Sustainable Earth Review

Journal homepage: http://sustainearth.sbu.ac.ir

Identification and determination of avalanche speed by using radar interferometry (A case study in Varangah Rud at Chalous Road, Iran)

Abolghasem Goorabi[a*], Mohammad Fathollahzadeh[a]

[a] Department of Physical Geography, Faculty of Geography, University of Tehran, Tehran, Iran

A B S T R A C T

Avalanche is one of the natural disasters that annually inflicts heavy casualties on human societies, especially the world's transportation systems, especially in mountainous areas. The use of remote sensing and radar interference knowledge is one of the expanding and efficient methods in identifying changes in the earth's surface, especially avalanches. In this study, radar imaging interference and offset tracking techniques were used to identify the avalanche incident on Chalus Road. The basis of this method is to determine the extent of changes in the characteristics of the Earth's surface, which is determined by changes in radar redistribution. This process is done by comparing the Sentinel-1 radar images before and after the event. After ensuring the results of radar interference by matching it in the Google Earth environment, using the histogram diagram, the frequency changes of radar distribution pixels, the average velocity of avalanche mass displacement in the domain were determined. Based on this, the maximum velocity of Avalanche mass was 45 cm and the maximum displaced volume of Avalanche mass was determined on a slope with a velocity of 5 cm per day, which indicates that the snow mass forming Avalanche has been moved in several stages and along with geomorphological characteristics. The area, the snowfall, and the increase in its volume on the slope have gradually overcome the frictional force between the slope surface and the lower part of the snow mass, causing the avalanche mass to move down the road.

A R T I C L E I N F O

Keywords:
Avalanche
Varangah Rud
Radar Interferometry
Offset Tracking

Article history:
Received: 14 Jan 2021
Accepted: 22 Feb 2021

*corresponding author.
E-mail address:
goorabi@ut.ac.ir
(A.Goorabi)

1. Introduction

Natural hazards have a significant impact on social and economic life, causing great material and human losses and stopping human activities in a short period of time (Ozzy, 2011). Avalanche is one of these natural hazards that annually inflicts heavy casualties on the world's transportation systems, especially in mountainous areas. This phenomenon is rapid and sudden, and its onset usually begins with mechanical breakage in a snowy brick at altitudes and places where temperature changes are in the range of zero degrees.

This phenomenon occurs when the force of gravity on the snow mass overcomes the friction between it and the amplitude surface. Sometimes, this happens gradually and with the weight of the snow mass on the amplitude.

In general, the avalanche is the result of the action and reaction of the avalanche triangle, i.e. snow cover, weather, and terrestrial effects (Fredston and Fesler, 1994). In general, the factors influencing the occurrence of avalanches are classified into two categories: natural causes and human causes. Natural causes include climatic conditions, vegetation, and geomorphological characteristics of the area. Temperature, precipitation, wind, and season (time) are some of the climatic factors influencing the avalanche. Temperature has a direct effect on melting snow and reducing its resistance. The need for an avalanche is the presence of a mass of snow and ice as a result of snowfall. After the snowfall, the wind stimulates the snow and moves it, accumulating it and forming large masses of snow, and sometimes causing the avalanche to start moving (Beyrudian, 2003).

