Landslide inventory mapping in Brazil: Status and challenges

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Abstract

Shallow landslides are one of the most frequent mass movements in Brazil. Methods to study this kind of process and for construction of shallow landslide inventories are heterogeneous, since there are no standardized mapping guidelines in Brazil. The aim of this paper is to review the methodologies mostly used for shallow landslide inventories construction in Brazil based on articles published on this subject. The procedures adopted were: (I) searching publications about landslide inventory construction in Brazil within five scientific online databases (ScienceDirect, Periódicos CAPES, Google Scholar, Scopus, and Web of Science), (II) quantification and comparison of publications found on the databases, and (III) bibliometric analysis of the specific topic. The results indicate that only a small amount of publications is directly related to inventories of landslides. Visual interpretation is the most applied method and data used for inventory creation is diverse. The results confirm the hypothesis that landslide mapping in Brazil is very heterogenous and that there is a need for common mapping guidelines.

1. INTRODUCTION

Shallow landslides are frequent natural processes in mountainous environments, mainly occurring on relatively steep slopes. They can affect people and infrastructure even in densely populated areas.

Methods to study landslides occurrence are varied. They can be qualitative or quantitative, depending on the research aim, scale and database available (Aleotti & Chowdhury, 1999). Landslide susceptibility, hazard and risk assessement, for example, can be determined by statistical analyses considering a wide range of data. A detailed examination by Van Westen et al. (2008) showed which data layers are required for these analyses. They can be divided into four groups: environmental factors, landslide inventory, triggering factors, and elements at risk. The most important information is the inventory of landslides (Van Westen et al., 2008), since any further analysis directly depends on the quality and accuracy of the inventory. For example, inventories that present errors influence the reliability of susceptibility analyses and create distortions (Steger et al., 2016).

Shallow landslide inventories can be constructed manually, semi-automatically or automatically (Scaioni et al., 2014). Inventories were traditionally created based on interpretation of aerial photographs or by time-consuming field surveys. Nowadays, the new era of high resolution (HR) and very high resolution (VHR) satellite images offers new opportunities to complement existing approaches (Hölbling et al., 2017). The spatial and temporal resolution of satellite imagery as well as new tools and methods for analyzing these data help to improve the quality of landslide maps (Guzzetti et al., 2012).

However, there is still a lack of standards for landslide inventory mapping and creating consistent landslide databases (Guzzetti et al., 2012). This is also true in Brazil, where no standardization for shallow landslide mapping exists. For example, the decision of how to delimitate landslide scars is a purely subjective interpretation of the researchers and technical professionals who perform landslide mapping. Moreover, there is no official agency responsible for landslide inventory mapping in Brazil. Research institutes such as Cemaden (National Center for Natural Disaster Monitoring and Alerts), IPT (Institute of Technological Research of the State of São Paulo), IBGE (Brazilian Institute of Geography and Statistics) and CPRM (Geological Survey of Brazil) have their own methodologies and do not apply common or national mapping guidelines. As a consequence, currently any inventories generated for Brazil's territory lack consistency and do not follow standardized guidelines.

Usually, landslide inventories are constructed based on remote sensing images of different origins and spatial resolutions. For instance, Carou et al. (2017) carried out a manual mapping using Google Earth Pro images for a watershed in Itaóca, São Paulo state, Brazil. They considered two factors for the delimitation of scars: the absence of vegetation and position on the slope.

Landslides occur frequently in Brazil. Serra do Mar is an area were high magnitude events are triggered mostly in the summer season (December to March). This area is characterized by a mountain range located in the south and southeast regions of Brazil (Figure 1), which presents steep slopes and elevations between 800 and 1,800 m a.s.l. (Almeida & Carneiro, 1998).

One of the most important landslide events throughout the Brazilian territory happened in Caraguatatuba city in 1967 (Figure 1-C). A rainfall amount of about 500 mm/48 h was registered (IPT, 1988) and resulted in 640 landslides and debris flows, leading to 120 deaths, social and economic losses (Cruz, 1974; De Ploye & Cruz, 1979) and about two thousand tons of displaced material (Petri & Suguio, 1971).

The aim of this paper is to review the methodologies most used for shallow landslide inventories construction in Brazil based on articles published on this subject and to discuss current limitations and potential future directions.

2. METHODS

2.1. DATA SOURCES

The analysis consisted of searching publications about landslide inventory construction in Brazil within scientific online databases. The following five data sources were selected: ScienceDirect (www.sciencedirect.com), Scopus (https://www.scopus.com), Periódicos CAPES (www.periodicos.capes.gov.br), Google Scholar (scholar.google.com), and the Web of Science (WoS) Core Collection database (apps.webofknowledge.com).

