Digital Elevation Model (DEM) from a specified zone on the Open Topography website allows for a more personalized approach to terrain study, especially in RAMMS simulation regions. Using the comprehensive information accessible on Open Topography, users may specify particular geographic locations important to their research or hazard assessment needs. Importing chosen zone data into ArcMap generates precise DEMs with high spatial resolution that are specially adapted to the RAMMS modelling needs. This tailored technique guarantees that the DEM precisely depicts the topographic features of the specified area, allowing for more exact simulations and concentrated investigation of landslip susceptibility and other natural hazards [11]. While choosing zones from Open Topography, it is crucial to take into account any potential restrictions, such as data availability and resolution limitations. Overall, integrating zone-specific DEMs from Open Topography into ArcMap for RAMMS simulations is a smart use of geospatial data that improves the precision and relevance of mitigation and evaluation efforts for hazards.

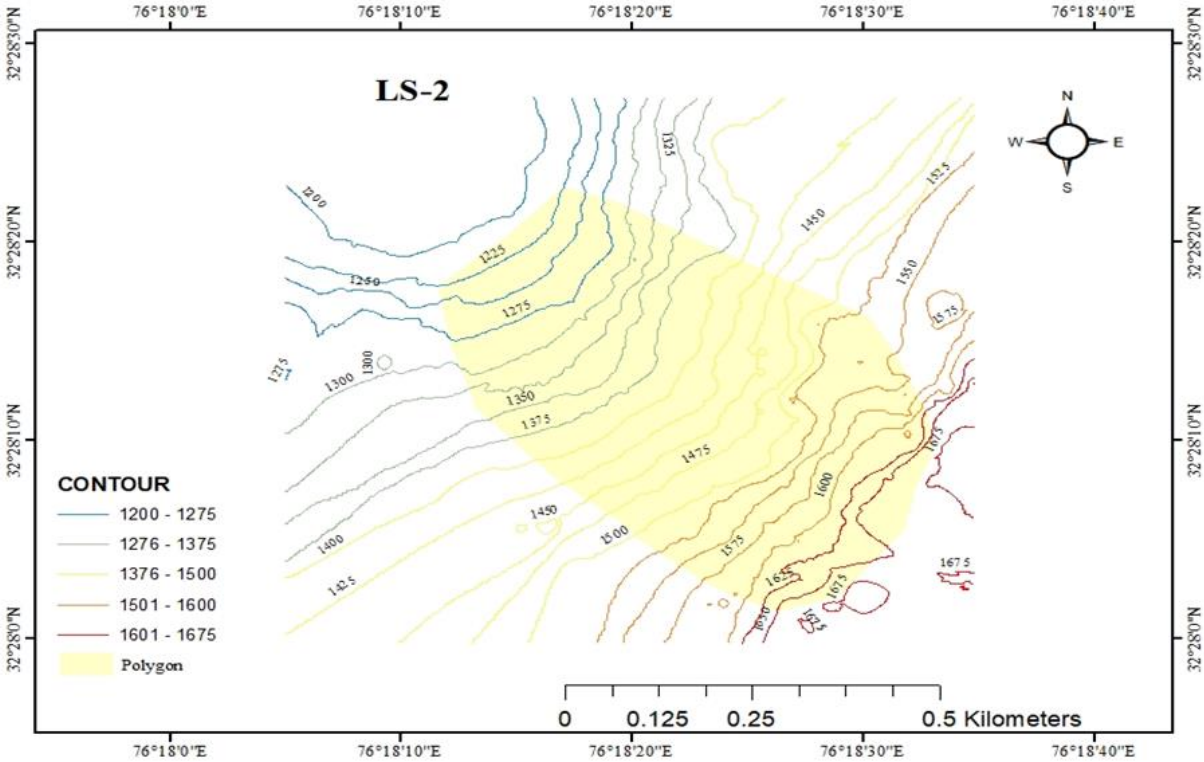

Figure 2. Topography Map of LS-1 (31°29'4.37"N, 77°41'21.46"E)

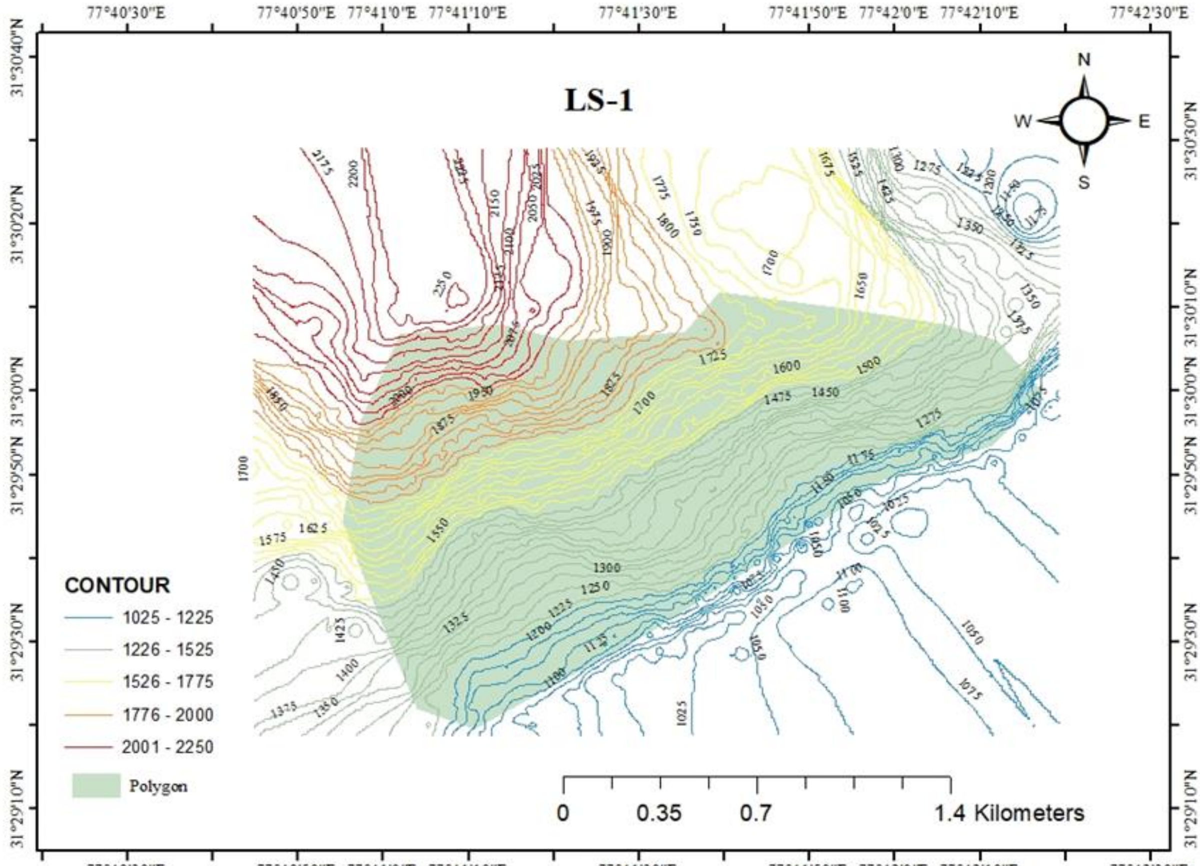

Figure 3. Topography Map of LS-2 (32°28'21.15"N, 76°18'26.10"E)

