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ARTICLE

Effect of Precipitation Characteristics on Spatial and Temporal Variations of Landslide in Kermanshah Province in Iran

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ABSTRACT

Landslide can be defined as the mass movement of sloping slopes under the influence of mass gravity and its stimuli such as earthquakes, floods and flood plains. This phenomenon is one of the natural hazards that every year causes a lot of financial and financial losses in mountainous, rain-fed and seismic areas. Detection of time and the magnitude of landslides are necessary to understand the causes of landslide and to warn potential hazards. In this research, the amount of landslide displacement in Kermanshah province was evaluated by the characteristics of rainfall. To this end, a network of fixed points in and out of the slipping mass of 20 points was created to monitor the amount of displacement on different slip load users and the amount of displacement of each point in 5 time intervals using the Global Positioning System for two-dimensional GPS measurement. The results of the 511-day follow-up showed that the total horizontal displacement of the moving points in the 5 intervals measured at 1658 mm has a monthly displacement rate of 112 mm. Also, the total vertical displacement of moving points at the same time is 899 mm, with a monthly movement rate of 71 mm. Then, precipitation variances such as rainfall, rainfall, precipitation duration, maximum rainfall intensity in the intervals of 10, 20, 30 and 60 minutes and the average rainfall intensity were calculated and extracted for each of the 5 time periods. The drawing of the vectors of points on the topographic map of the area indicated that the direction of mass movement is in the direction of elevation gradient of the region. The results showed that only the precipitation severity with the landslide had a good correlation. The landslide movement had the highest correlation with average rainfall intensity (R = 0.85) and with maximum 30 minutes rainfall (R = 0.67), respectively, and other rainfall characteristics like amount, duration, and type of rainfall had not significantly correlated with movement of landslides.

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1. Introduction

Dominant and landslide instabilities occur for several reasons. In this regard, the role of the intensity and duration of the landing is important for the beginning of the slip, so that today rain is known as the most common cause of landslides [2]. Hong et al. [5] also considered the role of hydrologic factors such as rainfall, soil moisture, subsurface flow and underground water depth in the stability or un-stability of various natural and artificial slopes, and stated that climate change such as increase Extreme and short-term rainfall, due to mild and long-term precipitation, is a factor in increasing landslides and damage caused by them. Rossi et al. [11] by analyzing rainfall data for long and short daily and hourly periods, it was concluded that heavy rainfall in the landslide has a role as a stimulant. Pham et al. [10] also found that at any time during the rainy season, the threshold of precipitation will exceed 682 mm, slip movements will occur. Also, Lin et al. [8] analyzed the landslide mechanism in the Taiwan, saying that extreme intensity and cumulative events of precipitation may be a large-scale and complex event causing disaster. Nevertheless, few studies have been conducted on the role of rainfall agent in landslide due to the lack of landslide data and the continued record of rainfall data globally [9]. Given that earth-landslide moving data is important for researchers in this science to evaluate the deformation stages and the rules of landslide motion, the Global Positioning System and computer science can be used as a tool to observe the amount of landslide displacement [7]. In their studies, observations of the global positioning system have replaced the size of the system in order to ensure the safety of the village, reduce the risk of investment and prevent earthquakes. The commonly used surveys are mapped and now play an important role in monitoring the variation of the surface of the earth. Huang et al. [6] used the observation of the GPS control station to investigate the subsidence of the mine and concluded that the observations of the GPS control network were accurate and highly efficient and could provide reliable data for analyzing the displacement and changes due to mining. Setiawan et al. [12] studied the status and controled of the landslide of a dam in Japan, designed and constructed the network point of this landslide in November 2016 and with six stages studied the planetary networks and the altitude of the landslide. The results showed that landslide movements with acceptable accuracy indicate the movement of the area towards the dam lake is relatively high, which is not the same for different parts of the mass; therefore, the relationship between intensity, duration and type of rainfall on the amount of landslide is monitored and Determining the direction of landslide with the help of the Global Positioning System GPS can be a turning point in the sustainable management of this natural disaster.