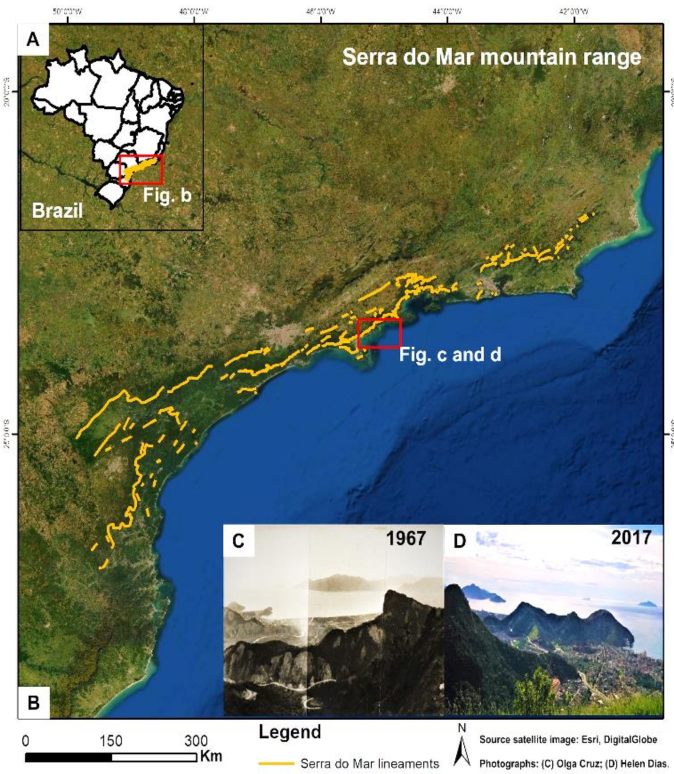

Figure 1. A: Location of Serra do Mar mountain range in Brazil; B: Details of Serra do Mar in the southeastern and southern coast; C: High magnitude event in Caraguatatuba in 1967; D: Caraguatatuba in 2017.

ScienceDirect, Scopus, Periódicos CAPES and WoS focus on scientific papers, mainly journal publications, Google Scholar was used to find any other research conducted about landslide inventory mapping, such as conference papers, reports, undergraduate research, dissertations and theses.

Keywords for ScienceDirect, Scopus, and WoS were only in English: Inventory, Landslide, and Brazil. Keywords for Google Scholar and Periódicos CAPES were in English and Portuguese: Inventário, Escorregamento and Deslizamento; and in English. We considered just publications with the words “Inventory” or “Inventário” in the title.

2.2. DATABASE ANALYSIS

Results found in the databases were quantified and compared. The analysis factors were: data source, publication type, year of publication and methods used for landslide inventory construction.

2.3. BIBLIOMETRIC ANALYSIS

A bibliometric analysis was made based on the keywords “Inventory” and “Landslides” to investigate the relationship between citations, volume and periodicity of publications on the specific topic worldwide. We analyzed only the words that occurred in the articles' titles.

The database used was Scopus and the analysis was done using VOSviewer (Van Eck & Waltman, 2010). Such an analysis provides general information and a better understanding of scientific output on landslide inventory mapping related to the authors and their origin. This procedure enables the verification of Brazil's representativeness on the topic.

3. RESULTS

3.1. PUBLICATIONS

The first set of analyses examined the impact of the theme on each online database based on searching with the specific keywords (as of June 2020). Results showed 7,750 publications (English) and 2,380 (Portuguese) for Google Scholar, 420 for ScienceDirect, 18 for WoS, 18 for Scopus and 526 (English) and 28 (Portuguese) for Periódicos CAPES. In each of the databases, only a small amount of publications is directly related to inventories of landslides.

On ScienceDirect only one publication related to the theme with either “Inventory” or “Inventário” in the title was found, on Google Scholar only six, on WoS only three, on Scopus only two and on Periódicos CAPES only one publication. The oldest publications are two conference papers from Hach-Hach & Zuquette (1998) and Rodrigues & Pejon (1998). The newest one is a paper by Carou et al. (2017), which was found on Google Scholar. Marcelino et al. (2009) was the only one that appeared in several databases, ScienceDirect, WoS, Scopus, Periódicos CAPES and Google Scholar.

The small number of publications indicates that this topic is not frequently addressed in Brazil or authors do not disclose the research in national nor international journals.

