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Research Article

Landslide Susceptible Mapping using InSAR and GIS Techniques: A Case Study at Debresina Area, Ethiopia

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ABSTRACT

Landslide is major problem in Ethiopian highlands (i.e. Debresina area).we mapped landslide susceptible using InSAR and GIS techniques. Researchers used digital elevation model (DEM), minister of water and resource soil map, LANDSAT 8 OLI/TIRS, Ethiopian road map to produce control factors of GIS methods. SAR images (sentinel 1A) also used for landslide displacement during InSAR mehod.result showed that GIS helps for landslide zoning (i.e. very high, high, moderate and low susceptible) and wrapped Interferogram shows -12 to 12 mm/yr displacement. Hence high and very high class overlapped on the highest displacement. Both results were validated with GPS data using Relative landslide density index (R-index) method. Accordingly 90.9 percent of sample points were occurred on displacement map (Interferogram) and the same percent of those points overlapped on high and very high zones. This implies that both InSAR and GIS method can be used for landslide susceptibility mapping but for more accurate works and quantify landslide displacement we recommend InSAR techniques.

Keywords: Landslide; InSAR; GIS; Debresina area

INTRODUCTION

Landslide is used to describe a wide variety of processes that result in the detectable downward and outward movement of a slope material (soil, rock, and vegetation) under gravitational influence. The materials may move by: falling, toppling, sliding, spreading, or flowing [1]. Landslides can be triggered by both natural and manmade changes in the environment. The main causes of landslide are classified in to two:

- Inherent causes of slope failure such as; weakness in the geological composition or geological structures within the rock or soil and
- External triggering mechanisms such as; rainfall, earthquake or volcanic activity, snowmelt and change in ground water level and human activity [2].

Synthetic Aperture Radar (SAR) images contain both the intensity and phase information of the return signals from the earth surface. Whereas SAR Interferometry (InSAR) is a technique in which two SAR images of the same area at the surface of the earth taken from slightly different satellite positions are used to generate an interferogram representing the phase difference between the return signals in two images [3,4]. InSAR technique has been successfully used to study surface deformation and associated features of landslide [4,5]. Space-borne Interferometric Synthetic Aperture Radar (InSAR) has developed rapidly over the past 20 years and has proven to be a valuable tool for topographic mapping and surface deformation measurements [3,4]. Because of its detail spatial coverage and competitive accuracy, InSAR has now become one of the most preferred geodetic methods to study surface deformation associated with slow-moving landslides [6,7]. The operational space born SAR sensor that makes the availability of SAR data currently for professionals across industries in this study was Sentinel-1. Because sentinel -1 is relatively good SAR image can be used for land deformation analysis including landslide mapping [8].

SARPROZ software is powerful software to easily process and analyze SAR data and generate products like Digital Elevation Model (DEM) or surface deformation maps, while giving you the option to integrate this information with other geospatial products. This unique data analysis capability converts the data to meaningful and contextual information.

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The present study area located in central Ethiopia is frequently affected by landslides causing significant damage and casualties to people and property. Therefore, landslide hazard and vulnerability of the lives and property of the community living in the area calls immediate attention to conduct detail investigation using the above mentioned techniques and recommend immediate remedial measures. Statement of the problem and justification

The Ethiopian highlands are frequently affected by landslides of various types, which often lead to eviction of inhabitants and damage to housing, infrastructures and arable land and loss of human lives [9]. Most of the landslides in this region, including the largest ones, are triggered by heavy precipitation occurring at the end of the rainy season [10]. In addition, earthquakes triggering slope failures, which resulted in rock slides, toppling and rock falls are reported by various workers [9].

In the project area, a number of researches related to landslide have been carried out and are mentioned below. Field hydro-geological investigations and geophysical sounding was conducted and reported by Alemayehu [11]. Abay and Barbieri (2012) mapped susceptibility zones and figure out earthquakes in southwestern Afar escarpment as one of the triggering factors [12]. According to these authors, large slope failure occurred in the Yizaba locality north of Debresina town. Hagos (2012) conducted remote sensing and GIS-based landslide mapping as well as landslide susceptibility evaluation at Debresina area [13]. Whereas Matebe carried out GIS-based frequency and logistic regression modeling for landslide susceptibility mapping at Debresina area [14]. Additionally, Kropáˇcek conducted a remote sensing technique for characterization and kinematic analysis of large slope failure [15]. However, the various works carried out in the project area showed substantial differences in the reporting extent and incident regarding the date of occurrence of the major land sliding event in Deberesina area; some authors reported that the major landslide occurred on September 2005 whereas others suggested on September 2006 [14-17]. Based on personal interviews with the local people, Alemayehu, reported existence of the two major landslides in the region one in September 2005 the other in September 2006 [13].

