S&G 15 (2020), pp. 38-45

S&G JOURNAL
ISSN: 1980-5160

STUDY OF THE RELATIONSHIP BETWEEN PRECIPITATION AND LANDSLIDES IN THE MUNICIPALITY OF PETRÓPOLIS - RJ

Giselle Petrungaro Torres
giselle.petrungaro@gmail.com
Federal University of Rio de Janeiro

Luiz Felipe Rodrigues do Carmo
l.docarmo.meteoroufrj@gmail.com
Federal University of Rio de Janeiro

Ana Cristina Pinto de Almeida Palmeira
anactn@gmail.com
Federal University of Rio de Janeiro

ABSTRACT

The municipality of Petrópolis, in the Serrana Region of the state of Rio de Janeiro, is often hit by natural disasters, such as landslides. Most of the times, such events are triggered by meteorological events. Due to this problem, this study was carried out based on the relationship between atmosphere and soil, to highlight this relationship and make it possible to draw up strategies for prevention and mitigation of the impacts of such events. Data from the occurrence of landslides, classified according to type, were used in conjunction with the precipitation records in the municipality of Petrópolis in a given time series and, through graphic computational tools, correlations and temporal and spatial analysis were generated. The preliminary results showed the highest relationship between rainfall accumulations and certain slide classifications. An example was in the case of mud races, in which it showed the relationship of these events with the characteristics of the place of occurrence.

Keywords: Precipitation; Sliding; Petrópolis

PROPPI / DOT
DOI: 10.20985/1980-5160.2020.v15n1.1611

S&G Journal
Volume 15, Number 1 1, 2020, pp. 38-45
DOI: 10.20985/1980-5160.2020.v15n1.1611

1. INTRODUCTION

According to the Brazilian Institute of Geography and Statistics (IBGE, 2020), the municipality of Petrópolis, located in the Serrana Region of the state of Rio de Janeiro, is the 16th in territorial area of the state, and is divided into five districts: Petrópolis, Cascatinha, Itaipava, Pedro do Rio and Posse. According to Figure 1, the municipality has as an important characteristic the spatial diversity and land use, being formed by rural and urban areas, with an average altitude of 845 meters.

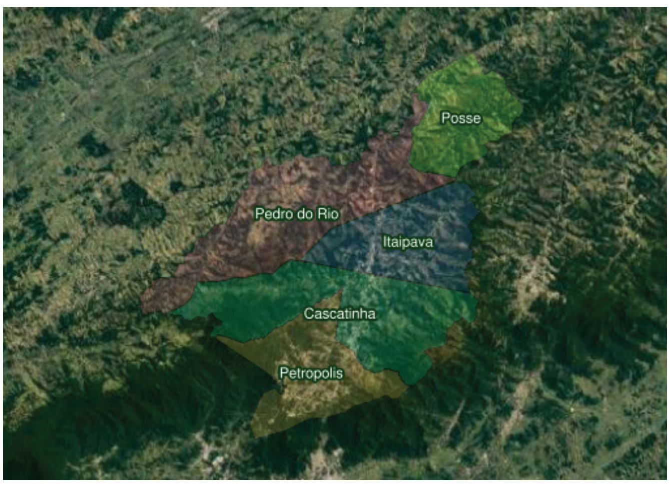


Figure 1. Districts of the City of Petrópolis
Source: Petrópolis City Hall and Google.

The municipality of Petrópolis is located in the Environmental Protection Area (APA) of the Mountainous Region of Petrópolis, created in 1982, with the Atlantic Forest as the predominant biome, according to the Chico Mendes Institute for Biodiversity Conservation (ICMBio, 2020). The purpose of the creation of this APA was the preservation of the remnants of the Atlantic Forest, the sustainable use of natural resources, the conservation of its cultural and landscape ensemble, and the improvement of the quality of life in the region. However, with the passage of time and the urban development of the municipality, native vegetation was replaced by secondary vegetation or was deforested to give way to irregular and disordered occupations (Guerra et al., 2007), which increases the vulnerability of the region.

The municipality of Petrópolis is mostly located in the Piabanha Hydrographic Region (RH IV), and partially in the Guanabara Bay Hydrographic Region (RH V) (INEA, 2013), which are managed by committees that aim, among others, to improve the quality of the hydrographic basins and to act actively in issues related to pollution and deforestation in that area (INEA, 2020).