2. Study Area

The location of the study area is shown in figure 1. Because of the mountainousness and the relatively high slope of the area, there is a potential for ground thrust [4]. This landslide occurred in 1163, with an area of about 12 hectares between the coordinates of 45.5° and 48° E longitude and 33.7° and 35.3° N latitude (the parallels that cut across the Mediterranean Sea and southern United States) and the landslide in this area passes through a distance of 62 meters from the power village and damaged the road, electricity rails, part of the gardens and agricultural lands of the village. The height of the landslide from the free sea level varies from 1312 to 0122 meters. The main part of precipitation is snowy in the winter season and its melting in spring and summer provides the main source of water in the rivers of the region. Due to the favorable weather conditions and abundance of surface waters in the upstream slopes of the fruit gardens and they have been constructed on a large scale which is irrigated traditionally. On the forehead of this landslide, an abyssal slope with an altitude of more than 82 meters was created and up to a radius of about 122 meters, it formed seams and severe cracks in the asphalt road and agricultural lands located on the upstream landslide.

3. Materials and Methods

After identifying the slipper mass, the spatial displacement of the slipper mass was measured through the creation and measurement of a precise position of the network of points inside and outside the slippery mass in 7 time intervals. The data on the amount of precipitation and its characteristics such as average rainfall, snow depth, average rainfall, and maximum rainfall were calculated at 10, 20, 30 and 60 minutes, and the total precipitation time was calculated for each 7 time periods. Finally, the relationship between the amount of displacement and rainfall characteristics was determined by determining the vertical and horizontal displacement of 15 points in the range of observation in 7 time intervals and precipitation periods for each time interval.

3.1 Identify and Plot the Slider Area on Google Earth and Prepare a Topographic Map

First, the area slip on the Google Earth and the overall information from the area and the slippery range was achieved. After field inspection and removal of the slippery range with a manual GPS device, the target area was

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transferred to the map of the inheritance and traced. It was also observed in desert visits that severe seams and cracks were created in a wide range of neighboring landslide landscapes that are likely to move in the future, which is why the range was also identified on Google Earth. Also, in order to provide a general view of the area and design of the monitoring points network and to identify the slope of each slope, which is one of the main causes of landslides, the topographic map of the slipping range with 1 meter elevation lines was prepared by land survey in 2015.

3.2 Studies of Land Slide Lithology

The sloping mass of the Madstone and Siltstone (related to the Miocene period is the Cenozoic era), and consists of rocks of rustic clay that are reddish and very fine grained. In terms of lithology, the sedimentary sequence is such that the layers of sandstone layers and The reddish conglomerate includes the Paleocene age of the Cenozoic stratigraphy, which is resistant to erosion, and in some parts has a thick layer. The complex of this structure, due to its high formability, tolerates intense corrosion and In general, the area is less visible horizontally. In fact, the mastonne and silt Columns that have high water absorption capacity have a background for landslide in the slab in the form of contiguous layers on a resistant layer and with low permeability of sandstone and conglomerate, along with a high slope and irrigation of the upland gardens. Covering these rocky units and providing these conditions that increase the forces of the actuator and reduce the forces of resistance, the possibility of the slab of the reddish stone unit on the sandstone will be very high.

3.3 Determine the Amount of Slippage Displacement by Creating a Behavioral Measurement Network

In the method of using two-dimensional global positioning systems, the position of the platforms installed on the slip surface on three axes X, Y and Z is calculated at specified intervals and, by analyzing the information, the mechanism of the landslide motion is evaluated. In this study, to monitor the spatial displacement of the slippery mass, a network of fixed points inside and outside the slipped mass was first created, and the precise position of each point in 7 time periods was measured using GPS.

Outside of the landslide area, 3 stations were established as a reference framework and a point network, whose strength was controlled by daily observation of the geodynamic station of the region, whose exact coordinates are determined and controlled daily by the Surveying Organization of the country. A total of 17 control stations were established in order to measure the slipping mass in critical points of the landslide surface with regard to the location of gaps, gaps and suspicious masses and to measure landslide motion. The grid points were selected in such a way that they provide a complete coverage of the driven area along with relative strength.