Even if a range of investigations have been carried out in project area, there are still significant variations in the date of occurrence of the major land sliding event in Deberesina area indicating existence of research gap. Furthermore, these authors utilized GIS and remote sensing techniques to investigate landslide occurrences in the project area. In this work:

- A robust geodetic method of SAR interferometry (InSAR), which has not been used in the project area as well as GIS technique of higher spatial resolution, will be utilized
- As a result, it is believed that the discrepancies about the major landslide occurrence date will be resolved by utilizing the high resolution InSAR and GIS techniques.

Therefore, this research is aimed at filling the research gap created by previous researchers as a result of utilizing a robust InSAR and GIS techniques.

DESCRIPTION OF THE STUDY AREA

This research conducted around Debresina area, which is, semen shewa zone, Amhara region, central part of Ethiopia (Figure 1). The study covers 39°29‘00’ to 39°55‘00’ and 9°44‘40’ to 10°10‘20’ longitude and latitude respectively. This study touches mainly Mafud Mezezo Majana wedera, also debrebirhan zuriana keyit,kewet,lalo miodrna mama midr and some extent ankobre woreda. Eight towns are located in study area which is debresina, malale, shewrobit, mezezo, sela dingay, armanya, tarmaber and gode beret. The total area of the study is 1760.103 km2, in other word the study covers 18 km radiues from 9.9500° latitude and 39.7000° longitude.

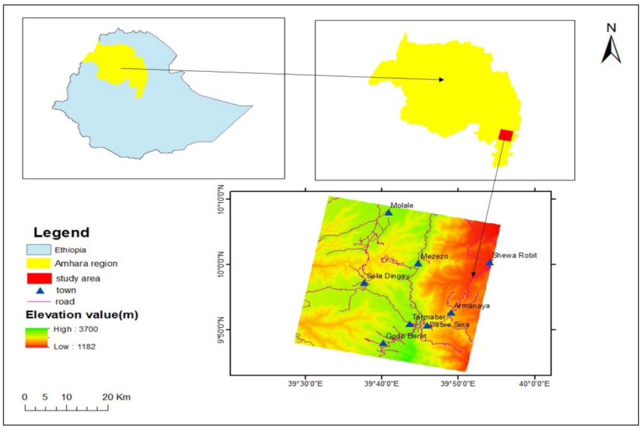

Figure 1: Location map of the project area.

DATA AND METHODOLOGY

Software and instruments to be utilized

To accomplish this study, the following software and instruments were implemented. These are:

SARPROZ-to easily process and analyze SAR data and generate landslide map using InSAR (PS-InSAR); Arc GIS-to produce landslide map by taking controlling factors, Handheld GPS -to collect landslide inventory data for landslide validation.

Data sources and acquisition techniques

In this study, all pertinent data were collected from primary and secondary sources (Table 1). By using direct field observations, primary data such as: GPS data using hand held GPS; others were collected from secondary data (Soil, DEM, Landsat image for GIS and sentinel images for InSAR purposes).

Table 1: Types of secondary data and their sources.

No	Types of data	Source	Purpose
1	DEM	SRTM	To produce slope and elevation maps of the study To generate stream feature to determine the distance from the stream

2	Landsat-8/OLI-TIRS	USGS	To prepare NDVI map
3	SAR images (Sentinel-1A C-band SAR mission)	Copernicus hub	To conduct InSAR particularly PS-InSAR techniques(to generate landslide map)
4	Soil data	Minister of water and Resource(MoWR)	To prepare soil map
5	Road feature	Eth_trs_roads_osm website	To produce road map that shows the relative distance from road
6	GPS data	Field observation using hand held GPS	For validation of landslide result

Methods of landslide mapping

There are different methods of landslide mapping, among these InSAR and GIS techniques are widely used [18,19]. So that this study employed these two techniques for landslide mapping of the study area. The general methodology of this study presented on figure 2, which depicted all data type and produced maps including software's used to accomplish the study.