The municipality of Petrópolis, which is located in a region with expressive declivity and relief, is often hit by natural disasters, such as overflows, floods and landslides - the focus of this study. As an example, the Quitandinha River is responsible for the largest history of overflow occurrences in the state, with a rapid response time to the rains that occur in the basin's contribution area (Carmo et al., 2018). The viability of these events, added to the growing urban occupation, sometimes disorganized, exposes the city to events that have great destructive potential, as it has already occurred several times. In 2011, the Serrana Region of the state of Rio de Janeiro was hit by more than 3,000 landslides, resulting in the death of thousands of people and generating serious damage to the urban and rural infrastructure of the region (Coelho Netto *et al.*, 2013).

The geological event called landslide has different definitions with small differences between them. According to Highland and Bobrowsky (2008), it is understood as the downward movement of soil, rocks and organic material, under the effect of gravity, and also the geological formation resulting from this movement. These authors stated that the events can be classified according to occurrence, extent, movement rate, triggering mechanism, and effects. It is also possible, within the classification of each event, to trace some of its predictability and therefore seek mitigating measures.

For it to be classified as a natural disaster, whether in cases of landslide or overflow, there must be an impact on the region in relation to the human population or the environment. Disasters can be well understood if analyzed as a result of the complex interaction between a potentially harmful physical event, such as those mentioned above, and the vulnerability of a society exposed to it, according to Licco (2013). These events can have different degrees of impact and the people affected, as well as the region, can have difficulty in restructuring that can take years.

Sometimes, landslides and overflows occur in the same period and even simultaneously, because they are linked to the occurrence of rain in the region, which is a major trigger for natural disasters. Therefore, it is necessary to know the potential for extreme events to occur at the site, considering possible scenarios as to atmospheric conditions. In other words, it is necessary to study the region in order to predict the reaction of these occurrences to the extreme weather conditions.

Intense rains hit the Serrana Region, especially in summer, characterized as the rainy season. In this time of the year, the biggest occurrences of landslides were registered, mainly in the last years. It is worth noting that these events are the result of a combination of geological, geomorphological, hydrological and climatic factors, in addition to the disorderly occupation of the slopes, according to Salles and Amaral (2013).

S&G Journal
Volume 15, Number 1, 2020, pp. 38-45
DOI: 10.20985/1980-5160.2020.v15n1.1611

According to D'orsi (2011), in the Southeast Region of Brazil, the events of heavy rainfall with consequent slippage are frequent and over the years dozens of new episodes are recorded. In general, as these processes have a serious and negative impact on society and the surrounding environment, several studies are conducted through different methodologies around the world in order to establish and better understand the rainfall rates capable of triggering these events.

Thus, the objective of this work is to statistically relate the events of landslides with the occurrences of rain in the city of Petrópolis so that, from this information, the bodies responsible for the management of the city (Civil Defense and the City Hall of Petrópolis) can always be in synchrony with professionals from each of the areas concerned and, consequently, use this information to draw up strategies for prevention, guidance, mitigation and resilience in the case of events.

2. DATA AND METHODS

For this study, data from the occurrences of landslide events in the municipality of Petrópolis, between the years 1940 and 1990, obtained by the Institute of Technological Research (*Instituto de Pesquisas Tecnológicas* – IPT), were used. The IPT counted on data acquired from direct observations, personal reports and records in newspapers and magazines published at the time. The authors also used data from landslides between 2000 and 2015, provided by the Laboratory of Cartography (GEOCART) of the Department of Geography of the Federal University of Rio de Janeiro, and they were approached with different methodology in relation to data from the previous period.

The data of the landslides were correlated with the precipitations of the Petrópolis rain station, of the IPT - Post 1, located in the first district of the municipality. Together with this information, the victim counts associated with each recorded event were considered, in order to relate the type of event to the potential danger it presents.

The recorded slide events were previously classified by GEOCART, in five categories, according to the IPT methodology: slide (E), block fall (QB), block rolling (RB), mud race (CL), and miscellaneous (D), as adapted in Table 1.

From the data obtained by the IPT and GEOCART institutes (each in a given period and according to the volume of data for each period), separate analyses were carried out for each set of information. This grouping was done in order to present a temporal analysis of the IPT data, between the years 1940 and 1990, and a spatial analysis of the GEOCART data, between the years 2000 and 2015.

In order to elaborate the relationship between the occurrences of events, the classification regarding the type of geological event and the accumulated rainfall in the station, the data was processed so that spurious rainfall recording data could be excluded. The data processing evaluated the incidence of systematic errors in the recording of rainfall in the rain gauge used. After being analyzed and confirmed as spurious, the data were disregarded in the analysis.

