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Soil Movements Correlation to Pluviometric Events in BR-101 Highway, in Santa Catarina, Brazil

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Abstract. Natural disasters involving soil movements are likely to occur in regions with irregular surfaces as Serra do Mar, a characteristic mountain range of the Brazilian coast, composed mostly by colluvium/talus deposits and residual soils. When slope failure occurs in highways, it can affect users and cause economic and environmental losses. Therefore, it is necessary to guarantee the safety during the lifetime of these roads. The stability of a natural slope is controlled by a complex interaction between hydrological and geological processes along with rainfall events of high intensity, which represents one of the main factors triggering slope instability. Thus, it is important to understand the relation between rainfall and mass movements. The main objective of this study was to analyze the mass movement occurrences recorded in the influence area of a rain gauge, located in km 140+700 m of BR-101 highway, in Santa Catarina, Brazil, and correlate them to the rainfall events registered by the instrument. The study period covers six years of monitoring, from July 2012 to June 2018, in which 16 occurrences were recorded in this area, in six different dates. The methodology was based in a pluviometric threshold and in the annual accumulated precipitation recorded. It was concluded that the movements were triggered by different accumulated rainfall scenarios, which depends not only in the rainfall event itself, but also in the distribution of the precipitation along the days preceding it. The correlations used identified short-time rainfall induced landslides and are an alternative to predict slope failures triggered by precipitation with these characteristics.

Keywords. Landslides, rainfall characteristics, geotechnical risk management.

1. Introduction

The coast of Santa Catarina, southern state of Brazil, presents a relief characterized by irregular surfaces from Serra do Mar mountain range, where most of the soil movements occurrences are registered. When affecting highways, these events can cause danger to users aside from economic and environmental losses.

The occurrence of a mass movement depends on landslide-predisposing factors, such as topography, lithology, structures, geomorphology, soil types, vegetation, land cover and flow distribution. However, there are also external factors triggering these

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events [1]. The main factor triggering landslides is rainfall and the correlation between them is well recognized in the literature [1]-[6].

With the purpose of finding a useful tool for the geotechnical risk management of the highway, this study aimed to define the correlation between precipitation and landslides recorded within the influence area of a rain gauge installed in a slope of BR-101 Highway. The local is part of a study project from the partnership between the Federal University of Paraná, the National Agency of Ground Transportation (ANTT) and the Arteris S.A. Company.

2. Study Area

This study focused in a slope located between the cities of Balneário Camboriú and Itapema in BR-101 Highway, in Santa Catarina, Brazil, known as "Morro do Boi". In 2008, the location was affected by mass movements triggered by rainfall events with extremely high intensity, causing accumulation of debris in the highway and interruption of traffic [7]. A rain gauge was installed in km 140 + 700 m and its influence area is determined by the contribution area of the hydrograph basin, as seen in Figure 1. The area is monitored since March/2012 and this study analyzed the data from July/2012 to June/2018.

The slope is composed by two rock formations: Morro do Boi migmatites and Nova Trento intrusive granites, and mostly by colluvium/talus deposits in direct contact with the rocks. These soil masses are typically unstable [8]. Besides, the slope is affected by NE-SW and NW-SE shear surfaces and by sub-horizontal fractures which decrease its mechanical strength and facilitates water flow [7]. The water level is deep and not much affected by precipitation.

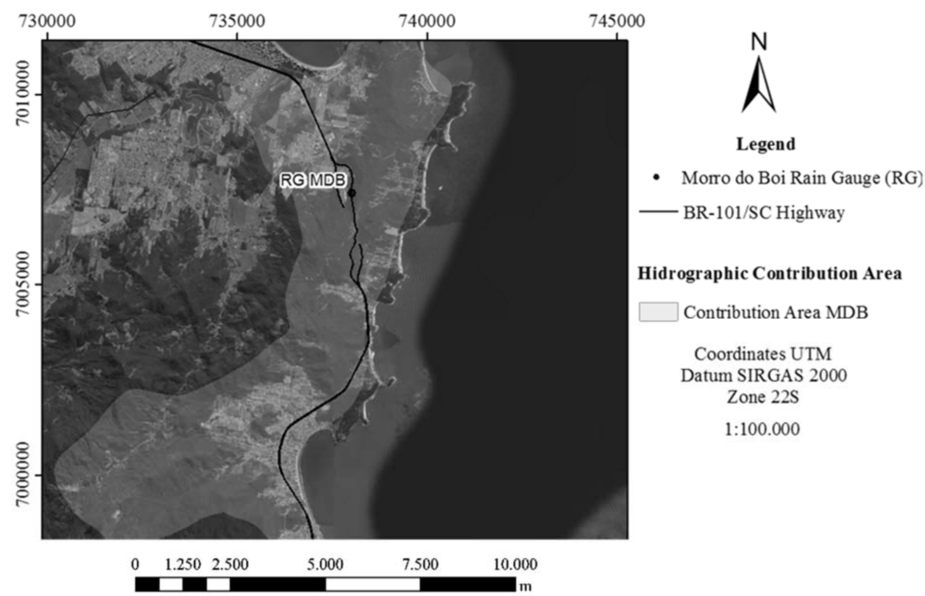

Figure 1. Contribution area of the hydrographic basin from Morro do Boi.