To determine the displacement of network points, consecutive observations of the monitored points were compared. The spatial variations of the control points in the slippery area were compared to 3 solid points outside the mass during 3 stages in 2015 and 2016, and 4 stages in 2017 and 2018 (3 time intervals by GPS).

Also, by calculating the relative elliptical error ellipse occurred at each point, the meaning of displacements in the dimension of the levels was determined so that if the movement vector was placed inside this ellipse, the analysis would be non-displacement, otherwise the analysis would lead to displacement.

3.4 Weather Data Analysis of Rain-gauge Station

To determine the relationship between rainfall characteristics and the amount of landslide movement, the data were takenat the base of the time of 10 minutes from the rain gardener located at 8 km of the study area was obtained. Also, the monthly statistics of the meteorological station, where snow depth is available in cm, was obtained from the meteorological station in order to determine the relationship between the type of precipitation and the landslide. In order to investigate the relationship between rainfall characteristics and the amount of landslide movement, firstly, the characteristics of each time interval such as average rainfall, as well as maximum precipitation time of 10, 20, 30 and 60 minutes, as well as snow height, average rainfall, and also the total precipitation time was calculated for each time interval. Also, to determine the relationship between precipitation patterns and the amount of displacement, first, the rainfall events less than 2 mm were calculated due to the lack of runoff from the data, and then the remaining features of rainfed events were calculated.

4. Results

4.1 Determination of the Plane and Elevation of Observational Data

At this stage, the difference in the coordinates of two consecutive observation periods was compared and the displacement of the planes and the height of 17 control points in the slip area in the AutoCAD environment were calculated as shown in table 1 to 5.

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4.2 Draw Vectors of Displacing Points on a Topographic Map

After determining the displacement values and directions for moving points, the position of the points of measurement on the topographic map of the foot area and the amount of displacement of points with exaggeration and on another scale in the calculated directions were drawn as directional vectors with their error oval. The minimum and maximum displacement vector of the points of observation with its opaque error on a part of the area are shown in figure 2 and 3.

4.3 Relationship of Rainfall Characteristics and Displacement Rate of Slipping Mass

Over the entire study period, a total of 65 incident occurrences, with a rainfall of more than 2 mm, or 52 cases. The characteristics of the maximum precipitation intensity of 10,20,30 and 60 minutes and the average rainfall, as well as the amount of precipitation, snow depth, the total duration of precipitation for each time interval were calculated and, finally, the correlation coefficient of the maximum rainfall intensity with its other characteristics with the average The horizontal and vertical displacement of points related to the same interval was determined. The results showed that among all the characteristics of rainfall, only the characteristics related to rainfall intensity, are more correlated with the mean horizontal and vertical displacement of 7 time intervals. But the rest of the precipitation properties did not show a good relationship with the displacements of the points.

5. Discussion

In this study the effects of rainfall characteristics on landslide is analyzed. It's very important to apply GPS and effects of rainfall characteristics in the landslide hazard research field and it could become a major tool for analyzing landslides that occur in the region.

However, previous studies did not consider this effect in Iran. Alcántara et al. [1], studied landslides around the world, visiting sites and analyzing post-landslide data. However, their study did not include Iran areas. Their study showed that the landslide happened on an active fault line that is creeping at a rate of 2.5 centimeters (1 inch) per year in specific areas. That might seem gentle, however over time the movement grinds and breaks up the rock, affecting the stability of surrounding slopes and making them more prone to landslides. Their results showed that tectonic weakening was a preconditioning element making that slope vulnerable to catastrophic failure.

They applied their ground observations to validate what they had observed in remotely sensed data. However, they only analyzed vertical movement of landslide. Nevertheless, this current study analyzed both vertical and horizontal movement of landslide.

In order to investigate rainfall as a potential factor that effect on landslide, Yang et al. [14] considered satellite imagery from TRMM. The TRMM image revealed that, in tropical area, more than sixty-eight centimeters (twenty-seven inches) of rain had fallen between February 4, 2006, and February 17, 2006. This was excessive rainfall beyond the monthly averages—more than twice as much that probably cause landslide. However, other rainfall characteristics did not consider in their study.