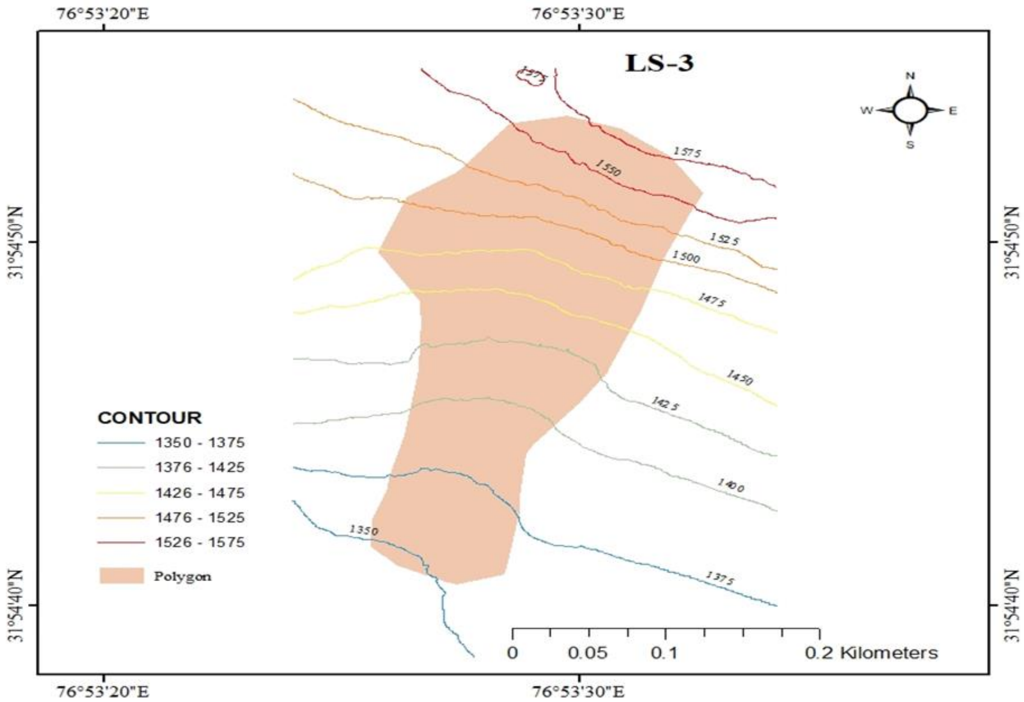

Figure 4. Topography Map of LS-3 (31°54'48.46"N, 76°53'28.36"E)

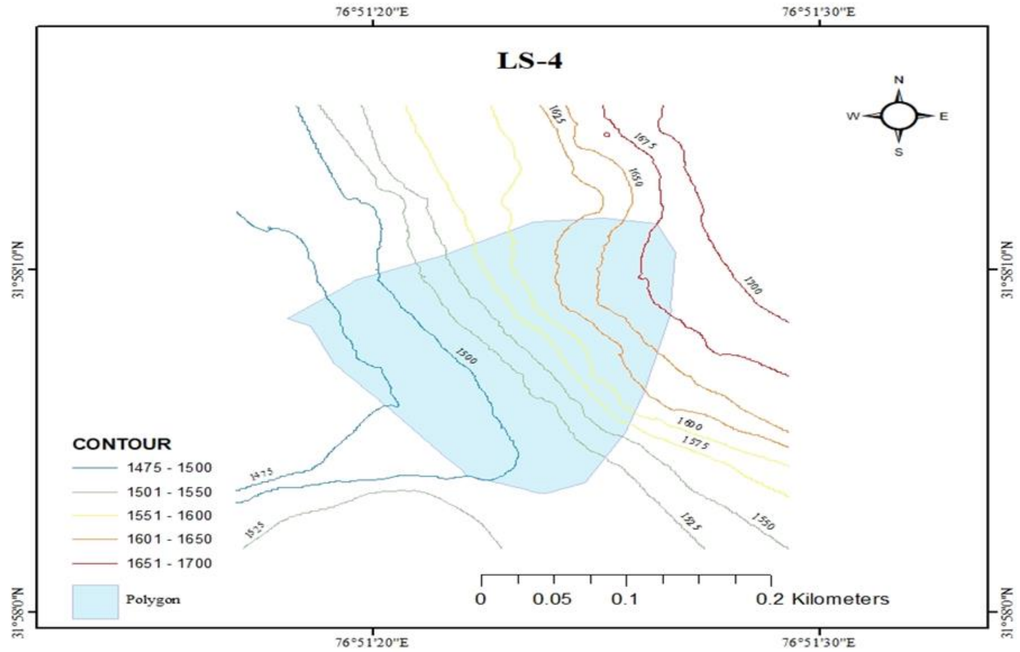

Figure 5. Topography Map of LS-4 (31°58'9.82"N, 76°51'20.73"E)

Landslide (LS)	Coordinates	Slope Direction	Inclination (^{0})	Elevation (m)	Width (m)	Height (m)	Depth (m)
LS-1	31°29'4.37"N, 77°41'21.46"E	300^0	43	1196	60.8	80	19
LS-2	32°28'21.15"N, 76°18'26.10"E	130^0	35	1237	44.6	35	11
LS-3	31°54'48.46"N, 76°53'28.36"E	220^0	42	1373	95	22	14
LS-4	31°58'9.82"N, 76°51'20.73"E	190^0	47	1493	43	31	24

RAMMS relies on DEM as the primary input dataset to establish the basic geometry of the model. It has been proposed that a 5x5m resolution is optimal and gives accurate output/results, contending that even utilizing a smaller resolution yield fairly comparable outcome (e.g. 4m x 4m) [12]. The latest version of RAMMS introduces the option to employ terrain models with enhanced resolution as the standard model. Increased precision in delineating source areas, erosion depth, and deposition was achieved by scanning surface topology at a 5x5m resolution [13]. These input data were employed to assess the numerical model, and the results were compared with outcomes derived from input data featuring a 30x30m resolution.

Topography data, resolution, and accuracy of data are essential inputs for simulations and have an important impact on the simulation results. Also, it requires more processing power and simulation time, using simulation flow models and DEMs with grid spacings of 25, 4, and 1 meter. The results showed that, for each flow model, a 25-meter DEM offers a rough calculation of the possible hazard zone. However, 4m and 1m DEMs mostly restrict the simulated debris flow to the channels that are already in location, which is consistent with observations of previous debris flow events [14]. The region that was simulated has 117,030 pixels. The majority of the satellite pictures used in this article came from Google Earth; they were derived from aerial photos and older images with a spatial resolution of 0.5 meters using Keyhole.

3. Debris flow simulation method

The basic steps for simulating debris flow using RAMMS software are as follows. First, CAD software is applied to create contour lines for the study area using elevation points. Next, the topographic contour map is imported into ArcGIS also called as ArcMap, where the Arc Toolbox is used to project the coordinate system into a Cartesian system compatible with RAMMS model. The contour lines are then converted to the Triangulated Irregular Network (TIN) format and subsequently to ASCII format using the global mapper software. Finally, the ASCII terrain data are imported into RAMMS, and the watershed range and provenance area data are exported for backup. RAMMS is then opened, and the terrain model, provenance area, and watershed range are loaded into the program sequentially. Thicknesses are then assigned to the provenance area based on survey data.

4. Study Area Characteristics

The Debris flow movement caused a land surface to slide occurred due to excessive rainfall near Raghunath Pura which is in Mandi District of Himachal Pradesh, India. The exact location of the debris flow or landslide lies on the coordinate 25°27'0" North latitude and 82°52'0" East longitude.