The data analysis was done through mathematical and graphical computational tools, being performed in stages. The mathematical and graphical computational tool used was the R program, executed through the Rstudio software. As a graphic tool, the spatial geoprocessing program QGis was used. Both programs are free. Through the R program, where the data treatment was performed, results related to the occurrences of events and accumulated rain in temporal analysis were generated, using the correlations and averages as statistical metrics, for example. In relation to the QGis program, products of spatial analysis were generated based on the points of occurrence of events in the municipality.

Chart 1. Slide Classification

Code	Classification	Type of event
E	Slide	It groups the terminologies related to soil movement used by newspapers: falling barriers, sliding, crumbling and slipping
QB	block fall	Cases related to the detachment of blocks and rock slabs with free fall movement
RB	block rolling	Cases related to the rolling of boulders and blocks of rock
CL	mud race	Material mobilization processes involving soil and rock, with large amounts of water, developing along drains
D	miscellaneous	Cases where there was a lack of clarity in the information. E.g.: landslide, which could be related to slippage or collapse of a building, undermining, etc.

Source: Adapted from database of the Institute of Technological Research, São Paulo.

S&G Journal
Volume 15, Number 1 1, 2020, pp. 38-45
DOI: 10.20985/1980-5160.2020.v15n1.1611

Due to methodological differences between the institutes mentioned, the total number of relevant cases, after data processing and spurious data removal, was discrepant: for example, the data counted by IPT showed a higher number of cases compared to those counted by GEOCART, which did not take into account personal reports and news, for example.

Correlations were made using information made available on the Petrópolis City Hall website regarding maps and cartography, based on data from the Geographic Information System (GIS), in which maps were obtained with information on hydrography, population density, urban and rural occupation of the region, among others. Among the most relevant data are those obtained in the Shuttle Radar Topography Mission (SRTM) for the year 2000, such as those related to altitude, relief and slope, which were georeferenced with the records of landslides in the municipality, in order to establish a spatial relationship between the events.

3. RESULTS AND DISCUSSIONS

In Figures 2a and 2b are the histograms with the total number of landslides per decade. In both periods there is a tendency to increase the number of cases. Most of the registered cases were classified as slippages, according to the counting of both institutes. Even if the data regarding slipping cases and unclassified cases were extracted from the analysis, a tendency of increase in the number of landslide occurrences would be observed over the decades, even if a decrease in these records occurred, as in the 1950s (Figure 2a). This trend is also present in the GEOCART information, although its data series is not as extensive as that of the IPT. It was observed that in six years, between 2010 and 2015, about 80% of the total cases observed in the previous decade, from 2000 to 2009, were recorded (Figure 2b).

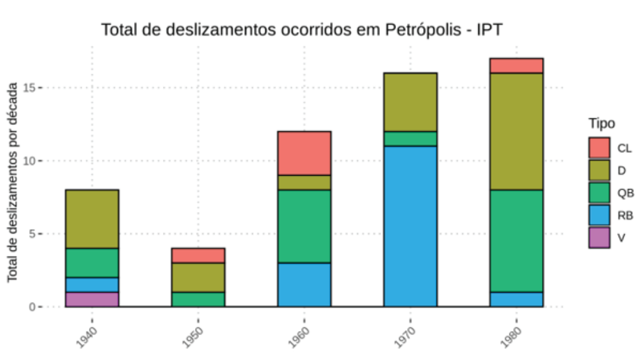


Figure 2a (Left). Total landslides per decade for the IPT between 1940 and 1990, excluding cases of slippage and those not classified.

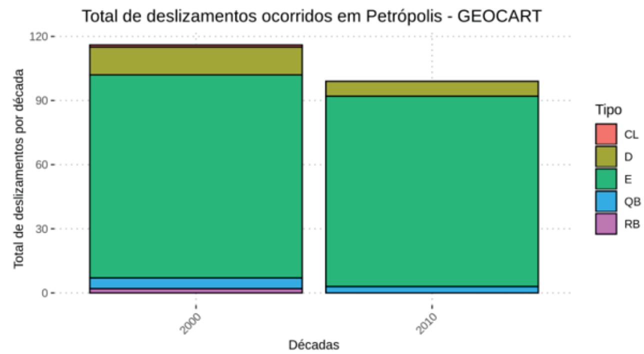


Figure 2b (Right). Total landslides per decade referring to GEOCART between 2000 and 2010.

This trend found in Figures 2a and 2b was also observed in a very expressive way in Figure 3a, which indicates the density of landslides in the periods under analysis according to the TPI. In Figure 3b, in relation to GEOCART, the records of accounted events showed a positive peak in the total of events in 2011 and a decrease in the years 2014 and 2015, which can be attributed to the occurrence of meteorological events in those years.