The keywords chosen aimed to identify and limit papers and results to the addressed topic. Although, other keywords were tested too, such as “Database” and “Mapping”. In these cases, only a few publications were found and most of them were not directly related to the topic. Thus, we did not include these terms in our search since they did not reveal further information compared to "Inventory", "Landslide" and "Brazil".

3.2. METHODS FOR LANDSLIDE INVENTORY CONSTRUCTION

Out of the eight identified papers, six were used to compare the methods applied and the data used for landslide inventory construction (Table 1). For two publications (Hach-Hach & Zuquette, 1998; Rodrigues & Pejon, 1998) the full papers could not be found, and thus, they were not considered for further analysis.

Visual interpretation is the most applied method. However, very little information was found in the literature on the question of the delimitation of landslides. Two publications assign procedures to delimit polygons of landslides. Lopes et al. (2007) did the mapping based on the absence of vegetation, size, shape and position on the slope (Figure 2), while Carou et al. (2017) considered the absence of vegetation and position on the slope (Figure 3).

Only one paper described field observations together with post-event image analysis, but does not mention attempts to delimit landslide polygons (Bauzys, 2012).

Table 1. Methods and data used for the construction of landslide inventories in Brazil.

Authors	Year	Method	Database
Lopes et al.	2007	Visual interpretation based on the absence of vegetation, size, shape, position on the slope, besides the overlap of contours and original photos.	Orthophotos (0.98 m)
Lopes et al.	2007b	Aero Lift.	Aerial photographs (1:25,000)
Marcelino et al.	2009	Visual interpretation of satellite images and MAXVER (pixel-by-pixel) classification based on spectral response and format.	Satellite images: HRV/SPOT-4 (10 m) and ETM+/Landsat-7 (30 m)
Bauzys	2012	Field survey and visual interpretation of post-event images.	Satellite images: ALOS and Landsat (the paper does not specify the resolution).
Mendonça et al.	2013	Visual interpretation of aerial photographs.	Aerial photographs (40 cm)
Carou et al.	2017	Visual interpretation with overlapping of contours following the criteria of absence of vegetation and position on the slope.	Google Earth Pro images

It is interesting to note that in all six case studies identified, different remote sensing data and scales were used, including aerial photographs, different satellite images and images available through Google Earth Pro. These results confirm the hypothesis that landslide mapping in Brazil is very heterogenous. Most of the papers perform a manual and visual interpretation of satellite images and aerial photographs.

The resolution, scale and processes to delimit polygons of landslides are varied and in some cases relevant information, such as criteria for landslides delimitation, is not even mentioned in the papers.

3.3. BRAZIL IN AN INTERNATIONAL CONTEXT

There is a growing need for the construction of reliable and up-to-date landslide inventories and the evaluation of morphodynamic processes in many countries. Guzzetti et al. (2012) mention that there is a high need for standards for producing landslide maps. However, also internationally, mapping standards are often still lacking.

In a European context, Van Den Eeckhaut & Hervás (2012) indicate that 22 out of 37 countries have or are constructing a national landslide database. In total, 645,230 landslides were mapped considering national and regional databases, and two-thirds of landslides registered are located in Italy (Van Den Eeckhaut & Hervás, 2012).

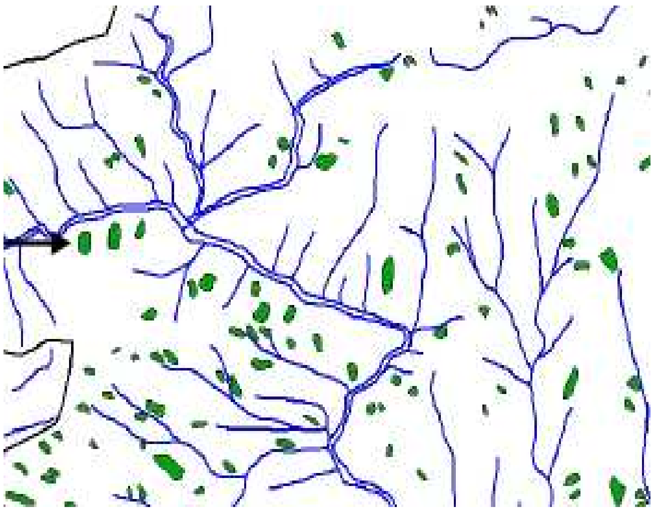

Figure 2. Inventory of landslides created by Lopes et al. (2007) by visual interpretation of satellite images.

