MAPPING, MODELING AND SIMULATION OF SNOW AVALANCHE IN ALAKNANDA VALLEY, CENTRAL HIMALAYA: HAZARD ASSESSMENT

Kunj Kishore Sethia[1], Pratima Pandey[1], Shovanlal Chattoraj[1], Surendar Manickam[2], Prashant K. Champati ray[1]

[1]Geosciences and Disaster Management Studies Group, Indian Institute of Remote Sensing, ISRO, Dehradun, India
[2]Friedrich-Alexander-University Erlangen- Nuremberg

ABSTRACT

An attempt has been made to map the potential avalanche zones of Alaknanda valley of central Himalaya by employing analytical hierarchy process (AHP) using remote sensing data in GIS environment. The AHP has been found to be an effective method for mapping of the avalanche prone areas of highly undulating mountains. Further, a numerical simulation of one of the potential avalanching site has been carried out using Rapid Mass Movement Simulation (RAMMS) model was used to determine the flow dynamics of the avalanche sites. The mapping of potential avalanche zones in combination with numerical simulation can provide promising results for prediction of natural hazards occurring in glacial and peri glacial areas.

Index Terms— Avalanche, Analytical hierarchy process (AHP), hazard, rapid mass movements (RAMMS), Himalaya

1. INTRODUCTION

Snow and ice avalanche are rapid and sudden down moving snow or ice after getting broke off from steep slopes. Snow and ice avalanches are frequently occurring natural hazards that significantly affect human lives and properties in the mountainous regions particularly the soldiers, trekkers and researchers. Himalaya is very dynamic mountain system where a large number of snow and ice avalanche is reported every year. Apart from affecting lives, snow avalanche can also alter the mass turnover of a glacier thus modifying the glacier geometry. Many a times the avalanche can trigger debris/mud flow and glacial floods causing extreme disasters. Since avalanches occur at high altitude inaccessible regions, the continuous field-based observation and monitoring is not possible. However, remote sensing along with geographic information systems can efficiently provide an alternative for avalanche and associated hazards. In this contribution we present GIS based AHP method to map the potential avalanching zones of Alaknanda valley of Central Himalaya using remote sensing data, simulation of possible snow/ice avalanches of selected sites where frequent avalanching have been reported by soldiers and locals. Alaknanda valley lies in the central Himalaya and is source of major rivers of India. Further, there are several pilgrimages of various faiths in this region viz. Hemkund Sahib, Badrinath Temple and others; where every year thousands tourists visit. Since, the valley is vulnerable to various glacial and periglacial hazards, it is important to map the potential avalanche zones of the region.

2. DATA AND METHODOLOGY

SRTM DEM with 30m resolution has been used o to derive slope, aspect, elevation and curvature profile. For ground cover classification, cloud free image of Landsat-8 of September 8, 2015 has been used with a horizontal resolution of 30m. A high resolution DEM from ALOS Palsar has been used as input to the RAMSS for the simulation of avalanche. The ALOS DEM has been used specifically for the simulation of RAMSS since the model requires high resolution DEM. The methodology followed for the work has been divided into two groups: avalanche site mapping based on AHP after assigning the weights to terrain parameters; and numerical simulation of the selected demarcated potential avalanche sites. Analytical Hierarchical Process (AHP) is most popular and widely used method in GIS-based decision-making problems [1]. The thematic layers of causative factors namely: slope, elevation, aspect, curvature (using DEM) and land cover (using Landsat-8 OLI imagery) were resampled to a common spatial resolution of 30m while using the SRTM DEM. These thematic layers were employed in GIS and were reclassified. Further ratings were assigned to each thematic layers in the scale of 1 being lowest to 9 being the highest. The highest weight value is allotted to slope factor, followed by elevation, aspect curvature and ground cover. Slope between 25^0 and 45^0 has been found to be most dangerous for avalanche occurrence. The elevation range between 5000 and 6000 masl has been assigned maximum rating. The north and northeast orientation have been more prone for bringing avalanche and have maximum ratings. As far curvature is concerned, the convex curvature has more potential for causing avalanche. Figure 1 explains the methodology followed for avalanche mapping. Snow covered area have been given more rating in ground cover and vegetation the least. In this study, climatic factors such as precipitation and temperature have not been considered as climatic data is this region is very sparse. The identified avalanche susceptibility map has been divided into five zones i.e. very low, low, moderate, high and very high.