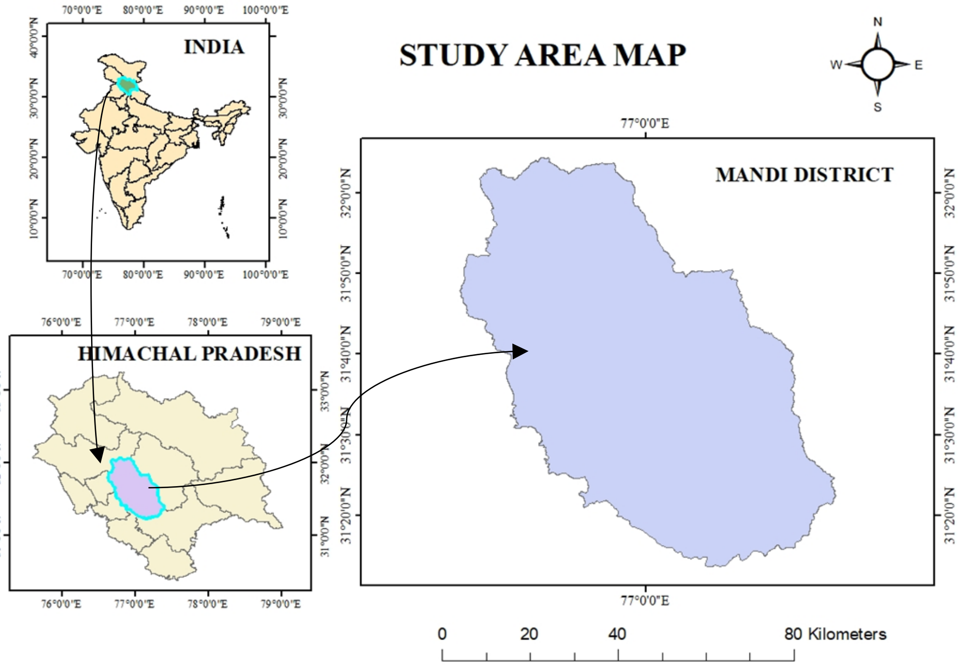

Figure 6. Study Area Map of Mandi, H.P (GSI)

Mandi, located in the northern Indian state of Himachal Pradesh, is characterized by rugged terrain and steep slopes, making it susceptible to landslides. The region experiences frequent rainfall events, particularly during the monsoon season, which further exacerbate slope instability [17]. Despite its vulnerability to landslides, comprehensive studies focusing on the geomorphic aspects of landslide-prone areas in Mandi are limited. This research seeks to fill this gap by conducting a detailed analysis of the geomorphic factors contributing to landslide susceptibility.

Mandi, nestled amidst the picturesque landscapes of Himachal Pradesh, India, boasts not only of its natural beauty but also of its susceptibility to landslides, which pose significant threats to lives, infrastructure, and the environment. Situated in the northwestern part of Himachal Pradesh, Mandi district is characterized by rugged terrain, steep slopes, and complex geological formations, making it inherently prone to slope instability and mass movements [18]. This introduction sets the stage for a detailed exploration of the study area, focusing on the causes, impacts, and mitigation strategies related to landslides in Mandi.

Figure 7. Field visit picture of LS-1 (31°29'4.37"N, 77°41'21.46"E)

Figure 8. Field visit pictures of LS-2 (32°28'21.15"N, 76°18'26.10"E)

Figure 9. Field visit pictures of LS-3 (31°54'48.46"N, 76°53'28.36"E)

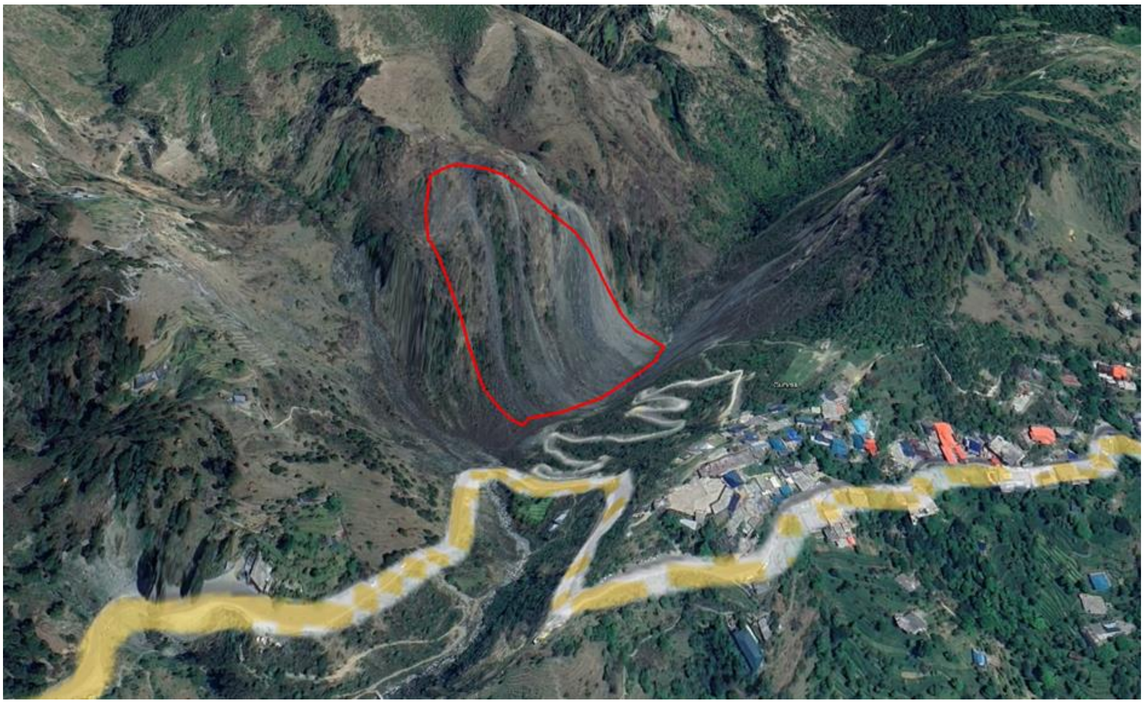

Figure 10. Google Earth Pro picture of marked LS-4 (31°58'9.82"N, 76°51'20.73"E)

4.1. Geographical Context

Mandi district spans an area of approximately 3,950 square kilometers, encompassing diverse topographic features ranging from high mountain peaks to deep valleys carved by the Beas River and its tributaries. The district is flanked by Kullu in the north, Kangra in the south, and Shimla and Bilaspur in the east. Its geographical location in the Indian Himalayas exposes it to the dynamic interplay of geological, hydrological, and climatic factors that contribute to landslide occurrence [19].

4.2. Geological Setting

The geological foundation of Mandi district comprises a complex assemblage of rocks belonging to the Lesser Himalayan sequence, which primarily consists of sedimentary and metamorphic formations. The presence of shale, sandstone, limestone, and schist renders the region vulnerable to landslides, with variations in lithology and structural discontinuities influencing slope stability. Furthermore, the tectonic activity associated with the Himalayan orogeny has led to the development of numerous fault zones and fractures, exacerbating the risk of mass movements [20].

4.3. Climatic Conditions

Mandi experiences a temperate climate characterized by distinct seasons, with cold winters, moderate summers, and heavy monsoon rainfall from July to September. The monsoonal precipitation, originating from the southwest summer monsoon, exerts a significant control on landslide activity in the region. Intense rainfall events, coupled with steep slopes and weak geological formations, act as predisposing factors for landslide initiation, particularly in areas with poor drainage and high soil moisture content.

4.4. Rainfall Condition

Rainfall, sometimes combined with debris or snowmelt, is the primary factor triggering most debris flows [27]. Mandi, Himachal Pradesh, typically experiences a temperate climate with three main seasons: summer, monsoon, and winter. The rainfall in Mandi largely depends on the monsoon season [26], which generally occurs from July to September [5]. During this time, the region receives the majority of its precipitation, with July and August being the wettest months. The most common device used for measuring rainfall is the tipping bucket rain gauge. Standard tipping-bucket rain gauges have a resolution of 0.1 to 0.5 mm per tip and provide simple and inexpensive rainfall measurements [27]. The monthly rainfall curve represents the variation in rainfall over each month of a year. This curve is typically plotted on a graph where the x-axis represents the months of the year, from January, 2022 to March, 2024 and the y-axis represents the amount of rainfall, usually measured in millimetres.