3. Rainfall and Landslides Description

The rainfall registered along the monitoring period is irregular; it is difficult to define a period of low or high precipitation. In general, from December to February, summer season, the precipitation is more intense (up to 22% higher) than from June to August.

As can be seen in Figure 2, the year of 2015 presents the highest precipitation records, with a total accumulated of 2,415 mm in the year, while the year of 2018 presents the lowest values already recorded in the monitoring period, with an accumulated of 480.2 mm until June. The other years present an annual cumulative precipitation with an average of 1,832 mm. It is important to note that some months present data record failures due to technical problems in the rain gauge.

Since the beginning of the monitoring plan, 16 landslides occurrences were recorded in 6 different dates (Table 1). The months in which theses landslides occurred had rainfall records superior to 250.0 mm accumulated in a month, the higher pluviometric record was of 427.6 mm in October/2015 and the lowest was 253.0 mm in January/2018. A relevant difference between these values is their distribution along the month, while January/2018 had 253.0 mm accumulated rainfall in 18 rainy days, October/2015 had 427.6 mm in 29 rainy days. The average of days with precipitation records in a month is 15.

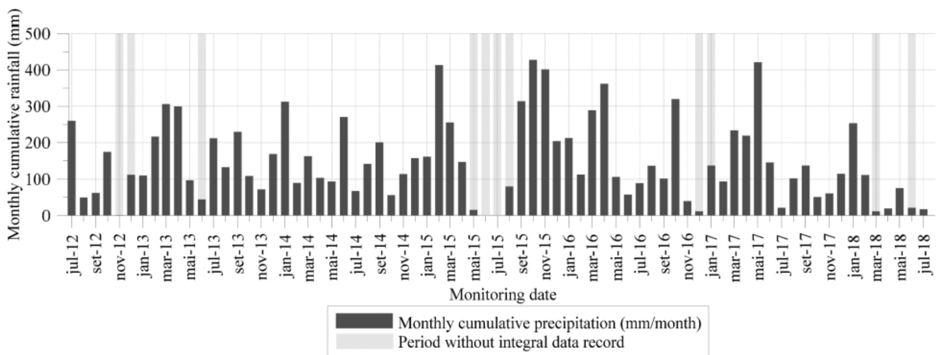

Figure 2. Monthly cumulative precipitation for Morro do Boi rain gauge.

Table 1. Number of landslides records within the rain gauge influence area.

Date	Number of records
2013-04-04	2
2015-09-28	2
2015-10-14	1
2016-03-25	1
2016-04-13	9
2018-01-10	1

In order to better understand the rainfall distribution along the months, Figure 3 presents the maximum daily precipitation volume in a month and the monthly accumulated precipitation for each month of the monitoring period. The bars in highlight correspond to months with landslide records. From the graph, it is clear the difference in the rainfall distribution between the months with landslide occurrences in 2015 from the other years. In September and November, 2015, the rain gauge recorded more than 400.0 mm of accumulated rainfall in the month, but daily precipitation inferior to 80.0 mm. Nonetheless, in the remaining months with occurrences, the monthly cumulative rainfall was lower (approximately 300.0 mm – 350.0 mm), but the daily precipitation was superior than 100.0 mm.

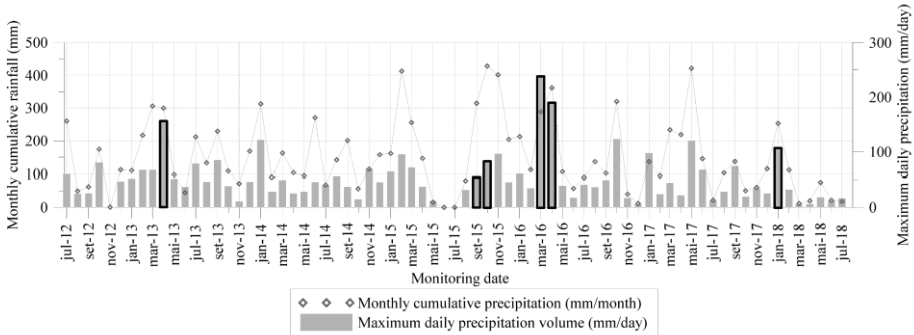

Figure 3. Maximum daily precipitation volume in a month (mm/day).