In addition, Ciabatta et al. [3] participated to the development of the TRMM Real-Time Multi-Satellite Precipitation Analysis (TMPA-RT) product. The TMPA-RT data, presently available online from 2002 through the present, are updated in real time, permitting users to measure if a region is currently receiving particularly intense rainfall or has reached a critical level of accumulation. However, the data is limited and not available for all countries and all regions.

Furthermore, a research on world assessed TMPA-RT data to help gauge precipitation and flooding in more than 250 river basins worldwide. It may also help to analyze landslide events [13].

Developing the TMPA-RT system can be more useful to local governments and organizations on the ground to analyze landslide movement for all regions in the world. As with many mountainous areas in the world, timely landslide hazard assessment may be difficult to accomplish without satellite data. This system will be valuable when national and international organizations must plan disaster mitigation or relief work. It can give them quantitative information about where exactly the hazard is and which areas are affected. So, for future research, analyzing the characteristics of precipitation with TMPA-RT system can recommend.

6. Conclusion

In this paper, the relationship between rainfall characteristics such as severity, amount, duration and type of precipitation on the landslide displacement in Kermanshah province was investigated. The results of the analysis of observations and the analysis of the displacement of points in 7 time intervals showed that relative displacement occurred between some points in the network. By drawing the vectors of moving points on the topographic map of the region, the direction of mass movement is in the direction of the general slope of the region. Meanwhile,

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although there are vertical and horizontal displacements between all the points of the network within the landslide range, there is a significant decrease in the displacement at the margins of points 1, 2, 4 and 8. The total amount of horizontal displacement of the moving points in 5 periods of time of observation is 1900 mm, with a monthly movement rate of 112 mm. Also, the total amount of vertical displacement of moving points at the same time is 736 mm with a monthly displacement rate of 51 mm. The results showed that among the different precipitation characteristics, only the rainfall intensity and slip density mass ratios are in good agreement. The previous studies also Similar results were obtained regarding the effective role of precipitation and the relationship between precipitation intensity and landslide occurrence. The highest correlation coefficient is between the average rainfall and the maximum rainfall of 30 minutes with the horizontal displacement of the slipper mass. There was no significant relationship between other characteristics of rainfall, such as amount, duration and type of precipitation, including snow or rain, and the amount of slippage mass. In general, it can be concluded that the effect of different factors such as topography, soil formation, geology, use and precipitation severity Has created favorable conditions for the slippage of the slipping mass in the area, but in this landslide, the effective role has been played by the intensity of precipitation.

Declaration

Competing Interests

"The authors declare that they have no competing interests."

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Authors' Contributions

Safieh Javadinejad designed this research and she wrote this paper and she collected the necessary data and she did analysis of the data.

Rebwar Dara participated in drafted the manuscript and he contributed in the collection of data and interpretation of data and edited the format of the paper under the manuscript style.

Forough Jafary participated in the data collected and data analysis.

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Supplements

List of Tables

Table 1. Network displacement values of points in the 175-day intervals of the first and second stages of observations (2015-2016)

Situation of vertical movement	Situation of horizontal movement	**Vertical movement (mm)**	**Horizontal movement (mm)**	**Movement on y axis (mm)**	**Movement on x axis (mm)**	**Number of point**
Movement happened	Movement happened	-26	34	-30	-17	1
Movement happened	Movement happened	-48	131	6	-130	2
Movement happened	Without movement	-15	2	2	2	3
Movement happened	Without movement	-13	6	-4	5	4
Movement happened	Without movement	-17	6	2	-7	5
Movement happened	Movement happened	-19	37	-35	-13	6
Without movement	Movement happened	7	10	-10	-4	7
Movement happened	Movement happened	-26	40	-32	-24	8
Movement happened	Without movement	-16	6	3	6	9
Without movement	Movement happened	-11	11	3	-11	10
Movement happened	Without movement	-15	5	-5	0	11
Movement happened	Movement happened	-21	6	-5	-4	12
Without movement	Movement happened	6	11	-8	-8	13
Movement happened	Without movement	-15	5	-2	4	14
Without movement	Movement happened	-9	12	-11	-3	15
Without movement	Movement happened	-14	11	-8	9	16
Without movement	Movement happened	10	22	-5	-22	17