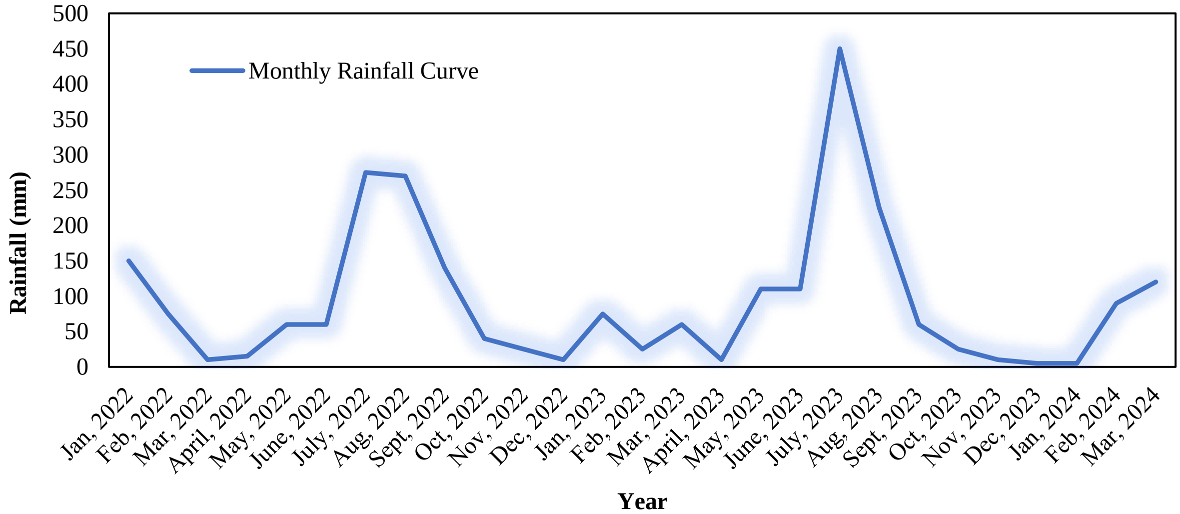

Figure 11. Monthly rainfall (in mm) trends for Himachal Pradesh from 01/01/2022 to 31/03/2024 (Source: WRIS India)

4.5. Historical Landslide Events

The history of Mandi is punctuated by several catastrophic landslide events that have left indelible scars on the landscape and collective memory of its inhabitants. Notable incidents include the 2017 Mandi landslide, which claimed numerous lives and caused extensive damage to infrastructure, including the Mandi-Pathankot National Highway. These events underscore the urgency of understanding the underlying causes of landslides and implementing effective mitigation measures to mitigate risks and enhance resilience.

5. Geology / Lithology Map of Mandi, H.P, India

Geological maps play a vital role in resource exploration and exploitation. Different colors represent different places of Mandi, H.P, India, while lines denote boundaries between geological formations or faults where the Earth's crust has shifted.

A lithology map is a geological map that illustrates the distribution of different rock types across a specific area. It also plays a vital role in land use planning and environmental management. In these map different colors are typically used to represent different types of rocks or geological formations. They also utilize satellite imagery and aerial photographs to gain a broader perspective of the region.

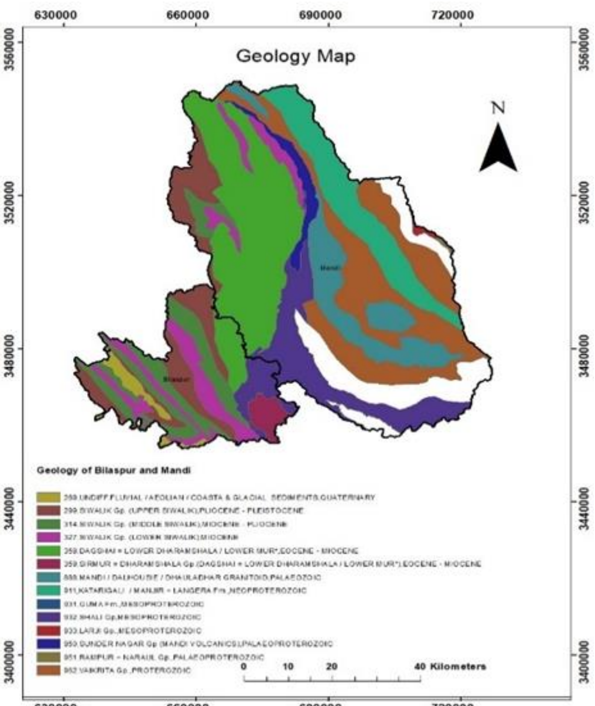

Figure 12: Mandi’s Geology Map

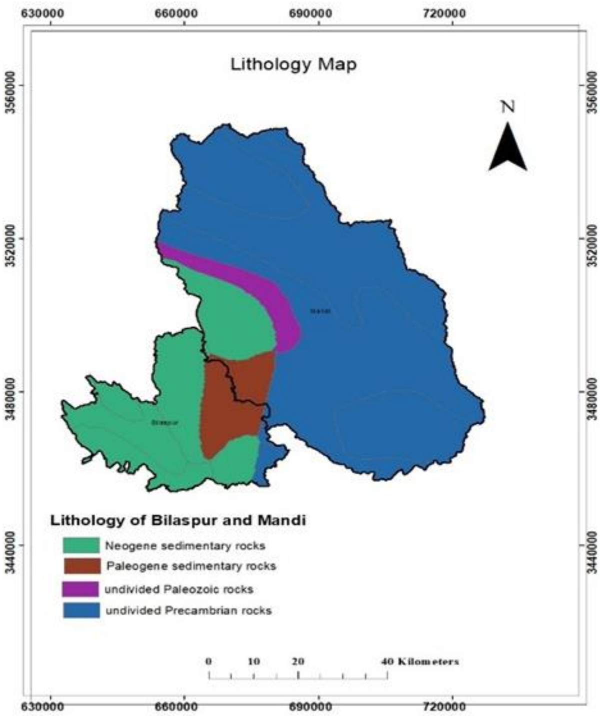

Figure 13: Mandi’s Lithology Map

6. Materials and Methods

6.1. DEM created using Google Earth Pro satellite data in ArcMap

This study focuses on a specific case where satellite data sourced from Google Earth Pro is leveraged to conduct RAMMS simulations within a designated region. The research methodology encompasses a series of crucial steps aimed at utilizing this satellite data effectively.

Firstly, the process commences with the acquisition of satellite imagery and relevant data from Google Earth Pro. The targeted area, marked for study, is identified based on historical landslide occurrences or identified high-risk zones. The study area or the landslide area is marked in such a way that every elevated part is pointed out to form a high-resolution image which shows detailed clarity of the topography of the marked study area. Through Google Earth Pro's user-friendly interface, researchers locate and download high-resolution satellite images of the selected region, ensuring comprehensive coverage of the study area.

Subsequently, acquired satellite data undergoes preprocessing procedures to render it compatible with RAMMS software requirements. This involves converting satellite imagery into a suitable format and aligning it with the desired coordinate system. Additionally, elevation data extracted from Google Earth Pro is processed to create a Digital Elevation Model (DEM), a crucial component for terrain representation in RAMMS simulations.

With the prepared satellite data at hand, the next step involves setting up the RAMMS model. This entails integrating the DEM generated from Google Earth Pro into RAMMS, conFigureuring model parameters, and establishing boundary conditions. The accuracy and resolution of the DEM play a pivotal role in ensuring the fidelity of the RAMMS simulation.

Following model setup, the calibration phase becomes imperative. Here, researchers fine-tune various parameters within RAMMS to align simulated debris flow behavior with observed data or historical records. Calibration ensures that the model accurately replicates real-world conditions, enhancing its reliability for hazard assessment purposes.

Once calibrated, the RAMMS simulation results undergo validation against independent datasets or additional landslide events within the study area. This validation step serves to verify the accuracy and predictive capability of the model, thereby bolstering confidence in its application for debris flow hazard assessments.