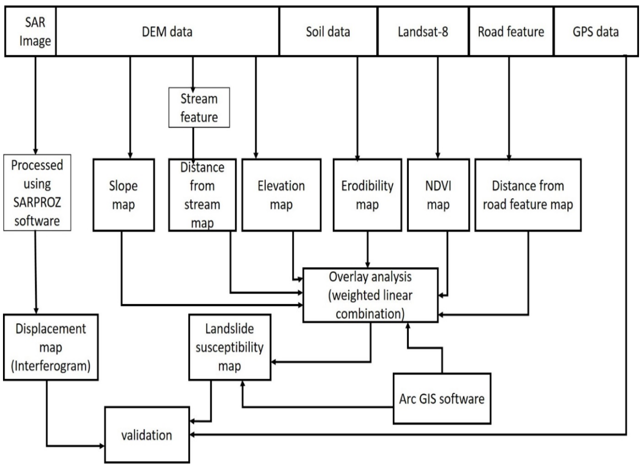

Figure 2: Flow chart showing the methodology pattern of the study.

InSAR method: SAR interferometry is used for the detection of Earth's surface displacements through Differential Interferometry (DInSAR), which has shown to be a tool of great potential over the last decades. Initial single interferogram DInSAR techniques, commonly referred to as conventional DInSAR technique evolved to advanced DInSAR technique which provides information on the temporal evolution of the ground displacement, with a theoretical millimetric precision under favorable conditions. Persistent Scatters (PS-InSAR) is one of advanced DInSAR technique method that work on localized targets), such technique have been applied to ground displacements such as landslide. The basic concept of the DInSAR techniques is to monitor an area through time on a regular basis. TheSAR images acquired in different dates are then combined in pairs to generate a set of differential interferograms that contain information on the interferometric phase. Ideally, differential interferograms should contain only the ground displacement component between the acquisition times of the two SAR images. However, in practice, there are other terms contributing to the interferometric phase that can mask the desired ground displacement information, e.g. phase contributions from atmospheric water vapor. The goal of the different processing techniques is to accurately isolating the displacement term from the remaining components [20].

For this case study , 23 Sentinel-1A data of Single Look Complex (SLC) images in Interferometry Wide swath mode (IW) with VV polarization and descending direction for two acquisition dates 05 June 2020 and 28 March 2015 were registered as master and slave, respectively, in SARPROZ software. SARPROZ is Matlab-written software designed for Multi Temporal Synthetic Aperture Radar processing, provides modules for SAR and InSAR data analysis. It needs license for running the software which is developed by Dr. Daniele Perissin. Although it supports most existing satellite formats and imaging modes, it has no focusing module. As a result, Single Look Complex (SLC) data are a must [21].

GIS method (Weighted linear combination): WLC method is extensively used for landslide susceptibility and hazard mapping due to its application flexibility and expertise knowledge depended. WLC is commonly used amongst researchers and landslide specialist but lacks clear refining steps to derive higher degree of accuracy probability maps. WLC is based on combining weighted averages of a number of parameters selected by the expert. There are no set criteria but purely on expert knowledge. The outcome can significantly vary between experts. Each parameter is classed and multiplied with its assigned weight and within a GIS overlay environment; the weighted averages are added to get the final output map [22].

In WLC, the weight of each parameter considered is added by means of overlay as follows:

$$S = \sum_{i} w_i X_i \quad \text{------Equation 1}$$

Where S is landslide susceptibility, Wi denotes weight of factor and Xi is the criterion score of factor. The different factors are combined by adding their weight to obtain the final output [22-24].

Landslide-Influencing Factors

There are no standard guidelines help to select important factors for landslide mapping. But the nature of the study area, the scale of the analysis, the data availability and the general literature guidelines were taken into account [25].

In our case the criteria are slope, elevation, soil, NDVI, distance from road and stream. These factors used to determine the landslide susceptible map using overlay analysis in GIS environment.