Plants have different effects on avalanches depending on the shape, density, and size of plants. Herbs and herbaceous plants can prevent avalanches. Assuming that the same conditions are observed during the day and night, the avalanche risk factor varies at different times. As the sun sets, the air temperature drops rapidly and the melted snow begins to freeze during the day, continuing until the morning, reducing the likelihood that the snow will move down the amplitude and the avalanche will occur. Of course, this only applies to old snow, and whenever it snows during the night, it is clear that the situation is reversed and the risk is doubled (Rajaei, 2010). The role of geomorphological factors in an area is very important in the occurrence of avalanches. Height, slope, and slope direction are among these features. Studies show that most avalanches in the spring fall at altitudes between 3,000 and 4,500 meters, and at altitudes below 1,500 meters and more than 7,000 meters, less avalanches occur. In winter, the height of 3 to 5 thousand meters is the highest risk of avalanches (Rajaei, 2010). Slope is one of the important factors in the avalanche, so that dry snow and coarse grains up to an angle of 22 degrees have no risk of falling. In general, slopes between 30 and 45 degrees have the highest risk of avalanches. In general, the risk of avalanches falling in the northern, northeastern and eastern slopes is higher than in the southwestern and western slopes, because due to less received radiation, more snow accumulates in these slopes, which can greatly increase the potential for avalanches. The special effect of westerly winds in the mid-latitudes has caused thunderstorms to move from west to east, causing snow to move from the western amplitudes to the northeastern and southeastern one (Karimi, 2008). Human activities in mountainous areas such as cutting down trees and destroying forests on mountain slopes, changing the use of amplitudes, including the creation of ski slopes, and most importantly, the construction of roads and sidewalks along with avalanche-prone areas play an important role in avalanches (Mears, 1992). The most common method in avalanche studies is to zone the risk of avalanches based on climatic characteristics and amplitude geomorphology. Among the works that have been done in this field, we can mention (Qanavati and Karimi, 2009) study in which the risk of avalanches in the region has been zoned based on the geomorphological features and climatic conditions of Haraz road. (Al-Modarresi and Delavar, 2013) in another study using the Geographic Information System (GIS) have identified avalanche-prone areas in the Saman catchment area and endangered residential areas. In this research, zoning has been done according to the geomorphological and climatic characteristics of the region. In addition to the methods of zoning the risk of avalanches, the use of remote sensing techniques is one of the expanding and efficient methods in identifying changes in the earth's surface, especially avalanches. The differential radar interferometry method was first used by (Gabriel et al., 1989). According to Gabriel, the accuracy in differential radar interferometry can be measured at 1 cm or even better, which means that it can be used to accurately measure geophysical, seismic, avalanche, and volcanic phenomena. Radar interferometry was first used to study surface movements in the 1990 earthquake in Landers, California. The basis of this method is to measure the movements of the earth's surface using repetitive images of radar. In this way, the image taken from one area at a given time (reference time) is combined with and compared to the image taken at another time by the same radar sensor from that area, and the changes that occur in the area are identified and determined. With this technology, you can study the movements and changes caused by various phenomena such as earthquakes, avalanches, floods, volcanoes, etc. The use of SAR (Synthetic Aperture Radar) technology to detect avalanches was first made by Italian researchers (Martinez and Fortuni, 2008). The identification of avalanches is done by measuring the difference between the two SAR images before and after the avalanche event, according to which the topographic characteristics of the avalanche area and the potential areas of the avalanche event can be identified and categorized (Eckerstorfer et al., 2015). (Eckerstorfer et al., 2014) among others, has done a lot of work in the field of avalanche study using radar interferometry techniques. In his research, he uses SAR technology and Radarsat-2 images to identify avalanches on various scales in northern Norway. (Wiesmann et al., 2014) using GPR and radar interferometry, identified the mechanism of changes in snow levels in the form of snow creeps that lead to avalanches. It was achieved by identifying a sharp reduction in the time convergence among the extracted interferograms. (Skrede et al., 2016) In a study in monitored the movement of avalanches in parts of Norway and Italy based on INSAR (Interferometric Synthetic Aperture Radar) technology, and while identifying avalanche areas, estimated the amount and speed of avalanche masses and forecasted avalanches in these areas. In another study, (Eckerstorfer et al., 2017) using Sentinel-1 satellite radar data with GRD (Ground Range Detected) characteristics, identified avalanches in different parts of Norway, prepared a map of each of them, and classified the avalanche-prone areas of the country. In this study, Karaj-Chalous road is considered as one of the most important transportation axes from Tehran to the northern cities of the country due to its strategic importance and has special climatic, geomorphic, and topographic conditions. This road that leads to frequent avalanches every year and causes a lot of damages, has been briefly examined to detect its avalanche-proneness and the area of avalanche movement has been identified and determined on February 19, 2017 using radar interferometry within the Varangah Rud area.