Table 2. The values of the network of control points in the 102-day intervals of the second and third stages of the year(2015-2016)

Situation of vertical movement	Situation of horizontal movement	Vertical movement (mm)	Horizontal movement (mm)	Movement on y axis (mm)	Movement on x axis (mm)	Number of point
Movement happened	Movement happened	-24	161	-143	-74	1
Movement happened	Movement happened	-113	168	4	-168	2
Without movement	Without movement	19	7	-5	-6	3
Without movement	Movement happened	6	16	-2	-15	4
Without movement	Without movement	2	6	-5	5	5
Without movement	Movement happened	-4	164	-160	-37	6
Movement happened	Without movement	-22	3	-2	-2	7
Movement happened	Movement happened	-83	244	-217	-112	8
Without movement	Without movement	7	6	-3	-6	9
Without movement	Without movement	-2	6	-5	6	10
Without movement	Movement happened	15	13	4	-12	11
Without movement	Without movement	7	4	-3	-4	12
Movement happened	Without movement	-25	12	12	5	13
Without movement	Without movement	-2	7	-2	-7	14
Without movement	Without movement	2	8	6	-7	15
Without movement	Without movement	-7	8	5	-7	16
Movement happened	Without movement	-25	10	7	8	17

Table 3. Networking values of points in the 70-day time interval of the first and second stages of the year 2017 and 2018

Situation of vertical movement	Situation of horizontal movement	Vertical movement (mm)	Horizontal movement (mm)	Movement on y axis (mm)	Movement on x axis (mm)	Number of point
Without movement	Without movement	-12	20	-18	-8	1
Without movement	Without movement	-19	19	-6	-18	2
Without movement	Without movement	-17	9	-9	2	3
Without movement	Without movement	11	17	-17	-6	4
Without movement	Without movement	-14	9	-5	8	5
Without movement	Without movement	-16	24	-21	-11	6
Without movement	Without movement	-10	12	2	12	7
Without movement	Movement happened	-25	47	-46	6	8
Without movement	Without movement	-13	9	6	7	9
Without movement	Without movement	-15	9	6	7	10
Without movement	Without movement	13	20	5	-19	11
Without movement	Without movement	-16	7	-6	-4	12
Without movement	Without movement	-19	17	-15	-8	13
Without movement	Without movement	-7	6	2	6	14
Without movement	Without movement	-8	10	-8	-6	15
Without movement	Without movement	-13	15	-15	-4	16
Without movement	Without movement	10	10	-9	-5	17

Table 4. Network displacement values of points in the 106-day period of the second and third stages of observations of 2017 and 2018

Situation of vertical movement	Situation of horizontal movement	Vertical movement (mm)	Horizontal movement (mm)	**Movement on y axis (mm)**	**Movement on x axis (mm)**	**Number of point**
Without movement	Movement happened	-27	73	-73	-5	1
Movement happened	Movement happened	-52	116	-28	-113	2
Without movement	Without movement	15	11	-4	11	3
Without movement	Without movement	-12	15	-7	-14	4
Without movement	Without movement	-6	9	8	6	5
Without movement	Movement happened	12	68	-68	-7	6
Without movement	Without movement	11	9	-9	0	7
Movement happened	Movement happened	-44	55	-55	5	8
Without movement	Without movement	13	15	-9	-13	9
Without movement	Without movement	-6	8	-7	-5	10
Without movement	Without movement	-23	10	-10	5	11
Without movement	Without movement	-14	11	-11	0	12
Without movement	Without movement	-16	16	9	14	13
Without movement	Without movement	8	5	2	5	14
Without movement	Without movement	-17	12	2	12	15
Without movement	Without movement	-14	14	-8	12	16
Without movement	Without movement	-28	14	-5	-13	17