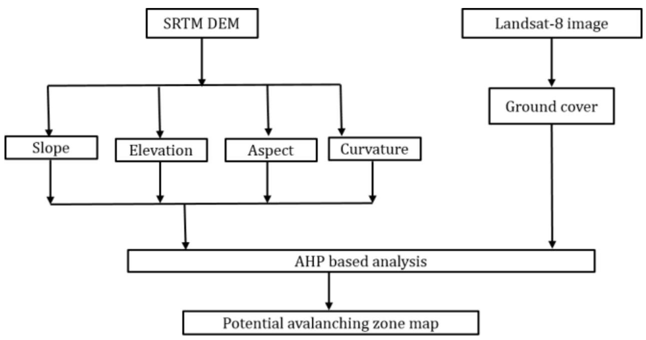

Figure 1: Methodology for avalanche hazard mapping

The Rapid Mass Movement Simulation (RAMMS) model was used to determine the flow dynamics of the selected avalanche sites. RAMMS has been used in other parts of Himalaya also to simulate the glacial lake hazards [2]. The methodology flowchart for numerical simulation model shown in Figure 2. The DEM, Release area and calculation domain, snow density and friction parameter are used as the input parameter for measuring the avalanche flow dynamics. The DEM in the form of ASCII X, Y, Z format and ESRI ASCII Grid format are required for implementation. The release area can be defined by a polygon shape file i.e. release area can be manually drawn in the software or a pre-defined release area shape file can be imported into RAMMS from any GIS software. The initial volume of the release area can be defined based on the height of the release zone. Height and release volume are interrelated i.e. if height of the area increase than volume also increase and vice-versa. In the present study, number of simulations were done by implying various combinations of friction parameters. The coefficient of dry-friction values extending from 0.1 to 0.6 and for turbulent friction; values varying from 1000-3000 m/s2 were used. The friction parameters were selected on the basis of altitude of release area, volume of release area, type of terrain and occurrence period of the avalanches [3]. The other parameters i.e. density, cohesion, release height and percent of momentum were kept constant.

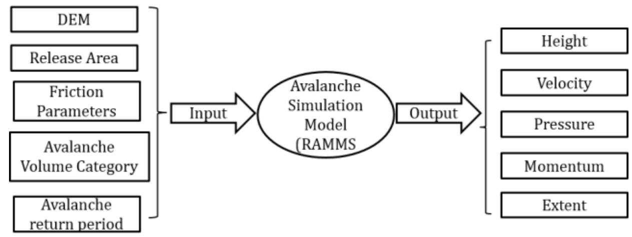

Figure 2: Methodology for RAMMS simulation

3. RESULTS

The identified potential avalanche zones of Alaknanda valley has been shown in Figure 3. The moderate and high and very risk categories covered about 73% of the total area of the valley which is quite significant (Table 1). About 15% area covered the low risk category and 12% as very low risk. After potential avalanche mapping, flow simulations have been performed near the holy town of Badrinath area, and Mana village, where frequent ice avalanche have been reported by local villagers and also by army personnel (Figure 4). The flow modelling delivers four output parameters i.e. velocity, height, pressure and momentum. The model also delivers longitudinal profiles and point profiles for particular location. The avalanche run-out distance, flow height and flow velocity are vital as it delivers the information on aerial extent of the avalanche flow and weather it blocks the road or reaches the road. The avalanche run-out distance, flow height and flow velocity are vital as it delivers the information on aerial extent of the avalanche flow and weather it blocks the road or reaches the road. In first simulation, the avalanche flow was unbranched till it reached the base and has a runout length of 1.9 km (Figure 5 and 6). The second simulation (Figure 7 and 8) has runout length of 2.7 km and its release area was at higher altitude then the first one. The first simulation has a maximum velocity of 42m/s and maximum height of 4.6-4.7m. The velocity and height for second simulation were 37m/s and 12.0-12.8m respectively. For the first simulation, the initial flow volume was 111,228m^3 as the release height was considered as 1m. the μ(Mu) and ξ(Xi) values were taken as 0.35 and 2500m/s^2 as per the software guidelines [2]. For second simulation, the initial flow volume was 230,743m^3. The μ(Mu) and ξ(Xi) values were taken as 0.4 and 1750 m/s^2 as per the software guidelines.

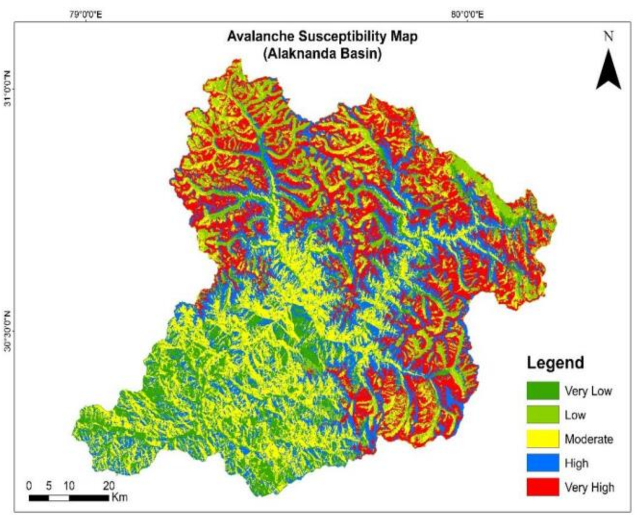

Figure 3: Avalanche hazard map for Alaknanda Valley

Table 1: Avalanche zones in various category

Hazards Zones	Area (km^2)	Area (%)
Very low	802.44	12.06
Low	995.37	14.96
Moderate	1723.41	25.91
High	1621.15	24.37
Very high	1508.7	22.68