2. Material and Methods

2.1. Study Area

Varangah Rud is located at 80 km of Karaj-Chalous road. This area is one of the environs of Asara section and its average altitude is 2550 meters above sea surface. The area is spread over a latitude of 36° 6' 14" to 36° 7' 30" north and longitude 51° 19' 44" to 51° 21' 45". The mountainous location of the region, as well as its climatic characteristics, cause snowfall on the road overlooking the road in winter, which results in an increased risk of avalanches in the rainy seasons (Fig. 1).

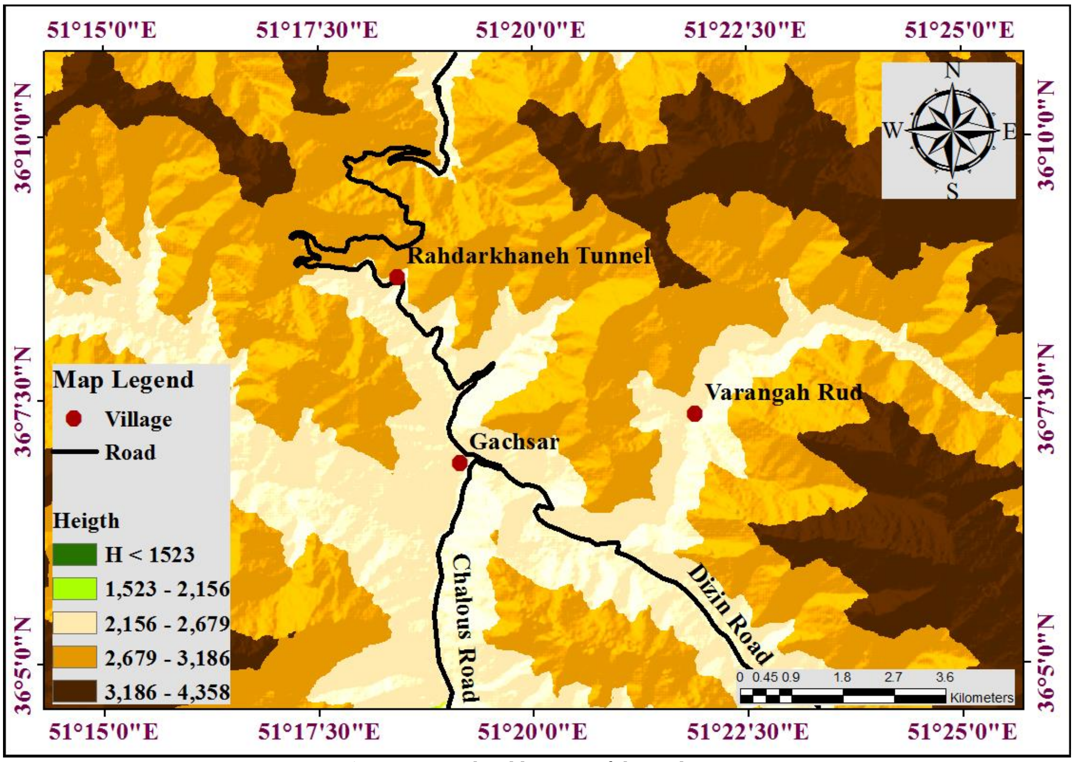

Fig. 1. Geographical location of the study area

The mountainous location of the region has led to the expansion of communication lines and roads in the region, especially in the thalwegs and the valley floor, and this has increased the potential for avalanches on the roads in terms of geomorphology. On the other hand, the slope of the amplitudes overlooking the road at the Dizin intersection is often above 30 degrees, which can be a factor in the occurrence of rapid range of motion, including avalanches in the winter in this area (Fig. 2).