Ultimately, the outcomes of this study highlight the efficacy of utilizing Google Earth Pro satellite data in conjunction with RAMMS for debris flow simulations. Through a systematic methodology encompassing data acquisition, preprocessing, model setup, calibration, and validation, researchers demonstrate the suitability of satellite-derived DEMs for enhancing debris flow hazard assessments. This integration of satellite data into RAMMS represents a promising approach towards improving landslide risk management strategies and enhancing community resilience in landslide-prone regions.

7. Discussion

Raghunath Pura flow was triggered after an excessive rainfall event in 2023. Continuous heavy precipitation for around 7-10 days affected triggering to many new landslides around the zone of Bilaspur-Mandi area (NH-205) in Himachal Pradesh.

Debris flow is considered as a highly heterogenous in lithological composition [8], as well as the particle size distribution (which is up-to size m^3 considered as boulders or blocks).

7.1. Input Data

DEM is the essential data used by RAMMS to define the basic layout of the model. The 0.4m, 5m, 12.5m, 30m resolution was recommended by several researchers as the ideal [21-24], describing how very identical findings were obtained even with a lower resolution. In this study area resolution of 0.4m is considered for all the landslide i.e. LS-1, LS-2, LS-3, LS-4. The possibility to utilize more agreeable, higher-resolution terrain models as the standard model is provided by the most recent upgrade to RAMMS. These input data were utilized to evaluate the numerical model and form a simulation as per the flow happened during the process of the calamity.

A block or the area with an average depth of 15m has been selected which defines the Source area or the release area. In previous outcome a large amount of initial material was resulted as the average depth was selected higher. Another option, which would have been far more appropriate for processes that were seen and flow heights that were recorded, was to create an input hydrograph.

8. Results

8.1. Voellmy Model

After the simulation with RAMMS are performed, the results can then be compared with the field survey data [25]. RAMMS results are highly representable of the actual occurrence as the deposition is approx. 4-5m.

Table 1. Maximum output result of LS-1

Sr No.	Coulomb friction (μ)	Turbulent friction (m/s^2)	Maximum velocity (m/s)	Maximum height (m)	Maximum pressure (KPa)	Release volume (m^3)
1	0.1	50	2.61846	0.244695	12.3414	98714.1
2	0.1	100	2.61846	0.244695	12.3414	98854.1
3	0.1	150	2.61847	0.244830	12.3415	98813
4	0.1	200	2.62007	0.244166	12.3565	99081.5
5	0.2	50	2.52140	0.394064	11.4435	98566
6	0.2	100	2.52140	0.394064	11.4435	98689.4
7	0.2	150	2.52140	0.394064	11.4435	98696.1
8	0.2	200	2.52140	0.394064	11.4435	98754.5
9	0.3	50	0.192163	0.220192	0.0664680	98588
10	0.3	100	0.192163	0.220192	0.0664680	98510.7
11	0.3	150	0.192163	0.220192	0.0664680	98499.6
12	0.3	200	0.192163	0.220192	0.0664680	98545.9
13	0.4	50	0.209171	0.163456	0.0787546	97751.5
14	0.4	100	0.209171	0.163456	0.0787546	97855.7
15	0.4	150	0.209171	0.163456	0.0787546	97791.5
16	0.4	200	0.209171	0.163456	0.0787546	97874.2

The maximum velocity for LS-1 is ranging from 0.192163 to 2.62007 m/s. The values are maximum when the value of coulomb friction 0.1 and that of turbulence coefficient is 200. Similarly, the values are minimum when the coulomb friction and turbulence coefficient is 0.30 respectively. Further, the result shows the volume of the debris flow is approx. 99081.5 m^3. The values for the maximum height and maximum pressure is 0.394064 m and 12.3565 Kpa. The direction of the debris flow is towards the North-West (300º), impacted areas length is 80m, and impacted area width is 60.8m. The impact of debris flow by the RAMMS software model is shown in the Figureure with respect to the simulating time duration.

8.2. Influence of the frictional coefficient on the movement of the slope debris flow of LS-1

The graph is the output result of the RAMMS model simulation of LS-1 which illustrates how important parameters like impact pressure, debris height, and flow velocity fluctuate during the specified duration intervals. It shows the exact timing of these occurrences and successfully illustrates the key times at which the simulated debris flow reaches peak velocity and maximum deposition.

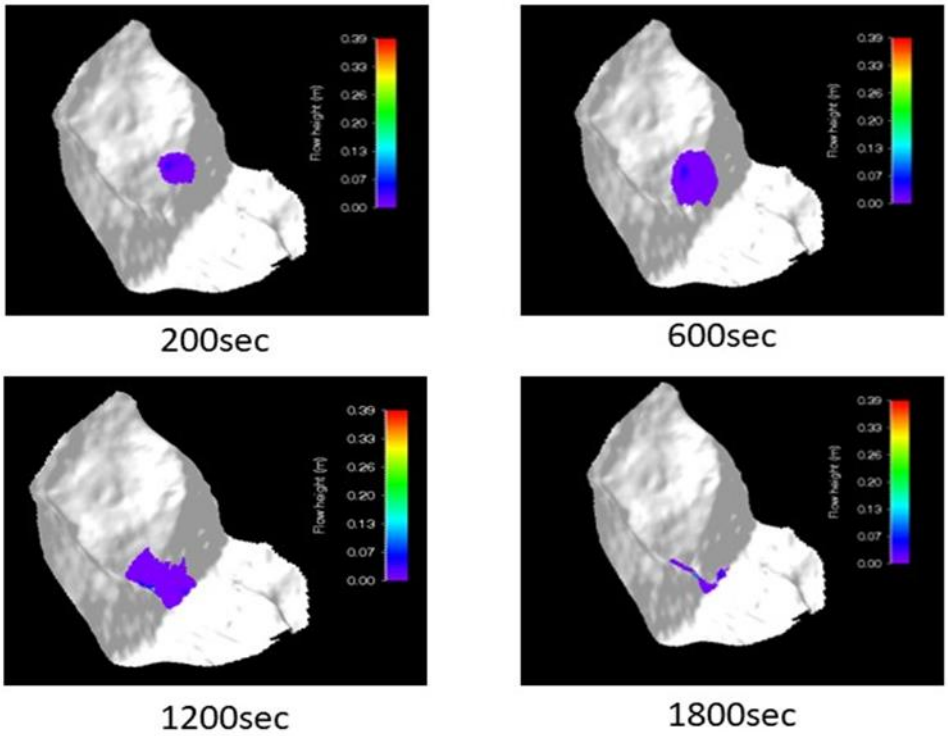

Figure 14. Simulation @200, 600, 1200 and 1800sec

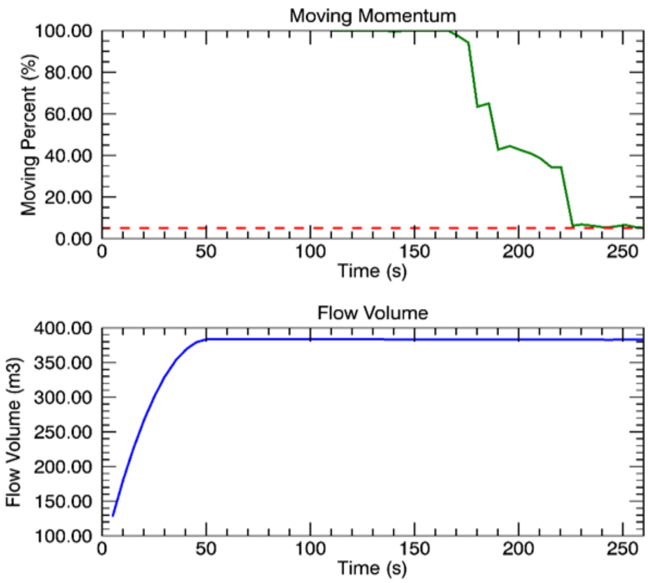

Figure 15. velocity vs time & flow volume vs time graph

Table 2: Maximum output result of LS-2

Sr No.	Coulomb friction (μ)	Turbulent friction (m/s^2)	Maximum velocity (m/s)	Maximum height (m)	Maximum pressure (KPa)	Release volume (m^3)
1	0.1	50	6.20092	0.237762	69.2126	18.38
2	0.1	100	6.07060	0.218661	66.3340	18.29
3	0.1	150	6.34878	0.203994	72.5526	18.23
4	0.1	200	6.34723	0.190913	80.5747	17.98
5	0.2	50	12.1204	1.90520	293.806	17.91
6	0.2	100	12.3286	2.00574	303.987	16.68
7	0.2	150	11.9271	2.09574	284.514	15.72
8	0.2	200	11.9082	2.14939	283.612	15.28
9	0.3	50	11.8831	1.48136	1155.12	8.34
10	0.3	100	12.5065	1.50958	312.824	8.74
11	0.3	150	11.9343	1.51393	284.853	8.13
12	0.3	200	11.5455	1.51827	266.595	8.2
13	0.4	50	12.1583	1.26683	261.632	0.61
14	0.4	100	11.4387	1.23045	261.688	0.65
15	0.4	150	12.7804	1.65535	326.676	0.77
16	0.4	200	13.0113	1.67611	338.590	0.88