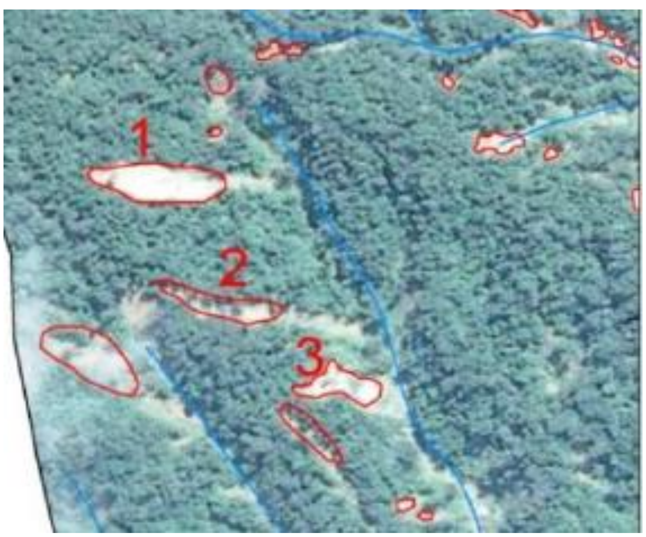

Figure 3. Inventory of landslides created by Carou et al. (2017) based on visual interpretation of Google Earth Pro images.

Italy has a national project named IFFI (*Inventario dei Fenomeni Franosi in Italia*) that aims to identify and map landslides over the whole Italian territory, based on standardized criteria. The project uses aerial photo interpretation, field surveys, collection of historical documents and archive data. The representations of landslides are made in three different manners: (1) a georeferenced point, located at the highest point of the crown; (2) a polygon, in case the landslide area is >10,000 m² and (3) a line, in case the width is too narrow and in case of debris flows (Trigila et al., 2007).

Herrera et al. (2018) described the necessity of standardized methodologies for the whole of Europe and to harmonize landslide inventories. Currently, each geological survey or the institution responsible for landslide inventory mapping of each European country applies its particular methodology for inventories construction. Next to implementing standards for landslide mapping and the need for greater coordination effort among the involved institutions to enhance data integration and harmonization, Herrera et al. (2018) suggest the development of a common European Landslides Directive that should constitute a legal framework for dealing with landslides. This is challenging to achieve on a continental level, since many different actors, who may have their dedicated requirements, need to agree on a common framework for landslide inventory generation.

Lin & Wang (2018) analyzed the Fatal Landslide Event Inventory of China (FLEIC), which includes data from 1950 to 2016. FLEIC considers only events that result in casualties in China and was compiled from different data sources based on punctual localization (latitude, longitude and radius of confidence). FLEIC represents landslides as georeferenced points. There is an uncertainty in event location, so they assigned a radius of confidence (in km) indicating the radius in which the landslide may have occurred. This national inventory enables the identification of trends for landslide occurrence and can be used for quantitative analyses and improvement of landslide hazard and risk assessment (Lin & Wang, 2018).

Monsieurs et al. (2018) investigated information on landsliding in a remote and underrepresented region in Africa, the central section of the western branch of the East African Rift (LIWEAR). They create an inventory with 143 dated and localized landslide events from 1968 to 2016. The location of landslides is not always accurate and sometimes was estimated by the authors. The objective was to collect information about mass movements in the African territory at a regional scale. However, they did not use guidelines for the delimitation of polygons.

Ideally, landslides should be delimited as polygons including metadata information (Harp et al., 2011). In Brazil, there is no common procedure nor any standard for doing that. This also concerns the delineation of different types of landslides or a potential differentiation of landslide scars and transport/deposition area. However, for producing a nationwide, reliable inventory this would be necessary.

Manual mapping is still very common, even though it presents some weaknesses. Its quality depends on the time spent for mapping, the data used, the purpose and its accuracy directly relates to the researcher's skills and experience (Galli et al., 2008; Guzzetti et al., 2012; Hölbling et al., 2015). The review of the existing literature showed that there are hardly any efforts to use semi-automated or automated methods for landslide mapping in Brazil.

3.4. ANALYSIS OF BIBLIOMETRIC VARIABLES

3.4.1. Cocitation and quote network

Scopus found 2.029 articles related to the topic (as of 2020-06-02). The bibliometric analysis exhibits two large clusters of cocitations concerning the landslide inventory topic and considering just authors with five or more published papers. One of them refers to B. Pradhan from Australia who has 77 publications and 7.297 citations. The other is F. Guzzetti from Italy, who has 57 publications and 6.074 citations (Figure 4).