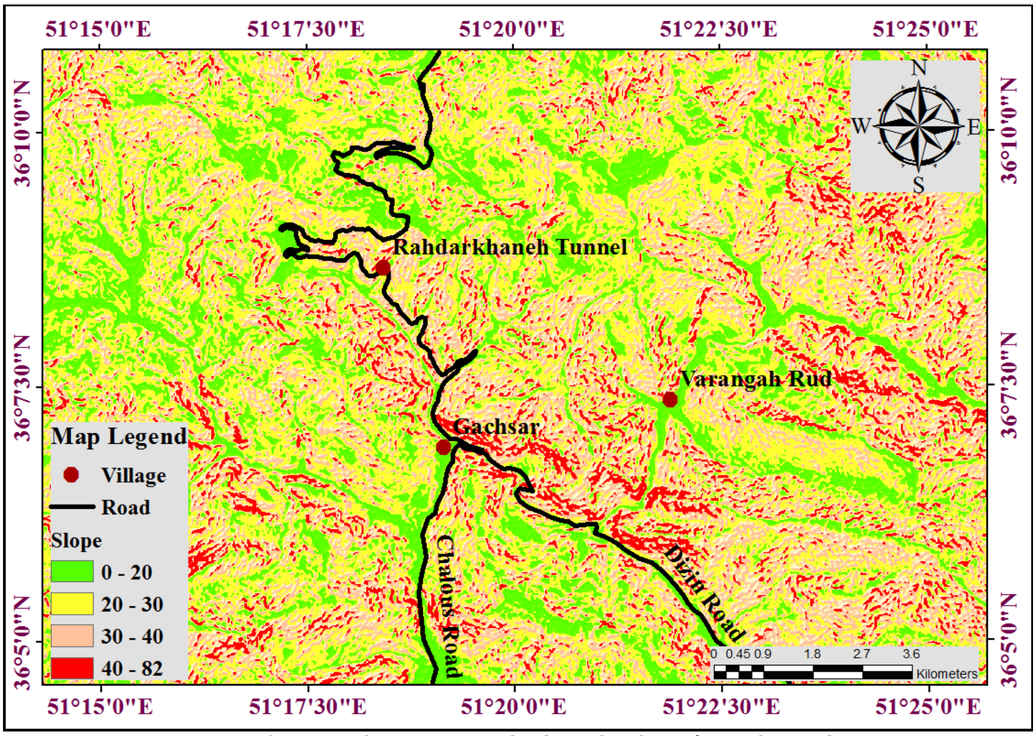

Fig. 2. Dizin three-way placement on amplitudes with a slope of more than 40 degrees

In order to place the amplitudes in this part of the road, according to its west-east trend, it is alternately toward the southwest and northeast. It causes more radiation to be received in the southwestern amplitude during the day, resulting in higher temperature changes in the area during the day and night. On the other hand, the opposite amplitude retains more snow due to less radiation, and this feature can be an important factor in avalanches when there is a mass of snow on the amplitudes. Therefore, the region is completely prone to avalanches in terms of geomorphology (Fig. 3).