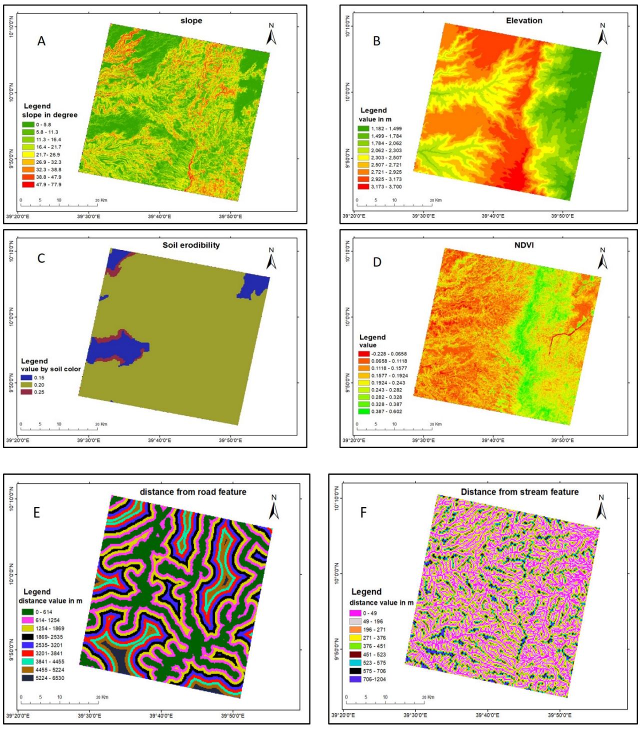

Figure 3: Landslide controlling factors.

Slope: The slope angle is an important controlling factor for landslide hazard analysis. The probability of slope failure increases, as the slope becomes steeper and landslide frequency is expected to be minimum in gentle slopes. The slope map of this study was prepared from ASTER data set which is DEM at 30 m resolution on GIS environment (Figure 3A).

Elevation: Elevation is considered to be important causative factor that affects the landslide susceptibility of a slope [26]. The elevation map of this study was produced from 30 m resolution aster DEM data set by reclassify techniques (Figure 3B)

Soil type: This is one of landslide control factors which type of soil determine the tendency of soil particle to resist sliding across each other. The nature of the movement is, controlled by the earth materials involved. Soil type based on their color can affect landslide. Accordingly in this study, eight type of soil were generated from 1:250,000 digital soil i.e., Chromic Cambisols, Chromic vertisols, Eutric Cambisols, Eutric nitisols, Eutric regosols, Leptosols, Pellic vertisols and Vertic cambisols (figure 3B) .Chromic vertisols and Pellic vertisols have black color. Chromic Cambisols, Eutric Cambisols, Eutric regosols, Leptosols and Vertic cambisols have brown color. Eutric nitisols has red color. The black soils have 0.15 erodiblility (k factor), brown soil type has 0.20 erodibilitty and red soil has 0.25 (Figure 3C) [27].

These means that red colors which has 0.25 erodiblity highly affected by erosion consequences high landslide. But black colors which have 0.15 erodibility have been low affected by erosion consequently less landslide. Here argument is erosion aggravates landslide so that greater erosion leads greater landslide.

Normalized difference vegetation Index (NDVI): Vegetation cover plays an important role in reducing soil erosion. Extensive network of root system provide natural interlocking anchorage of the soil layer along slopes. Highly vegetated slope area generally reduces the effects of soil erosion along the slopes which reduces the susceptibility of landslides and mass movements. Comparatively, a barren area with less or no vegetation is highly prone to erosional activities [24]. For our case NDVI map was produced from Landsat-8 image (OLI-TIRS sensor) with acquisition date May/08/2020 in ArcGIS environment particularly at raster calculator (Figure 3D).

Distance from the road and stream: It is known that the nearest distance to the roads and drainage network show the most susceptibility to landslide occurrence due to the natural slope disruption by roads construction and slope toe erosion by rivers [28]. For this research proximity to road map (m) was generated by clipping from Ethiopia Road Network and proximity to stream map (m) was also generated according to the distance from stream feature (m) which was produced from aster DEM data set at ArcGIS environment particularly using Euclidean distance tool (Figure 3E & 3F respectively).

RESULTS AND DISCUSSION

Landslide hazard zonation

In this study landslide susceptibility map was resulted from triggering factors i.e. Slope. Elevation, Soil, NDVI, Distance from Steam and Road features. Hence spatial relationship between the occurrence of landslides and each landslide causative factor class was derived using overlay analysis (WLC) in GIS environment.