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Table 5. Network displacement values of points in the 78-day period of the third and fourth stage of observations of year 2017 and 2018

Situation of vertical movement	Situation of horizontal movement	Vertical movement (mm)	Horizontal movement (mm)	Movement on y axis (mm)	Movement on x axis (mm)	Number of point
Without movement	Movement happened	-25	77	-57	-53	1
Movement happened	Movement happened	-88	138	11	-137	2
Without movement	Without movement	-20	8	-6	-6	3
Without movement	Without movement	17	13	-13	-4	4
Without movement	Without movement	-11	10	-6	8	5
Without movement	Movement happened	-18	100	-88	-22	6
Without movement	Without movement	-18	10	4	9	7
Movement happened	Movement happened	-47	100	-98	-21	8
Without movement	Without movement	-20	18	-15	11	9
Without movement	Without movement	-12	10	-9	4	10
Without movement	Without movement	13	11	10	6	11
Without movement	Without movement	10	4	3	-2	12
Without movement	Without movement	-4	22	-21	-9	13
Without movement	Without movement	-30	11	-8	-8	14
Without movement	Without movement	-14	11	-10	-4	15
Without movement	Without movement	15	9	6	-7	16
Movement happened	Movement happened	-166	46	-32	-33	17

Table 6. Correlation coefficient of rainfall characteristics with horizontal and vertical displacement of points of observation in 7 time intervals

Movement	Whole duration of rainfall	Average of duration of rainfall	Snow height	Amount of rainfall	Average of intensity of rainfall	Intensity of rainfall in different time interval(mm/hr)			
						10	20	30	60
Vertical	0.006	0.02	0.018	0.006	0.029	0.62	0.40	0.38	0.43
Horizontal	0.092	0.118	0.103	0.060	0.864	0.37	0.60	0.66	0.53

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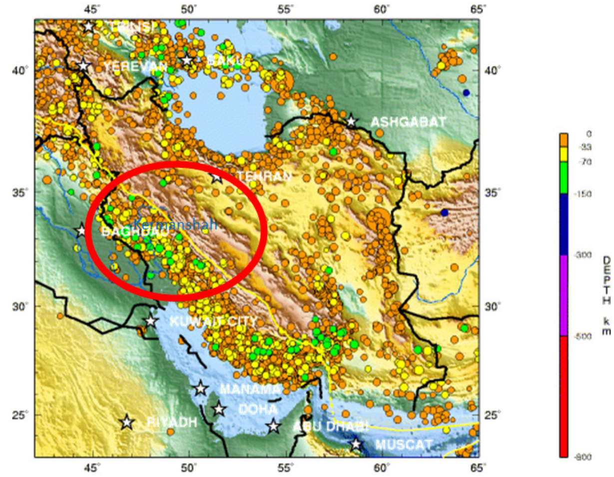

Figure 1. Study area and the location of Kermanshah

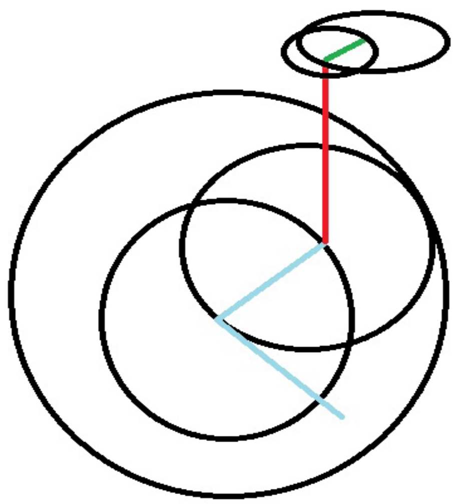

Figure 2. The minimum displacement vector of the points of observation with its opaque error on a part of the area

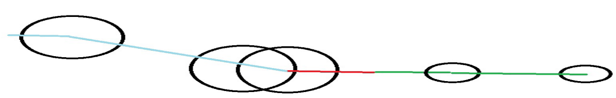

Figure 3. The maximum displacement vector of the points of observation with its opaque error on a part of the area

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