The maximum velocity for LS-2 is ranging from 6.07060 to 13.0113 m/s. The values are maximum when the value of coulomb friction 0.4 and that of turbulence coefficient is 200. Similarly, the values are minimum when the coulomb friction and turbulence coefficient is 0.10 and 100 respectively. Further, the result shows the volume of the debris flow is approx. 0.88 m^3 for the maximum velocity. The values for the maximum height and maximum pressure are 2.14939m and 1155.12 Kpa. The direction of the debris flow is towards the South-East (130^o), impacted areas length is 35m, and impacted area width is 44.6m. The impact of debris flow by the RAMMS software model is shown in the Figureure with respect to the simulating time duration.

8.2 Influence of the frictional coefficient on the movement of the slope debris flow of LS-2

The maximum velocity for LS-3 is ranging from 16.1724 to 18.9362 m/s. The values are maximum when the value of coulomb friction 0.1 and that of turbulence coefficient is 200. Similarly, the values are minimum when the coulomb friction and turbulence coefficient is 0.40 and 50 respectively. Further, the result shows the volume of the debris flow is approx. 150863.91 m^3 for the maximum velocity. The values for the maximum height and maximum pressure are 14.8743m and 717.156 Kpa. The direction of the debris flow is towards the South-West (220^o), impacted areas length is 22m, and impacted area width is 95m. The impact of debris flow by the RAMMS software model is shown in the Figureure with respect to the simulating time duration.

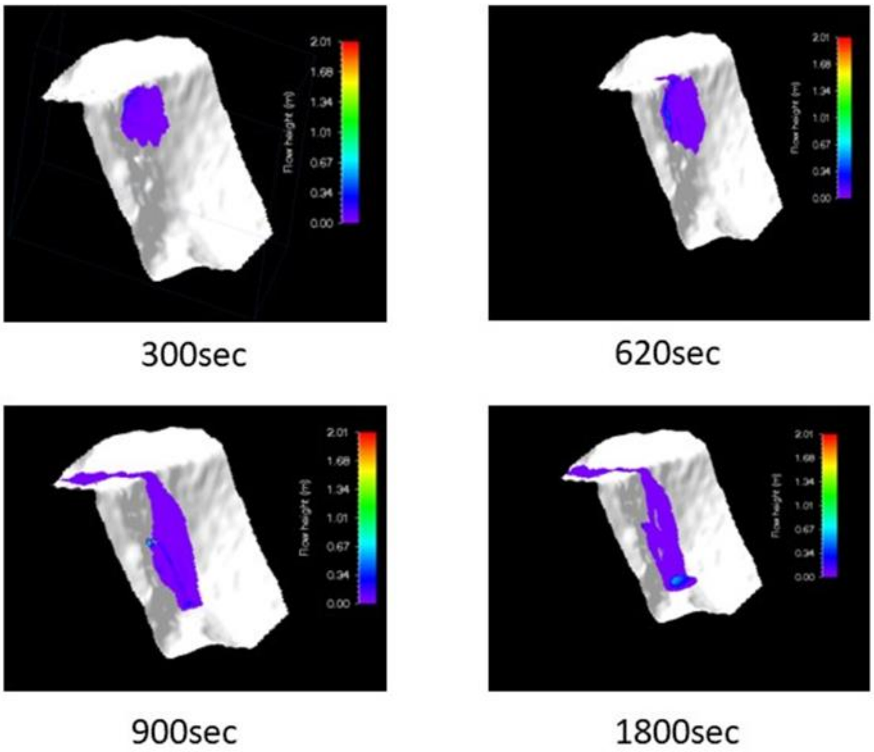

Figure 16. Simulation @300, 620, 900 and 1800sec

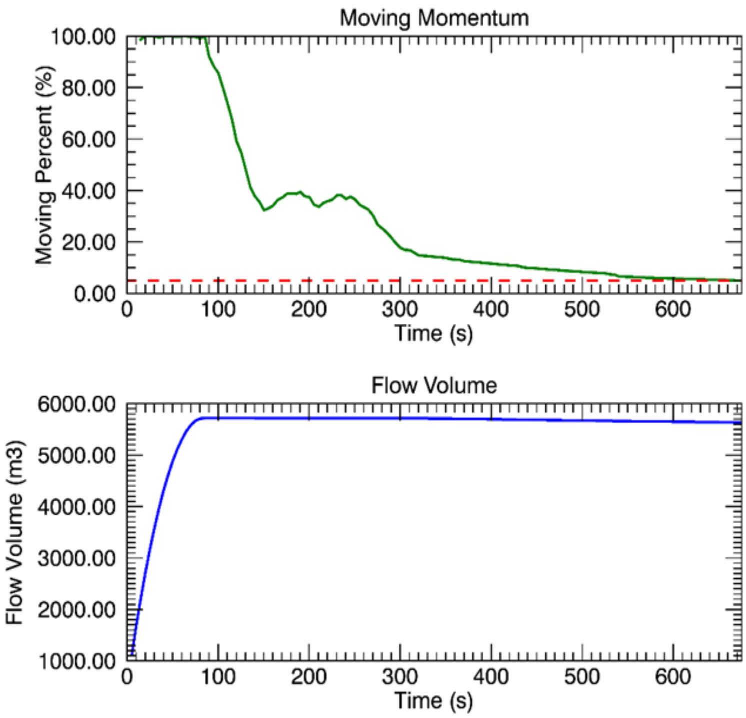

Figure 17. velocity vs time & flow volume vs time graph

Table 3. Maximum output result of LS-3

Sr No.	Coulomb friction (μ)	Turbulent friction (m/s^2)	Maximum velocity (m/s)	Maximum height (m)	Maximum pressure (KPa)	Release volume (m^3)
1	0.1	50	18.8209	12.1289	708.456	151009.73
2	0.1	100	18.8344	11.1503	709.466	149912.04
3	0.1	150	18.6847	11.0409	698.235	150652.49
4	0.1	200	18.9362	10.9979	717.156	150863.91
5	0.2	50	17.0886	13.6920	647.054	147363.61
6	0.2	100	17.7071	13.0802	627.084	146517.63
7	0.2	150	17.7217	12.6149	628.117	146121.46
8	0.2	200	17.6438	12.6341	622.606	145055.38
9	0.3	50	18.1272	14.8432	657.192	137147.78
10	0.3	100	18.3476	14.3541	673.266	135166.35
11	0.3	150	18.3258	13.9730	671.673	133206.99
12	0.3	200	18.4126	13.8558	678.047	131531.09
13	0.4	50	16.1724	15.4453	523.095	112395.57
14	0.4	100	16.9348	14.8743	573.574	111345.32
15	0.4	150	16.4781	14.7802	543.052	110606.53
16	0.4	200	16.7123	14.5896	558.604	110647.51

8.3 Influence of the frictional coefficient on the movement of the slope debris flow of LS-3

The maximum velocity for LS-4 is ranging from 8.92712to 16.0658 m/s. The values are maximum when the value of coulomb friction 0.1 and that of turbulence coefficient is 200. Similarly, the values are minimum when the coulomb friction and turbulence coefficient is 0.40 and 50 respectively. Further, the result shows the volume of the debris flow is approx. 108429.67 m^3 for the maximum velocity. The values for the maximum height and maximum pressure are 10.9665m and 516.220 Kpa. The direction of the debris flow is towards the North-West (300^o), impacted areas length is 80m, and impacted area width is 60.8m. The impact of debris flow by the RAMMS software model is shown in the Figureure with respect to the simulating time duration.