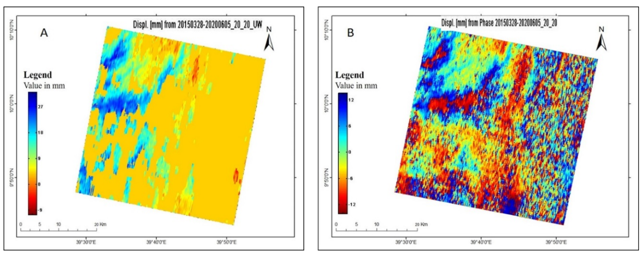

Figure 4: Landslide susceptible Zoning map.

The resulted Landslide map was categorized in to four susceptibility zone i.e. low, moderate, high and very high. Such classification supported with literatures/or research findings like Muhammad B [29]. According to the landslide result map (Figure 4), 280.4868 km^2 area (15.9358%) of the study area covered with low susceptibility, 754.2225 km^2 area (42.851%) covered with moderate, high susceptibility covered 544.2327 km^2 (30.920%) and 181.161 km^2 (10.2932%) was covered with very high susceptibility, which needs high attention to protect present and future loss of life and treasure.

Displacement map (Interferogram

The landslide deformations in Debre Sina area is analyzed by using PS-InSAR (advanced D-InSAR) techniques, which used to observe displacement in the study area specially the area which have very high hazard and high hazard zones in the landslide hazard zonation map.

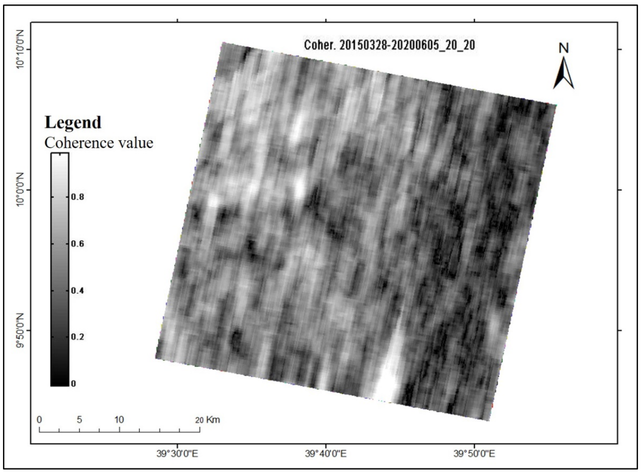

Figure 5: Interferogram (multi look of 20 20) landslide deformation map.

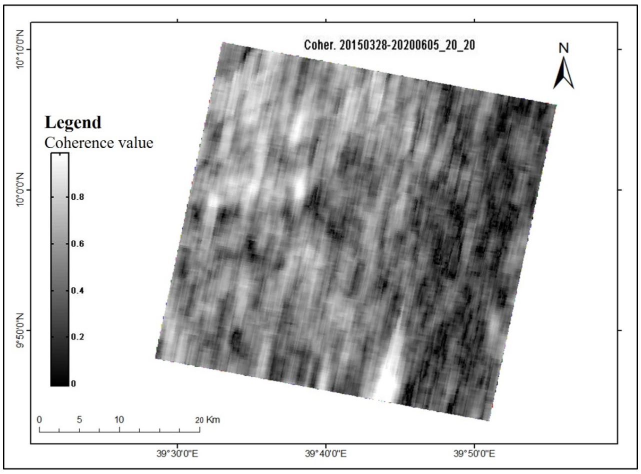

Figure 6: coherence (multi look of 20 20) map of the study area.

The analyzed deformation time-series revealed the presence of displacement from 9 up to 27 mm/year in the velocity of landslide movement for the slopes. The PS-InSAR results depicted that the process of surface displacement in the area is still active. Unwrapped phase applied to get continuous deformation phase value. The temporal phase difference for each PS pixel are calculated and then unwrapped spatially from reference PS pixels using an iterative least square method. PS pixel is also filter using Goldstein phase filter before performing unwrapping (Figure 5A).

Wrapped interfrograms from descending orbit data acquire over Debresina area landslide. The color represents 12 and -12mm of displacement. This can then be estimated using the phase values of the individual PS pixels (Figure 5B).