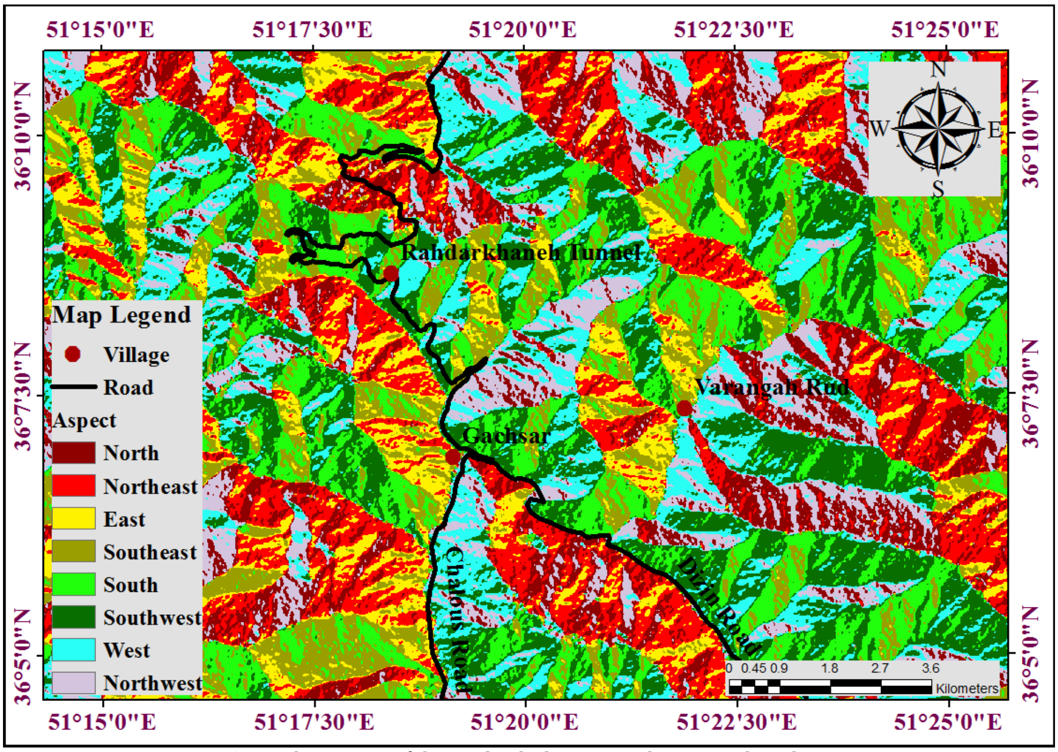

Fig. 3. The position of the amplitude direction in the Varangah Rud area

The study area is influenced by factors such as west-east trend of Alborz Mountain, influence of wet western and northwestern and cold Siberian air masses and proximity to deserts in the Iranian plateau and local conditions. Since most meteorological and rain metering stations have been established in the valleys, the available statistics do not indicate the actual amount of precipitation in the region. Due to the region's relatively high altitude and mountainous conditions, snow accounts for a large share of precipitation, which is the source of most of the region's wastewater, especially in May (Ghelichi et al., 2012).

To determine the potential for an avalanche in the Varangah Rud area and to investigate the presence of a mass of snow in the area, we prepared an optical image of the sentinel-2 optical zone related to February 2, 2017 (before the avalanche event) and examined the area in terms of snow cover. As shown in Figure 4, the Varangah Rud area is completely covered by snow. As a result, there was an initial condition for the avalanche, i.e. snow, on the amplitudes overlooking the road in this time frame (Fig. 4).