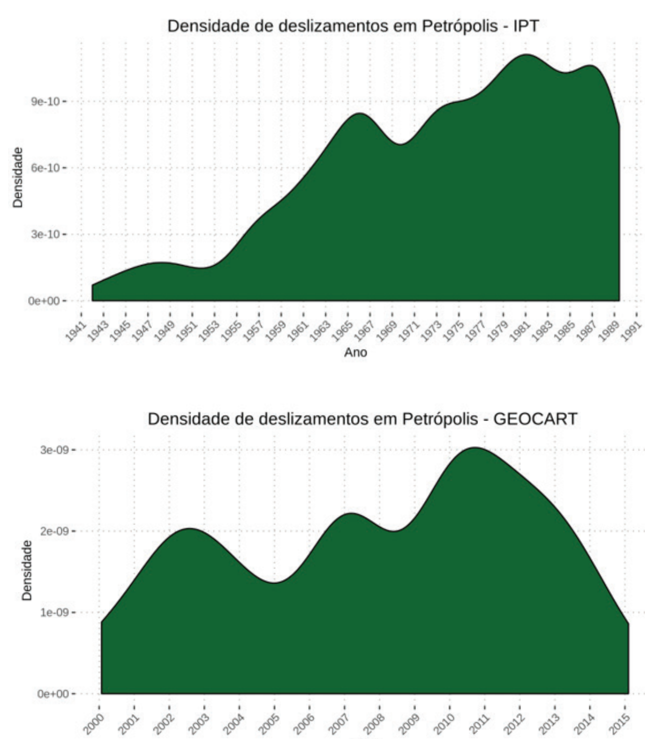


Figure 3a and **Figure 3b.** Density of slides counted by IPT (left) and GEOCART (right).

Figures 4a, 4b, 4c and 4d show the temporal distributions of the 24h, 48h, 72h and 96h rainfall accumulations, respectively, in relation to the type of event and number of fatalities. The largest records were the slippage cases, which were

S&G Journal
Volume 15, Number 1, 2020, pp. 38-45
DOI: 10.20985/1980-5160.2020.v15n1.1611

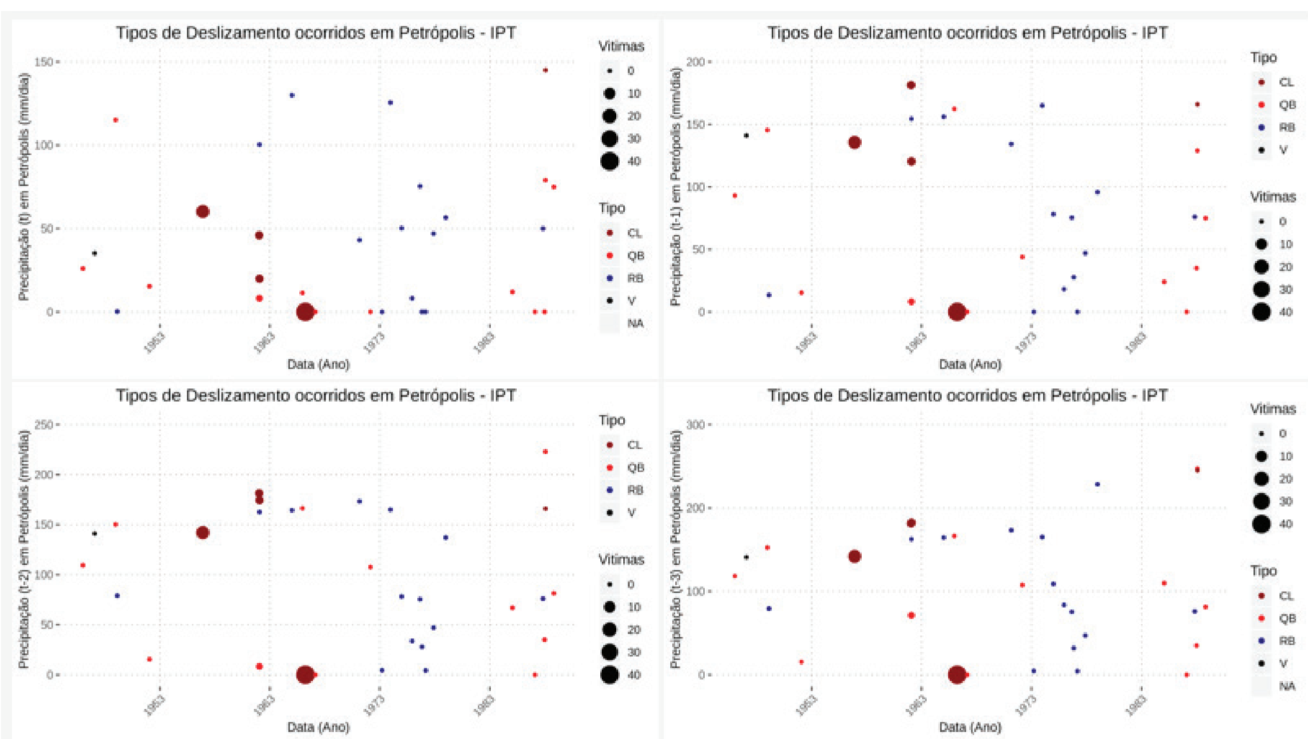
not related to the precipitation, as well as those events classified as diverse, where it would not be possible to establish correspondence. Therefore, these data could be hidden in this correlation, besides being disregarded in these results. Together with these results, for each event the victim count was considered in order to profile the destructive potential of the types of landslide treated. A greater correspondence between Mud Running (CL) events was observed, with higher precipitation and victim count values, especially for the 48h and 72h accumulations.