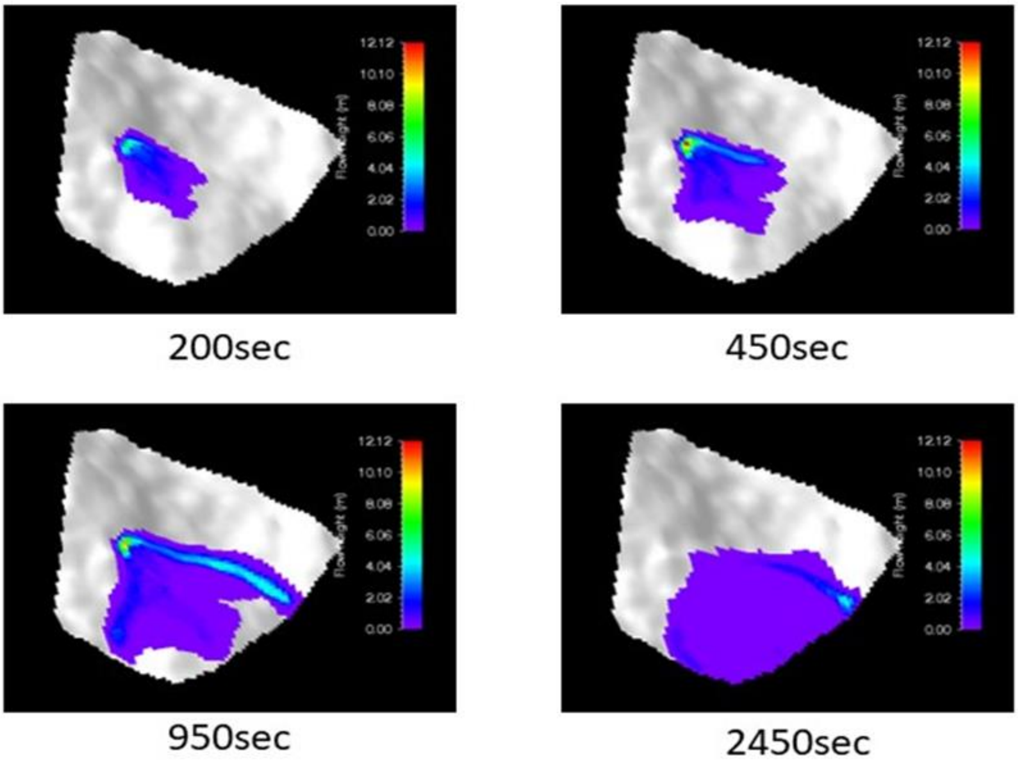

Figure 18. Simulation @300s, 750s, 1300s and 2100sec

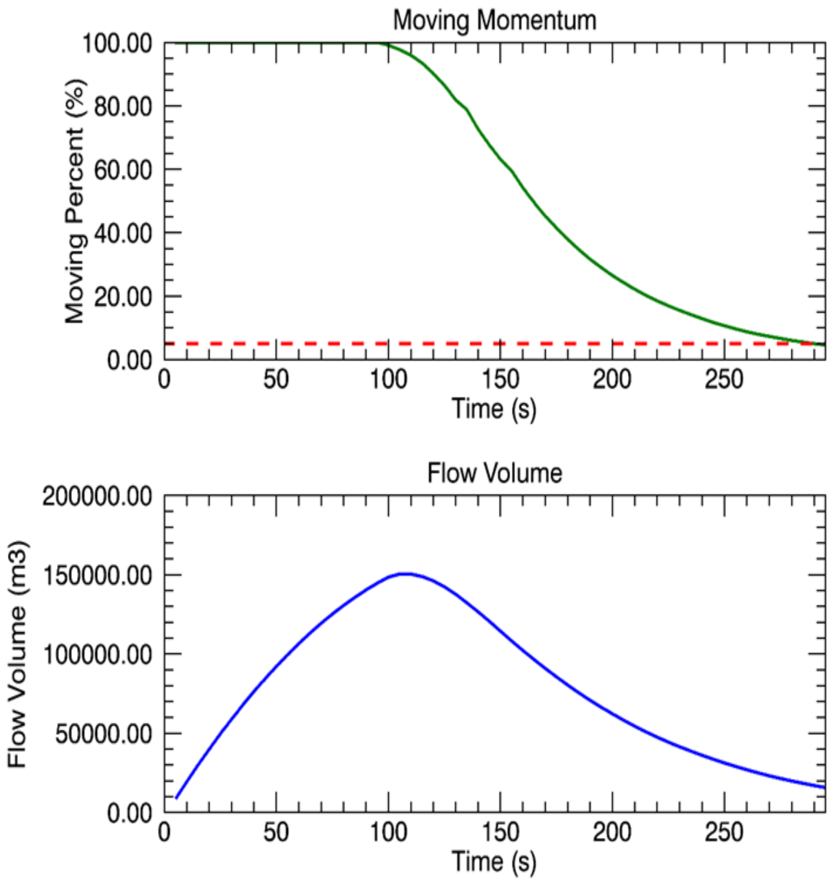

Figure 19. velocity vs time & flow volume vs time graph

Table 4. Maximum output result of LS-4

Sr no.	Mu	g	Maximum velocity (m/s)	Maximum height (m)	Maximum pressure (KPa)	Release volume (m^3)
1	0.1	50	9.79360	10.7563	191.829	108791.06
2	0.1	100	12.4572	10.5860	310.366	108296.02
3	0.1	150	14.5246	10.5152	421.930	108422.38
4	0.1	200	16.0658	10.4735	516.220	108429.67
5	0.2	50	9.50228	9.96358	180.587	90183.08
6	0.2	100	12.3522	9.68979	305.153	94394.45
7	0.2	150	14.3919	9.57180	414.252	96510.06
8	0.2	200	15.8814	9.60932	504.437	97799.81
9	0.3	50	9.11614	10.2145	166.208	64387.54
10	0.3	100	12.1382	9.93930	294.673	66832.52
11	0.3	150	14.1176	9.82213	398.613	67479.09
12	0.3	200	15.5521	9.72740	483.737	69617.06
13	0.4	50	8.92712	10.9665	159.387	18726.71
14	0.4	100	11.9948	10.7754	287.752	19936.43
15	0.4	150	13.9712	10.7397	390.388	20730.78
16	0.4	200	15.6380	10.7272	489.095	21292.81

8.4. Influence of the frictional coefficient on the movement of the slope debris flow of LS-4

Studies on the rate at which debris flows occur throughout time show a relationship between flow velocity and terrain during the initial stages of debris flows. Because the simulation relies on the block release approach, which makes the source starting to landslide comparable, the starting velocity increases with slope steepness.