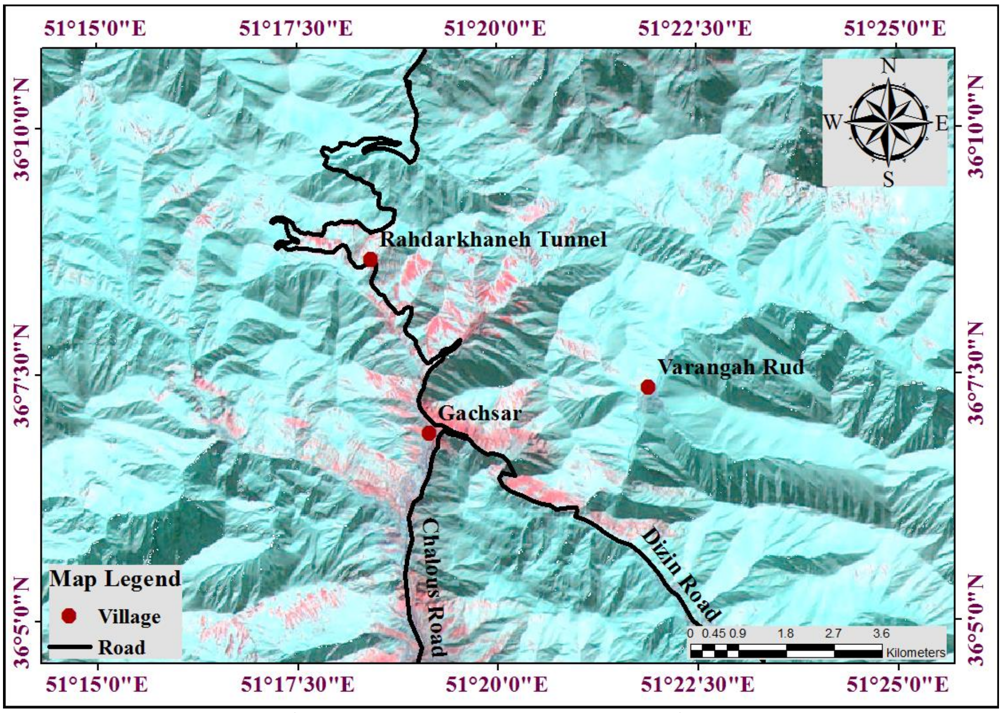

Fig. 4. Existence of snow cover in Varangah Rud valley area before avalanche incident

To detect avalanches in the Varangah Rud area using radar interferometry, Sentinel-1A radar images with GRD characteristics and descending related to the previous date (February 13, 2018) and after the avalanche incident (February 25, 2018) were prepared in the Varangah Rud valley with a suitable spatial baseline (Table 1).

Table. 1. Specifications of images used to identify avalanches

Image	Date	Orbit	Base line(m)	Track
S1A_IW_GRDH_1SDV	2018/02/13, T= 02:37:16	20582	0	35
S1A_IW_GRDH_1SDV	2018/02/25, T= 02:36:50	20757	115.84	35

Offset Tracking technique, which is one of the methods of radar interferometry, was used to identify the anomaly caused by avalanches and determine the average speed of its mass movement in the amplitude. In this method, using the measurement of the change in the distance between the sensor and the amplitude surface in the avalanche motion and causes a change in the surface redistribution of the amplitude, the anomaly caused by the motion of the avalanche mass on the amplitude is determined. Image preparation and processing steps are performed to identify the avalanche range and its movement speed is performed in the SNAP software environment (Fig.5).

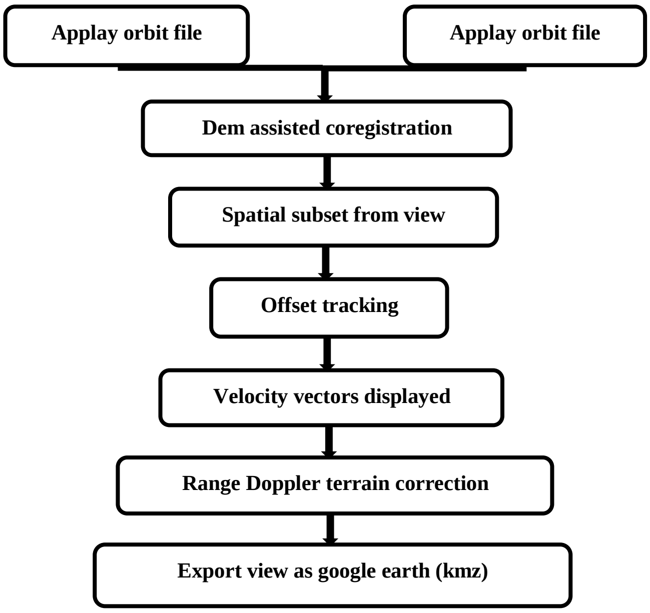

Fig. 5. Flowchart for model execution in SNAP software environment

3. Results and discussion

After processing the images and performing radar interferometry using the Offset Tracking technique in the SNAP software environment, a significant and specific anomaly was observed in the final output of the model, which indicates a fundamental change in radar distribution from the ground surface. To ensure its compliance with the avalanche mass, the model output was transferred to the Google Earth environment (Fig. 6).