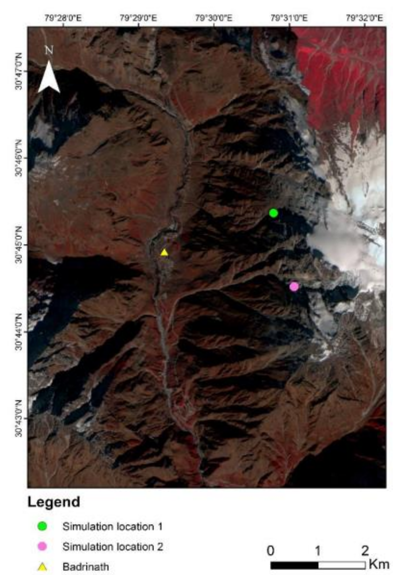

Figure 4: Location of RAMMS simulation sites

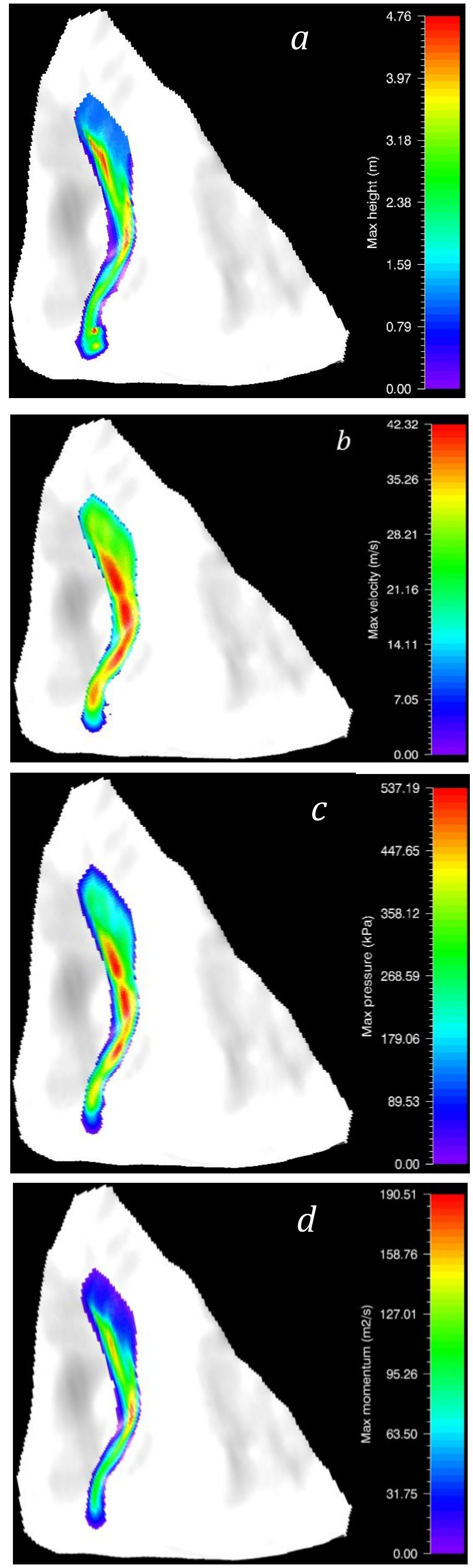

Figure 5: 3D view of simulated flow (a) height (b) velocity (c) pressure and (d) momentum for simulation location 1