The difference between the data volume of the institutes proved to be an important criterion to be considered in the approach of the data of each institute, making it necessary to adapt the results for the volume and type of data obtained. Thus, in the GEOCART data, the correlation between the events and the precipitation records was not satisfactory.

Using the same data for IPT, in Figures 5a, 5b, 5c and 5d, there are boxplots for the 24h, 48h, 72h and 96h accumulated, respectively. One can notice a smaller dispersion of data in the event CL when related to the accumulated of precipitation, mainly in the accumulated of 72h, even considering outlier points.

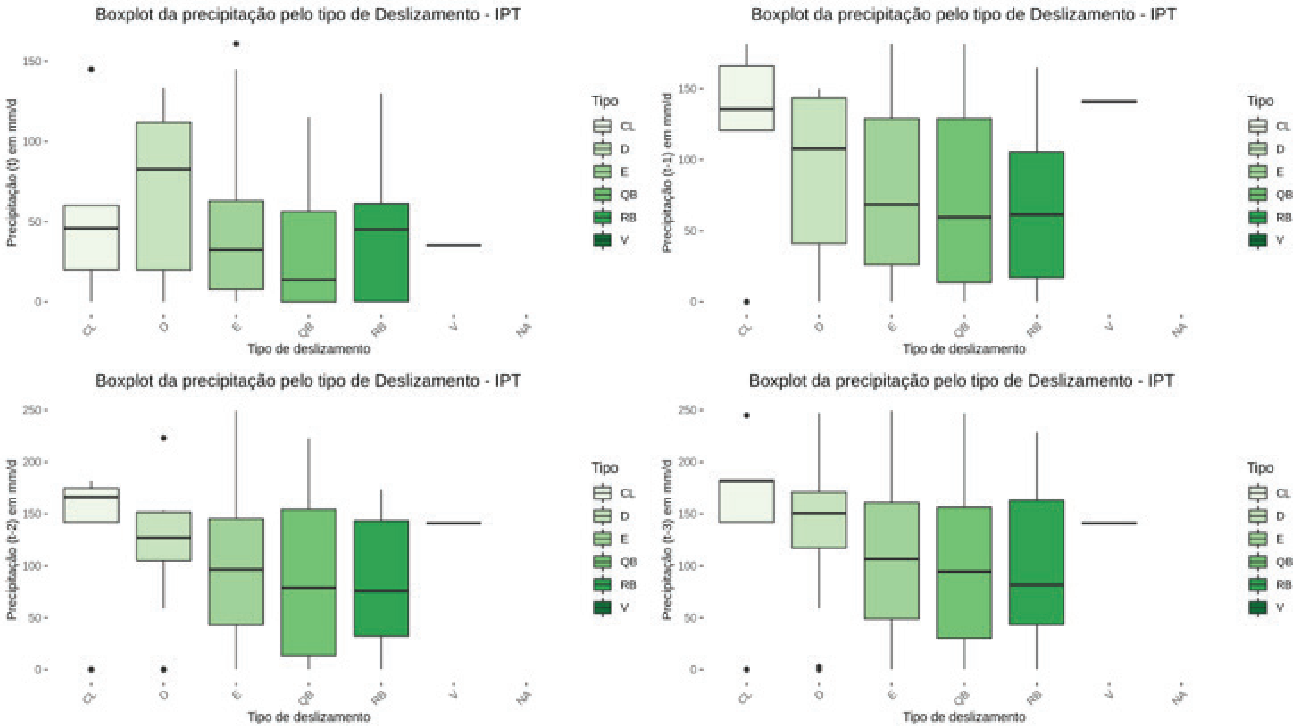
Figures 6a, 6b, 6c and 6d show, respectively, the relationships established for the 24h, 48h, 72h and 96h (from 1940 to 1990) accumulated precipitation, Smooth function. This function has shown, in a softened form, a tendency of increasing the precipitation accumulation in the station in relation to the 24h accumulation (Figure 6a), with small dispersion between the data. In relation to the trend in 48h (Figure 6b), stability was observed among the accumulated, but with greater dispersion among the data, mainly at the beginning of the time series. In the 72h and 96h trends (Figures 6c and 6d) similar behaviors were observed, with less marked elevation and greater dispersion at the beginning of the time series.