Furthermore, it was possible to identify that the occurrences were mostly related to cumulative precipitation above 100.0 mm in 1 day and 200.0 mm in 2 days. From the data record, these characteristics were observed in 9 different dates and 13 landslides occurred in 4 of them.

4. Methodology

A significant number of correlations between rainfall and landslides were developed in the literature. In general, the rainfall intensity-duration method is often used for short-time rainfall induced landslides, less than 48 hours, while cumulative rainfall method is appropriate for long-time rainfall-induced occurrences [1]. Even though most of landslides in this study are related to short-time rainfall, there are no record of the exactly time of the occurrence, precluding the use of rainfall intensity-duration correlation.

It is common to fix values of hourly precipitation (mm/h) or one day accumulated precipitation (mm/24h) and correlate those to different scenarios of accumulated precipitation to find the best configuration for the curve that separates rainfall events that can cause landslides from those that are not a risk [3]. This study was based in this methodology to delineate a pluviometric threshold for the area, using available data of precipitation and landslide records. It was defined 4 different scenarios that correspond to the probability of landslide occurrences. The best configuration was found to be the relation between accumulated precipitation in 24h (mm/24h or mm/1 day) and the accumulated precipitation in 72h (mm/72h or mm/3 days). This configuration and the curves related to the scenarios were defined based on the percentage of points in each scenario.

Another correlation was observed when analyzing the annual cumulative precipitation in a daily scale. The graphs in Figures 5, 6 and 7 present the cumulative precipitation from July to June of the following year, to encompass the rainy season entirely. High daily precipitations produce a peak in the graph that can correspond to dates with landslides. It was observed that the peaks are usually related to 2 days of accumulated rainfall superior to 200.0 mm, characteristic that represents some of the occurrences registered.

5. Results and discussions

As described in item 4, the pluviometric threshold categorizes the events in 4 different scenarios in order to make it a useful tool for the geotechnical risk management of the highway. The scenario 1 is related to events that do not tend to cause landslides and the scenario 4 is related to pluviometric events that can cause significant landslides. The intermediate scenarios, 2 and 3, represent events that are likely to cause landslides and are distinguished by the accumulated precipitation, while scenario 2 corresponds to 3 days accumulated precipitation of maximum 300.0 mm and 1 day accumulated of 80.0 mm, scenario 3 corresponds to 3 days accumulated precipitation of maximum 120.0 mm and 1 day accumulated of 200.0 mm.

In the pluviometric thresholds for Morro do Boi rain gauge (Figure 4), 96.53% of the events are plotted in scenario 1, 2.77% in scenario 2 and only 0.56% in scenario 3. For the most critical scenario, 100% of the plotted points represent landslide occurrences.

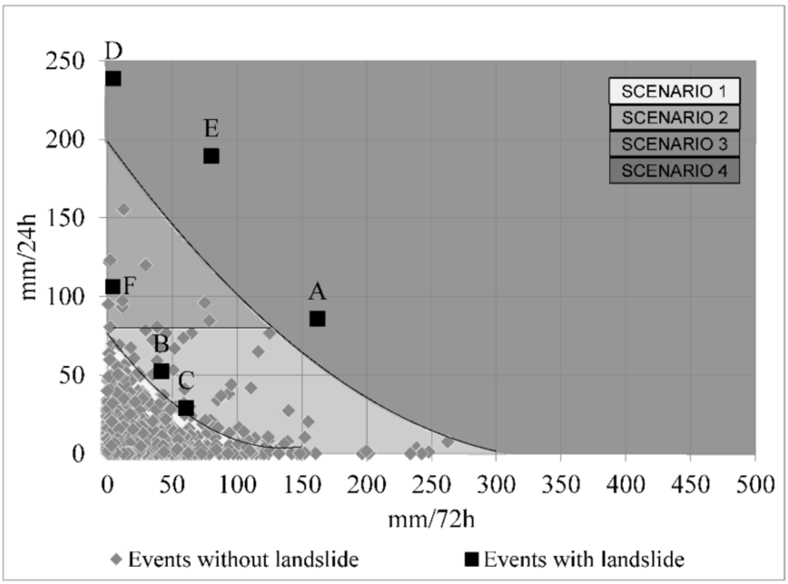

Figure 4. Pluviometric threshold for Morro do Boi rain gauge.