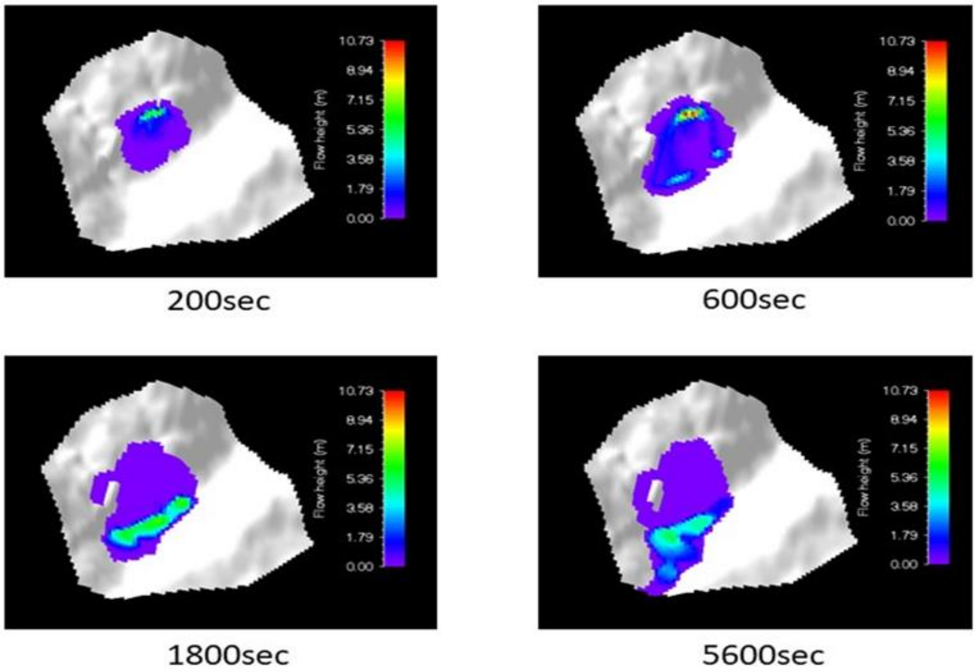

Figure 20. Simulation @200s, 600s, 1800s and 5600sec

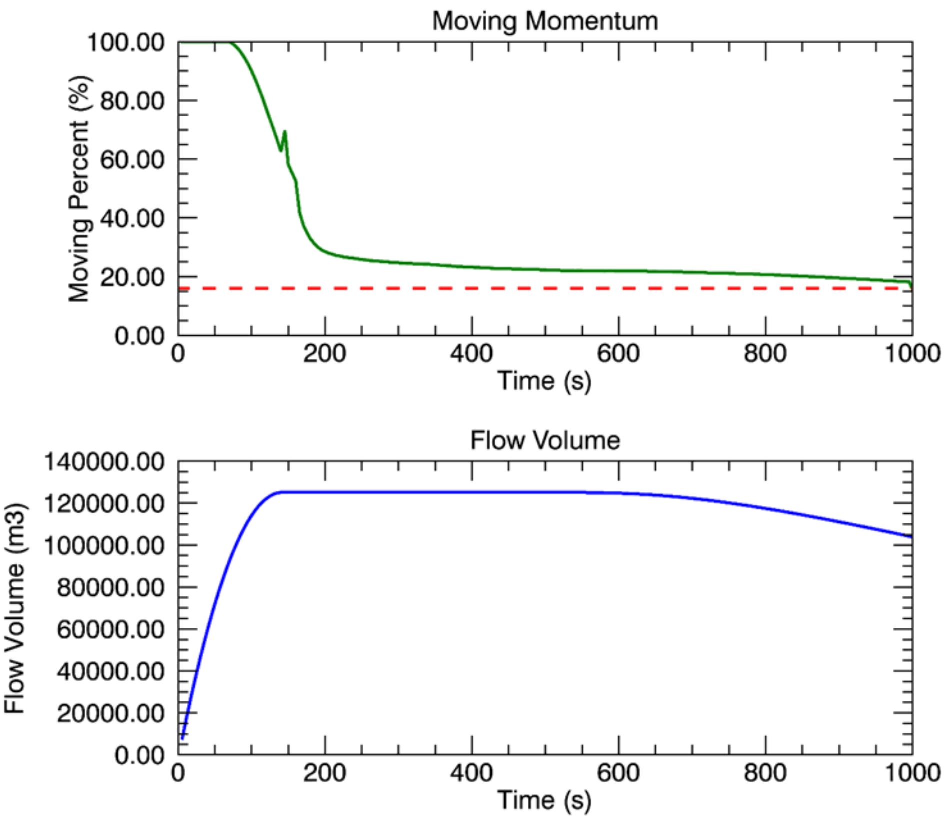

Figure 21. velocity vs time & flow volume vs time graph

9. Conclusions

The comprehensive assessment conducted in this study highlights the significant potential of the Rapid Mass Movement Simulation (RAMMS) tool in effectively predicting and mitigating various types of landslides. Through extensive field visits and detailed photographic documentation, we were able to capture critical pre- and post-landslide conditions, providing a robust dataset for RAMMS simulations. The modeling of different landslide scenarios—rockfalls, debris flows, and avalanches—revealed critical insights into their impact zones, flow velocities, and deposition patterns. These findings emphasize the accuracy and reliability of RAMMS in reflecting real-world landslide behaviors. The successful validation of RAMMS models against field observations demonstrates the tool's applicability in practical settings, reinforcing its value in landslide risk assessment and management. This study also identifies crucial factors that influence landslide susceptibility, contributing to a deeper understanding of landslide dynamics. The proposed mitigation measures, grounded in simulation results, offer targeted strategies to enhance the resilience of at-risk communities. In conclusion, this research underscores the importance of integrating advanced simulation technologies like RAMMS with empirical field data. Such integration not only advances our predictive capabilities but also strengthens the development of comprehensive landslide risk management frameworks. Future studies should continue to refine these models and expand their application across diverse geographical and environmental contexts to further bolster landslide mitigation efforts globally.

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شبیه سازی حرکت توده‌ای سریع بر اساس تجزیه و تحلیل زمین لغزش در امتداد بزرگراه ملی ۲۰۵ در هیماچال پرادش، هند

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پژوهشگر، گروه عمران، دانشگاه چندیگر، موهالی، پنجاب، هند

ارسال ۲۰۲۴/۰۶/۱۴، پذیرش ۲۰۲۴/۰۸/۲۵

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چکیده:

این مطالعه به بررسی کاربرد ابزار شبیه‌سازی حرکت سریع جرم (RAMMS) در ارزیابی و کاهش انواع زمین لغزش می‌پردازد. این تحقیق شامل بازدیدهای میدانی جامع از مناطق مختلف مستعد زمین لغزش، گرفتن شواهد عکاسی دقیق برای مستندسازی شرایط قبل و بعد از زمین لغزش است. با استفاده از داده‌های میدانی، شبیه‌سازی‌های RAMMS برای مدل‌سازی دینامیک سناریوهای مختلف زمین لغزش، از جمله ریزش سنگ، جریان زباله و بهمن انجام شد. شبیه‌سازی‌ها بینش‌هایی را در مورد مناطق تاثیر بالقوه، سرعت‌های جریان، و الگوهای رسوب زمین لغزش‌ها تحت شرایط محیطی متفاوت ارائه می‌کنند. نتایج کارایی RAMMS را در پیش‌بینی رفتار زمین لغزش و هدایت استراتژی‌های کاهش نشان می‌دهد. با مقایسه خروجی‌های شبیه‌سازی با مشاهدات میدانی، ما دقت مدل‌های RAMMS را تأیید کردیم و کاربرد آن‌ها را در برنامه‌های کاربردی دنیای واقعی نشان دادیم. علاوه بر این، این مطالعه عوامل کلیدی مؤثر بر حساسیت زمین لغزش را شناسایی می‌کند و اقدامات کاهش هدفمند را برای افزایش انعطاف‌پذیری جامعه پیشنهاد می‌کند. این تحقیق بر اهمیت ادغام ابزارهای شبیه‌سازی پیشرفته مانند RAMMS با داده‌های میدانی تجربی برای توسعه چارچوب‌های مدیریت ریسک زمین لغزش قوی تأکید می‌کند.

کلمات کلیدی: جریان زباله، شبیه سازی، RAMMS، مدل سازی، لغزش زمین.