In Figures 7 and 8, with the data obtained with GEOCART from 2000 to 2015, one can find, respectively, the altitude, relief and slope of the region (obtained from the SRTM product) and the spatial distribution of landslide occurrences. Based on urban occupation data, it was possible to establish a relationship between landslide events with relief and land use. The cases of landslides are related to downward movements of materials in downhill regions, under the effect of gravity. Consequently, regions of lower altitude, lower areas near these higher slope points, are more affected by these

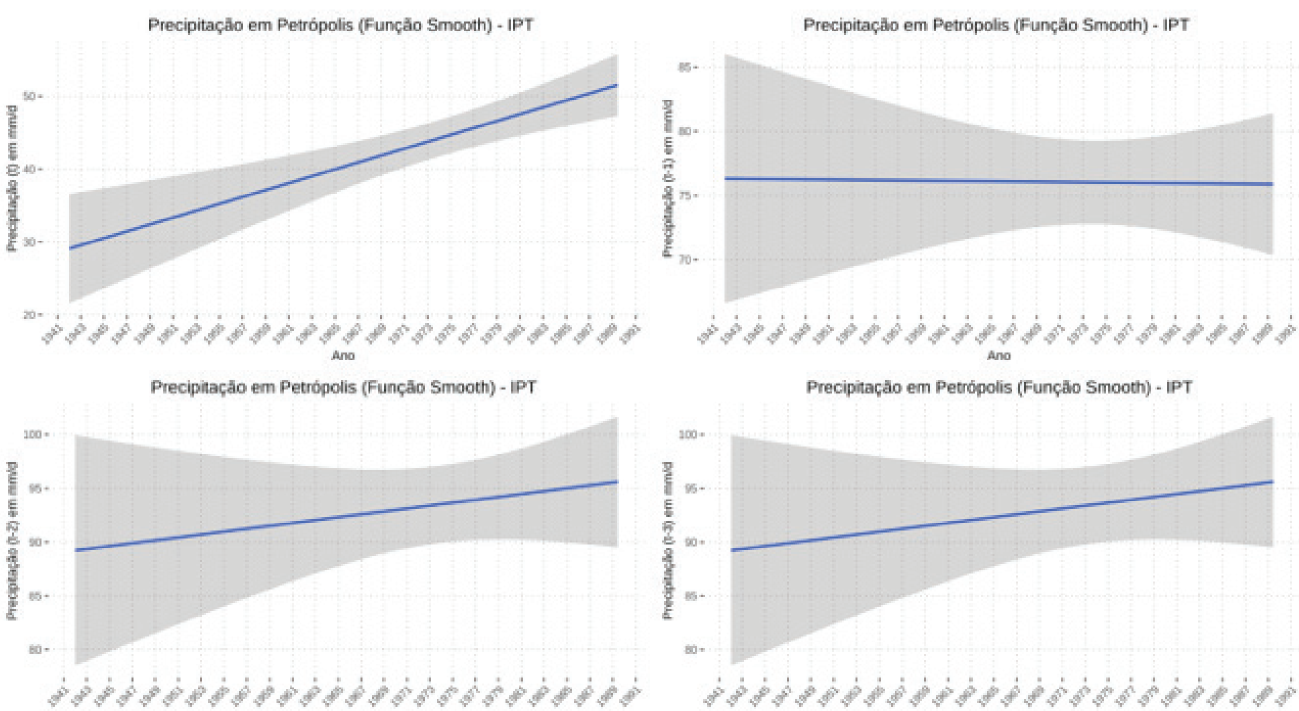


Figures 4a (upper right). Correlation between the types of landslide and the number of victims with the accumulated 24-hour rainfall in a time series related to the IPT. **Figure 4b (upper left).** Correlation between the types of landslide and the number of victims with the accumulated 48-hour rainfall in a time series related to the IPT. **Figure 4c (bottom right).** Correlation between the types of landslide and the number of victims with the accumulated 72-hour rainfall in a time series related to the IPT. **Figure 4d (bottom left).** Correlation between the types of landslide and the number of victims with the accumulated 96-hour rainfall in a time series related to the IPT.