Coherence map used to show the correlation between master and slave images, and it determined the quality of resulted Interferogram [30]. In this study 0.3 coherence level was used to generate coherence map (Figure 6). Multi look process was applied for unwrapped, wrapped and coherence map to reduce the speckle appearance and to improve the image interpretability.

Validation of landslide susceptibility map

Produced landslide map was validated using Relative landslide density index (R-index) method which helped to assess the relationship between the landslide susceptibility and landslide inventory map (GCP). The sample points were collected in field investigation using handheld GPS. This was carried out by overlay GCP points on susceptible map. In this techniques susceptibility zones correlated with inventory data.

$$R = (ni/Ni)/\sum(ni/Ni) \times 100 \quad \text{------------Equation 2}$$

Where ni the number of landslides occurred in the sensitivity class i and Ni the number of pixels in the same sensitivity class i [31].

Among 11 GCP points that showed landslide occurrence, 10 points which is 90.9 % were coincide on very high and high susceptibility zone.at the same time these points also overlapped on Interferogram which depicted landslide occurrence. Based on this landslide susceptibility could be mapped using InSAR and GIS, but for better landslide mapping, using InSAR is more important than GIS which is only useful for only zoning not actually quantify the amount landslide displacement. This is why slide susceptibility mapping at GIS environment can be validated by InSAR methods. Jan Kropáˇcek revealed that landslide in Debre sina area were very large and affected human activity starting 13 September 2005.in addition Slopes of the Ethiopian Highlands are frequently affected by landslides of various types, which often lead to eviction of inhabitants, damage to housing, infrastructure and arable land and even loss of human lives [10,32]. According to these premises the researchers realized the finding was valid.

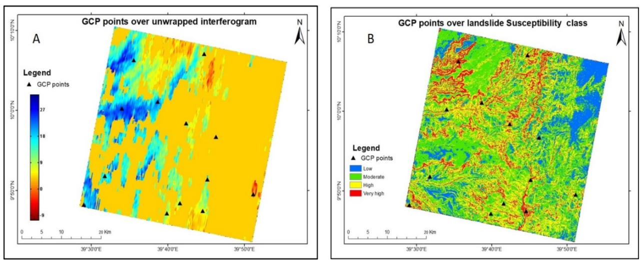

Figure 7: Validation of InSAR and GIS results by GCP points.

CONCLUSION

Landslide susceptibility mapping provides fundamental information for hazard assessment and monitoring strategies. In mountainous area like Deberesina, direct ground based landslide triggering factor mapping and evaluation is expensive and virtually impossible within a short period of time.to solve such limitations, InSAR and GIS techniques provide powerful alternatives for detecting, identifying and monitoring landslides and their related factors.

Six control factors (slope, elevation, soil, NDVI, distance from stream feature and road feature) were used to map landslide zoning. Aster DEM data was used to produce slope, elevation and proximity map from stream and Landsat 8 OLI image was used to generate NDVI map. Eth_trs_roads_osm website and digital soil data from Ethiopian Minister of water and resource (MoWR) were used to get proximity from road and soil map respectively. Consequently, vector data were converted to raster data (30 m resolution).

All causative factors overlaid produced landslide susceptibility zone by weighting linear combination techniques at GIS environment. But the weight of each factors were given according to literatures. Each factors were classified in to 9 class by natural breaks (Jenks) classify method. Among the classified classes, highly slopes and elevations, red color soils which lead high erosion, less vegetation (bare lands), very close proximity distance from the road and stream were the most susceptible to landslide. The final landslide susceptibility map categorized in to 4 classes very high, high, and moderate and low susceptible. Since Debresina area is characterized with highly sloppy and elevation, approximate 41 % strongly affected with slide displacement.

PS-InSAR (advanced D –InSAR) also the most important techniques for landslide displacement mapping. In this project, we used SARPROZ software (which is asked be licensed to install and use) for analyses SAR images. Accordingly,-9 mm/yr. to 27 mm/yr. Displacement which means upward to 27 is uplift and downward to -9 refers subsidence.

The resulting landslide map was validated using R index method which is simple, and this was carried out using GPS points as inventory data. Unfortunately most of selected sample points were put on place where very high or highly prone to landslide. Generally researchers conclude that InSAR and GIS could be used for landslide mapping together or individually. And we strongly believed that for real/quantifying mapping, InSAR method is the more preferred, but for simple zoning class of susceptibility, GIS is also good techniques.

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