The annual cumulative precipitation graphs show peaks of precipitation that are easy to visualize in the years of 2013 and 2016. These points correspond exactly in days with landslides records, as shown in Figures 5 and 6. The occurrence recorded in January/2018 is also related to a peak in the graph (Figure 7), but it is not so attenuated due to its lowest precipitation.

The landslides recorded in 2015, as described in item 3, are related to long-time duration rainfall, with a high monthly accumulated precipitation but low daily precipitation volume. Thus, the annual accumulated precipitation graph increases intensely in the year of 2015 but there are no precipitation peaks. Besides, in the pluviometric threshold, these occurrences, plotted as letters B and C, are close to the inferior limit that separates scenario 1 from 2 and 3, since the accumulated rainfall used in the threshold is low.

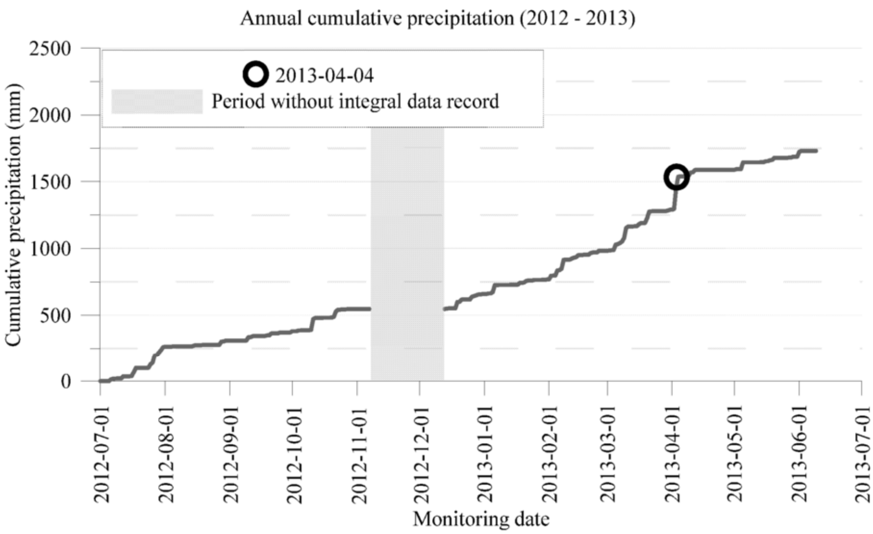

Figure 5. Annual cumulative precipitation and landslides occurrences between 2012 and 2013.

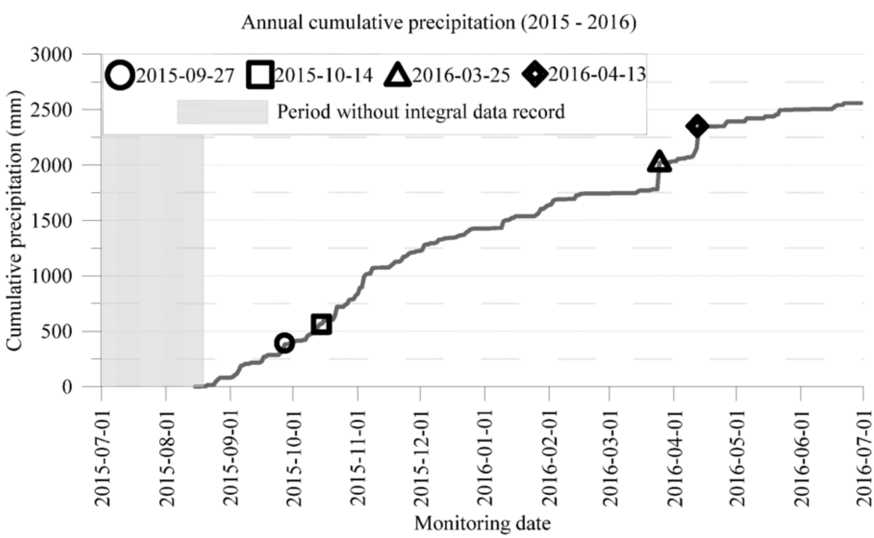

Figure 6. Annual cumulative precipitation and landslides occurrences between 2015 and 2016.