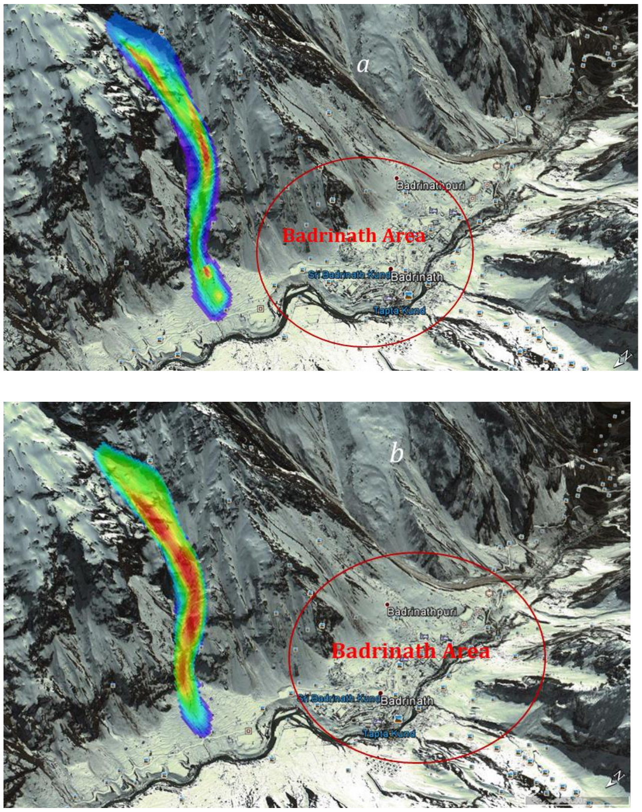

Figure 6: Simulated results for location 1 on Google Earth (a) Height and (b) velocity

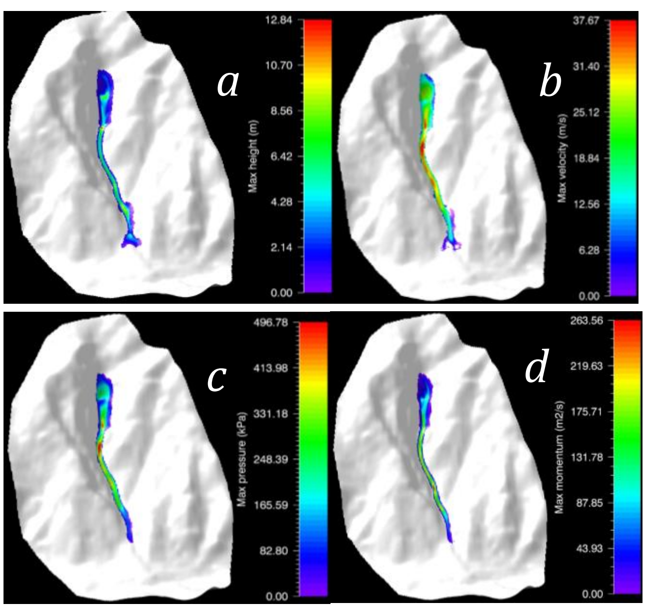

Figure 7: 3D view of simulated flow (a) height (b) velocity (c) pressure and (d) momentum for simulation location 2

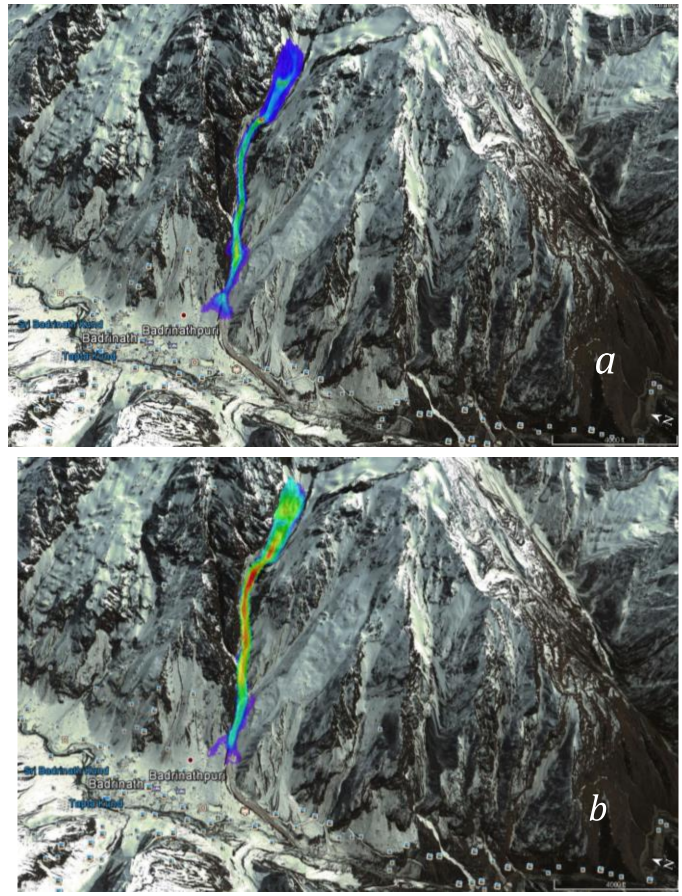

Figure 8: Simulated results for location 2 on Google Earth (a) Height and (b) velocity

4. CONCLUSION

The AHP based methodology is found to be an efficient way of mapping the avalanche prone areas of undulating terrain of Himalaya. Combined with RAMMS, an early warning system can be developed for avalanche and debris flow in the mountainous terrain.

5. REFERENCES

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