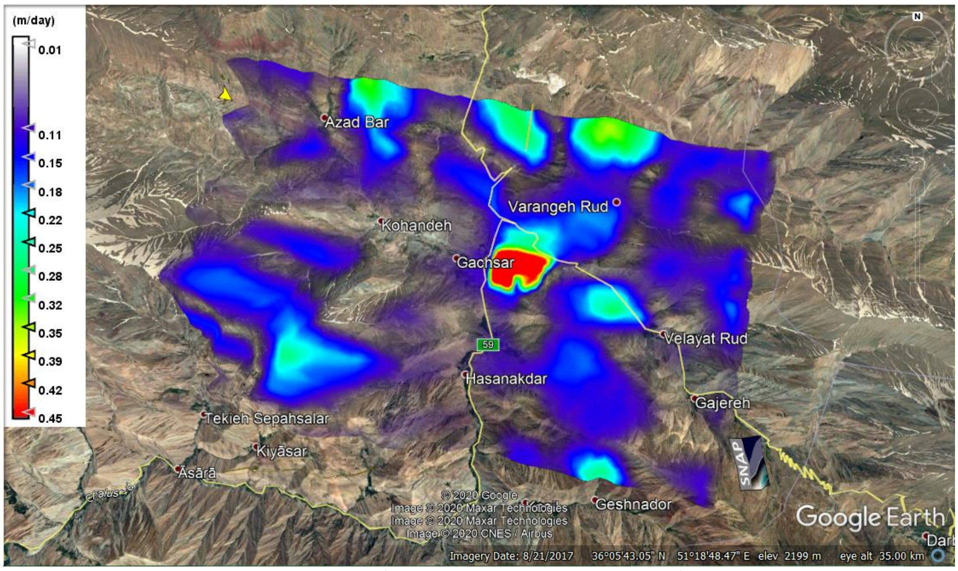

Fig. 6. Determining the range of an avalanche event by radar interferometry (red area)

As can be seen in the figure, the changes identified by the radar interference are fully consistent with the avalanche event area. After ensuring the results obtained from radar interference, using the histogram diagram of the frequency changes of radar distribution pixels, the average velocity of avalanche mass displacement in the amplitude was determined. Accordingly, the maximum speed of the avalanche was determined to be 45 cm per day and it was found that the highest displaced volume of the avalanche occurred on an amplitude with a speed of 5 cm per day, which indicates that the avalanche constituent of the avalanche has been moved in several stages.

In addition to the geomorphological characteristics of the region, snowfall and increasing its volume in the amplitude gradually overcame the frictional force between the amplitude surface and the lower part of the snow mass and caused the downward movement of the avalanche mass towards the road (Fig.7).