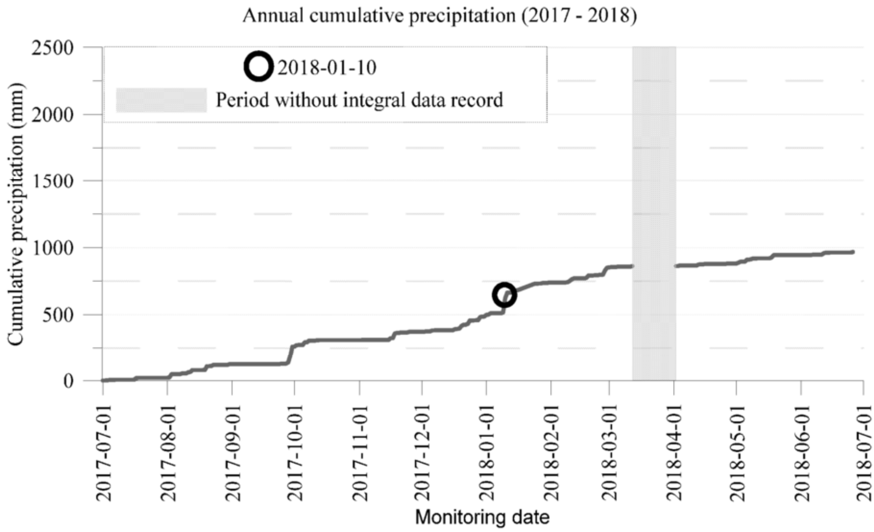

Figure 7. Annual cumulative precipitation and landslides occurrences between 2017 and 2018.

6. Conclusions

The correlations between rainfall and soil movements defined in this work are a good alternative to the geotechnical risk management of the BR-101 Highway, when analyzing short-time rainfall induced landslides. Both the pluviometric threshold and the annual cumulative precipitation graphs well represented the landslide occurrences records related to high accumulated precipitation in 1 or 2 days. The peaks found in the annual cumulative precipitation graphs are plotted in critical scenarios of the pluviometric threshold, confirming the usefulness of both correlations to landslides prediction.

The occurrences related to accumulated precipitation of greater duration however are not visible in the annual cumulative graphs, precluding its use to predict landslides triggered by this type of event. In the pluviometric threshold these occurrences are found in critical scenarios but close to the inferior limit, what makes this threshold not so reliable when predicting long-time rainfall induced landslides.

The application of different correlations is important to identify the characteristics of the rainfall that trigger the soil movements. The use of correlations between rainfall and landslides is an easy and useful tool to predict slope failures induced by precipitation, a good alternative to geotechnical risk management. However, it was possible to conclude that not only the rainfall event itself but also the condition preceding it has influence in the soil response. Besides that, it is necessary to consider that there are other variables involving landslides.

Acknowledgments

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References

[1] Li W. Y., Liu C., Scaioni M., Sun W. W., Chen Y., Yao D., Chen S., Hong Y., Zhang K., Cheng G. (2017). "Spatio-temporal analysis and simulation on shallow rainfall-induced landslides in China using landslide susceptibility dynamics and rainfall I-D thresholds". *Earth Sciences* 60(4): 720-732.

[2] Kanji M. A., Cruz P. T., Massad F., Araujo F. H. A. (1997). "Basic and Common Characteristics of Debris Flows". 2º Pan Am. Symposium, 2º COBRAE, Rio de Janeiro, (10): 223-231.

[3] D'Orsi R. N. (2011). Correlação entre pluviometria e escorregamentos no trecho da Serra dos órgãos da rodovia federal BR-116 RJ (Rio – Teresópolis). Doctoral Thesis – Post-Graduate Program in Civil Engineering, Federal University of Rio de Janeiro, COPPE, Rio de Janeiro, RJ.

[4] Souza F. T., Ebecken N. F. F. (2012). "A Data Based Model to Predict Landslide Induced by Rainfall in Rio de Janeiro City". *Geotechnical and Geological Engineering* 30(1): 85-94.

[5] Victorino M. M., Sestrem L. P., Kormann A. C. M. (2017). "Definição de uma faixa pluviométrica crítica para deflagração de movimentos de terra em taludes rodoviários localizados no trecho da serra do mar da rodovia BR-376/PR". *Transportes* 25(1): 113-120.

[6] Ran Q., Hong Y., Li W., Gao J. (2018). "A modelling study of rainfall-induced shallow landslide mechanisms under different rainfall characteristics". *Journal of Hydrology* 563: 790-801.

[7] Sestrem L. P., Kormann A. C. M. (2013). "Implantação De Um Sistema De Monitoramento Automatizado Para Monitoramento De Uma Encosta Litorânea Rodoviária". *8° Brazilian Congress of Highways and Concessions*, Santos, SP.

[8] AUTOPISTA LITORAL SUL (2015). "Avaliações de estabilidade e do desempenho de sistemas de proteção de taludes rodoviários em uma encosta litorânea". *Research Report.*