S&G Journal
Volume 15, Number 1 1, 2020, pp. 38-45
DOI: 10.20985/1980-5160.2020.v15n1.1611



Figures 5a (upper right). Boxplot of the types of landslide by the accumulated rainfall in 24h for IPT. **Figure 5b (upper left).** Boxplot of the types of landslide by the accumulated rainfall in 48h for IPT. **Figure 5c (bottom right).** Boxplot of the types of landslide by the accumulated rainfall in 72h for IPT. **Figure 5d (bottom left).** Boxplot of the types of landslide by the accumulated rainfall in 96h for IPT.



Figures 6a (upper right). Smooth function of the 24h accumulated precipitation trend in time series referring to the IPT. **Figure 6b (upper left).** Smooth function of the 48h accumulated precipitation trend in time series referring to the IPT. **Figure 6c (bottom right).** Smooth function of the 24h accumulated precipitation trend in time series referring to the IPT. **Figure 6d (bottom left).** Smooth function of the 24h accumulated precipitation trend in time series referring to the IPT.

S&G Journal
Volume 15, Number 1, 2020, pp. 38-45
DOI: 10.20985/1980-5160.2020.v15n1.1611

events and face greater consequences. However, this study area can still be better explored and developed as it is relevant and essential in several sectors.

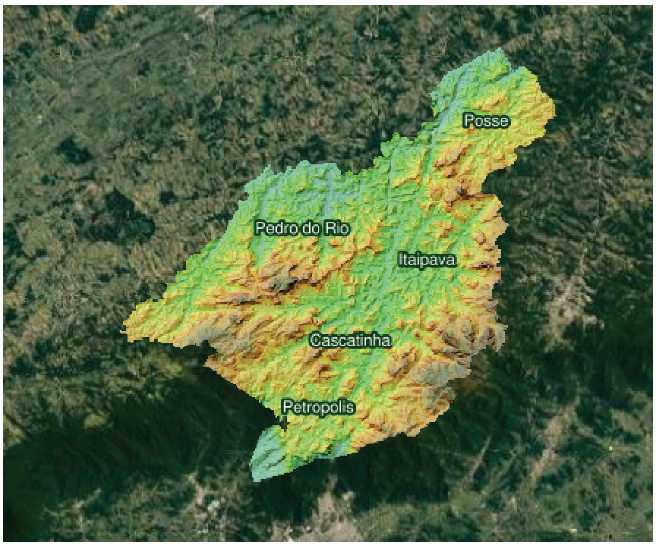


Figure 7. SRTM product with altitude, relief and slope data for the region, 2000.

Source: Petrópolis City Hall and Google.

Figure 8. Spatial representation of the GEOCART landslide points for the period between 2000 and 2015.

4. CONCLUSIONS

This work highlighted the close relationship between soil and atmosphere studies. Combining these issues is beneficial when it comes to management. Likewise, it would be possible to integrate other areas of knowledge in order to optimize processes and better understand the causes, impacts and consequences of a given phenomenon.

The observed results show the tendency of increase in the events of landslides over the years, as well as a certain tendency of increase in the accumulation of precipitations, mainly referring to 24 hours. This tendency to increase the occurrence of events shows that there is a real need to know the types of events, their causes and damages, in order to try to predict the occurrence of these phenomena so that initiatives can be taken in the short term to minimize the consequences. In cases of CL, for example, where there is a greater relationship between the accumulated rain and victim count, the accumulated 72h (3 days before the event) showed greater association with the occurrence of the events, as well as had some relationship with the accumulated 24h, 48h and 96h. Factors such as these, associated with a study of the treated region, can be taken into consideration when drawing up prevention plans for the events in order to reduce the danger and consequently the damage that can be caused.

It is observed that meteorological events are related to the largest number of occurrences of landslides, mainly in the Serrana Region, which in its characteristic is formed by relief and declivity. Adding these factors to the land use in the region, it is possible to have as a result the most vulnerable places in cases of landslides and it is necessary to have better strategies together with the responsible agencies. According to Figure 8, in the region with the highest urban occupation, 1st District of Petrópolis, the number of landslide events was higher in relation to other districts. This same region, as seen in Figure 7, is between points of higher relief and altitude.