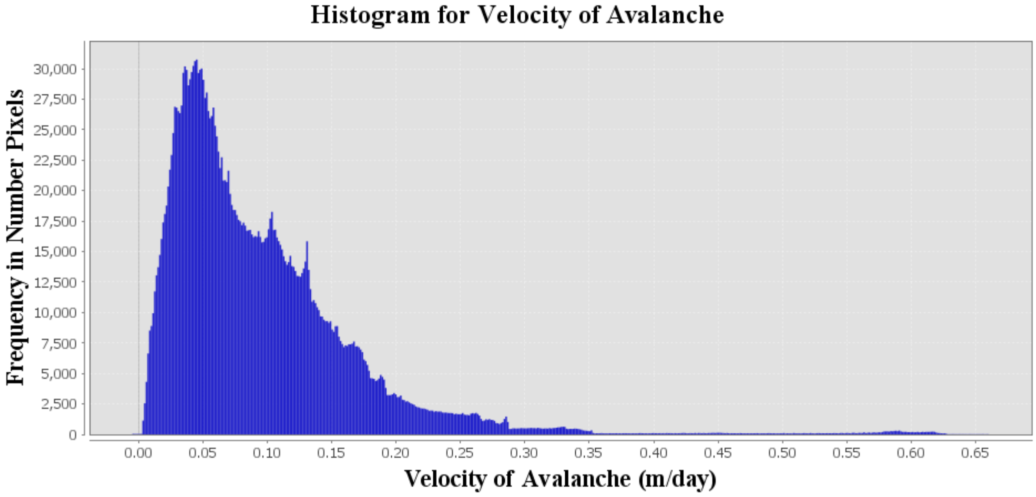

Fig. 7. The speed of the avalanche mass moving down the slope

4. Conclusion

An avalanche is a large mass of snow, ice, and rock that moves down a mountain amplitude. Avalanche is one of the natural hazards that annually inflicts heavy casualties on the world's transportation systems, especially in mountainous areas. The use of remote sensing and radar interferometry knowledge is one of the expanding and efficient methods in identifying changes in the earth's surface, especially avalanches. In this study, radar image interferometry and offset tracking technique were used to identify the avalanche event. Using the histogram diagram of the frequency changes of radar distribution pixels, the average velocity of avalanche mass displacement in the domain were determined. Based on this,_the maximum movement speed of avalanche mass was 45 cm and the maximum displaced volume of avalanche mass was determined on the amplitude with a speed of 5 cm per day. It indicates that the snow mass that forms the avalanche has moved in several stages. In addition to the geomorphological characteristics of the region, snowfall and increasing its volume in the amplitude have gradually overcome the frictional force between the amplitude surface and the lower part of the snow mass and caused the downward movement of the avalanche mass towards the road. The results of this study show that the use of radar interference along with field research can show acceptable results in identifying changes caused by various events, including avalanches on the ground surface.

References

Al-Madrassi, A. & Delavar, A., 2013. Identification of avalanche-prone areas by using GIS (Geographic Information System), *Journal of Environmental Hazards*, 3, p.1-15 (In persain).

Birudian, N., 2003. *Snow and Avalanche (Management of Snow-covered areas*), Imam Reza University Press (In persain).

Eckerstorfer, M., Malnes, E., Frauenfelder, R., Domaas, U. & Brattlien, K., 2014. Avalanche debris detection using satellite-borne radar and optical remote sensing. *In Proceedings of the Inter-15 National Snow Science Workshop*, p. 122-128.

Eckerstorfer, M., Bühler, Y., Frauenfelder, R. & Malnes, E., 2015. Remote sensing of snow avalanches: Recent advances, potential, and limitations. *Cold Regions Science and Technology*, 121, p. 126-140.

Eckerstorfer, M., Malnes, E. & Müller, K., 2017. A complete snow avalanche activity record from a Norwegian forecasting region using Sentinel-1 satellite-radar data, *Cold Regions Science and Technology*, 144, p. 39-51.

Fredston, J. & Fesler, D., 1994. *Snow Sense: A Guide to Evaluating Snow Avalanche Hazard*, Alaska Mountain Safety Center, 116p.

Gabriel, A.K., Goldstein, R.M. & Zebker, H.A., 1989. Mapping small elevation changes over large areas: Differential radar interferometry, *Journal of Geophysical Research Soil Earth*, 94, p. 9183-9191 (In persain).

Ghelichi, E., 2012. *Effects of morphoclimatic and morphodynamic domains on the construction of roads in mountainous areas of the study area of Karaj-Chalous road to Kandovan tunnel*, M.Sc. thesis, Tarbiat Modares University (In persain).

Martinez-Vazquez, A. and Fortuny-Guasch, J., 2008. A GB-SAR processor for snow avalanche identification. *IEEE Transactions on Geoscience and Remote Sensing, 46*(11), p.3948-3956.

Mears, A.I., 1992. *Snow-avalanche hazard analysis for land-use planning and engineering* (No. 49). Colorado Geological Survey, Department of Natural Resources, State of Colorado.

Ozzi, R., 2011. *Geography of Hazards*. Tabriz University Press, 470p (In persain).

Qanavati, E. & Karimi, J., 2009. Bahman Danger Zone on Haraz Road based on Geomorphological Characteristics, *Journal of Applied Research in Geographical Sciences*, 9(12), p. 83-100 (In persain).

Rajaei, A., 2010. *The study of avalanches and its danger zone and providing solutions (case study of Semirom city)*, Master's thesis, Azad University, Tehran Research Sciences Branch (In persain).

Skrede, I., Kristensen, L. & Rivolta, C., 2016. Use of ground based insar radar to monitor glide avalanches, Proceedings, *International Snow Science Workshop*. Breckenridge, Colorado.

Wiesmann, A., Caduff, R., Strozzi, T., Papke, J. & Mätzler, C., 2014. Monitoring of dynamic changes in alpine snow with terrestrial radar imagery. *IEEE Transactions on Geoscience and Remote Sensing,* p.3662-3665