The quote network shows that authors usually do not directly relate to each other, although the object of their research is similar. One major connection is made by C.J. Van Westen from the Netherlands, who has 37 publications and 2,752 citations (Figure 5).

Most scientific work on landslide inventories is concentrated in Europe and Asia/Oceania. Only four authors were identified in Latin America, three from Mexico (I. Alcántara-Ayala, F.G. Murillo-García and M.T. Ramírez-Herrera) and one from Argentina (S.M. Moreiras), no Brazilian author was identified by this analysis.

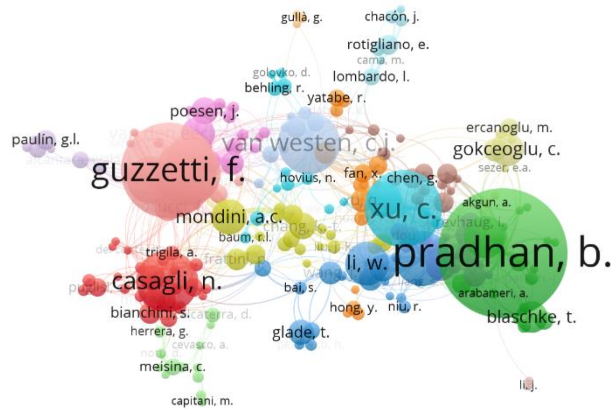

Figure 4. Clusters of scientific papers quantity and cocitation related to inventory of landslides.

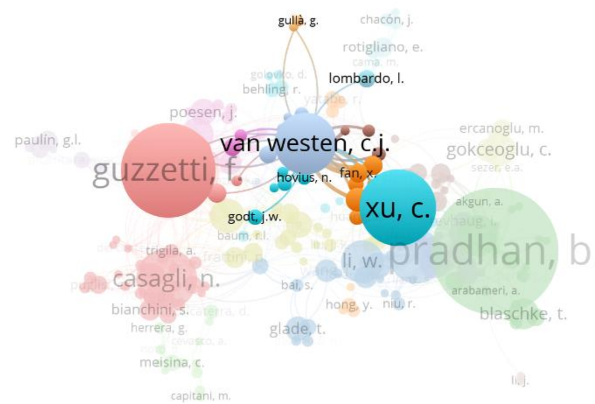

Figure 5. Quote network of C.J. Van Westen.

3.4.2. Most cited keywords

The bibliometric analysis shows that the most cited keywords are: “Landslide” (361), “Landslide susceptibility mapping” (202), “Inventory” (198), “Earthquake” (174), “Susceptibility” (162) and “Susceptibility assessment” (108) (Figure 6).

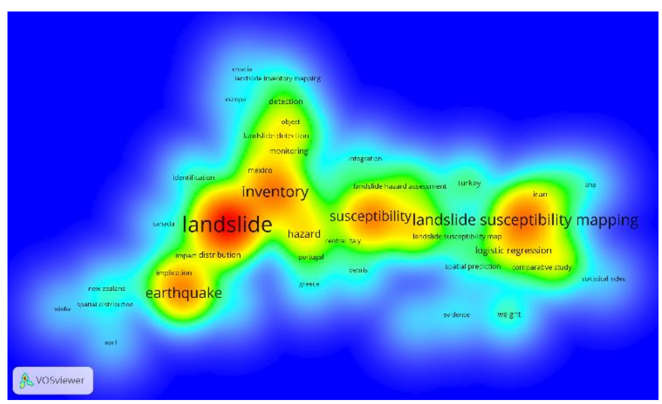

Figure 6. The most frequently used keywords in papers related to inventory of landslides.

Publications that cover the landslide inventory topic are often directly related to susceptibility studies with an earthquake as a triggering factor.

4. CONCLUSIONS

This study has gone some way towards enhancing our understanding of landslide inventory construction in Brazil, but also showed worldwide examples from Europe, Africa and China. Countries are at varied levels of addressing the topic, have different approaches to landslide mapping and face different challenges. Europe and Asia/Oceania lead the production of scientific papers related to inventories, whereby the research focuses on susceptibility assessment of landslides.

Our analyses show that Brazil, but also other countries, lack of common procedures for landslide inventory construction. As shown in this brief review, shallow landslide inventories in Brazil are constructed mostly manually by visual image interpretation. The database selected varies (aerial photographs, satellite images, Google Earth Pro images), and standards and common guidelines are missing.

The results indicate a necessity to improve methodologies for landslide mapping at the national scale in Brazil, as well as the development of guidelines for the delimitation of landslides scars.

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