Finally, the integration of studies from different areas is allied to risk and disaster management. In addition, knowledge in these areas can be applied to various occurrences. The Municipality of Petropolis is commonly affected by extreme events (landslides and overflows) and city departments, such as the Civil Defense, for example, need to act together with technical professionals in order to better understand the particularities of the region and the events that affect it.

5. ACKNOWLEDGEMENTS

The authors thank the Laboratory of Cartography (GEOCART), of the Department of Geography, located at the Institute of Geosciences of the Federal University of Rio de Janeiro, for having made available the data that made this work possible.

REFERENCES

Carmo, L.F.R., Nascimento, M.M.S., Martins, C.A., Silva, L.F.C., Sousa, R.C., Mota, L.L.O., Cruz, A.L.S.C. 2011. Desenvolvimento de modelo estatístico de elevação do Rio Quitandinha. Revista INEANA 6, 72-88. http://www.inea.rj.gov.br/wp-content/uploads/2018/12/Revista-Ineana-6.3.pdf

Coelho Netto A.L., Sato, A.M., Avelar, A.S., Vianna, L.G.G., Araujo, I.S., Croix, D., Lima, P., Silva, A.P., Pereira, R. 2013. January 2011: The extreme landslide disaster in Brazil. In: Margottini, C., Canuti, P., Sassa, K. (eds). Landslide Science and Practice. Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-31319-6_51

D'Orsi, R.N. 2011. Correlação entre pluviometria e escorregamentos no trecho da Serra dos órgãos da rodovia federal BR-116 RJ (Rio – Teresópolis). Tese de doutorado, COPPE, Universidade Federal do Rio de Janeiro.

Guerra, A.J.T, Lopes, P.B.M, Santos Filho, R. D. 2007. Características geográficas e geomorfológicas da APA Petrópolis, RJ. Revista Brasileira de Geomorfologia 8, 77-86. http://www.lsie.unb.br/rbg/index.php/rbg/article/view/87/80

Highland, L.M., Bobrowsky, P. 2008. O Manual de Deslizamento: Um Guia para a Compreensão de Deslizamentos. Reston, Virginia: U.S. Geological Survey.

Instituto Brasileiro de Geografia e Estatística (IBGE). 2020. IBGE Cidades. Petrópolis. https://cidades.ibge.gov.br/brasil/rj/petropolis/panorama

Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio). 2020. APA da Região Serrana de Petrópolis. http://www.icmbio.gov.br/portal/unidadesdeconservacao/biomas-brasileiros/mata-atlantica/unidades-de-conservacao-mata-atlantica/2178-apa-de-petropolis

Instituto Estadual do Ambiente (INEA). 2020. Comitês de Bacias Hidrográficas – CBHs. http://www.inea.rj.gov.br/Portal/Agendas/GESTAODEAGUAS/RECURSOSHIDRICOS/Comitedebacias/index.htm&lang=PT-BR

Instituto Estadual do Ambiente. 2013. Resolução CERHI-RJ nº107, de 22 de maio de 2013. Estado do Rio de Janeiro, Diário Oficial. https://www.comiteguandu.org.br/legislacoes/ResolucoesCERHI/Resolucao-CERHI-107.pdf

Licco, E.A. 2013. Vulnerabilidade social e desastres naturais: uma análise preliminar sobre Petrópolis, Rio de Janeiro. Revista de Saúde, Meio Ambiente e Sustentabilidade 8, 25-41. http://www3.sp.senac.br/hotsites/blogs/InterfacEHS/wp-content/uploads/2013/07/2_DOSSIE_vol-8n1.pdf

Prefeitura Municipal de Petrópolis. http://sig.petropolis.rj.gov.br/lm/index.php/view/map/?repository=publico&project=petropolis

Salles, R.O., Amaral, C. 2013. Estudo da correlação entre chuvas e escorregamentos na Região Serrana do Rio de Janeiro. Conferência Brasileira de Encostas, 6, Angra dos Reis.

Received: Feb 10, 2020

Approved: Mar 06, 2020

DOI: 10.20985/1980-5160.2020.v15n1.1611

How to cite: Torres, G.P., Carmo, L.F.R., Palmeira, A.C.P.A. (2020), Study of the relationship between precipitation and landslides in the municipality of Petrópolis - RJ, Revista S&G 15, No. 1, 38-45. https://revistasg.emnuvens.com.br/sg/article/view/1611