Developing a spatiotemporal model to integrate landslide susceptibility and critical rainfall conditions. A practical model applied to Rio de Janeiro municipality.

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I Introduction & Study area

Rio de Janeiro municipality & landslides

- Circa **1,200Km²** and is often affected by landslides (Coelho Netto et al., 2007; 2009).
- **6.2 million inhabitants, of which 22.7% reside in favelas.** These communities are usually located at the hillslopes and often have a poor infrastructure.
- 583 of the 1664 landslides occur in Favelas.
- The **city is highly susceptible to the occurrence of landslides** due to complex geomorphological and climatic settings.
- The city is closely monitored through rainfall records (**33 stations, recording measurements every 15 minutes**). Rainfall data is freely available for a few decades.
- There is an **urgent need to increase awareness and preparedness for future events (**Dias et al., 2021**)**.
- Especially when considering climate change scenarios, which are **expected to increase the frequency and magnitude of catastrophic events** (Pelech et al., 2019; Marengo et al., 2021).

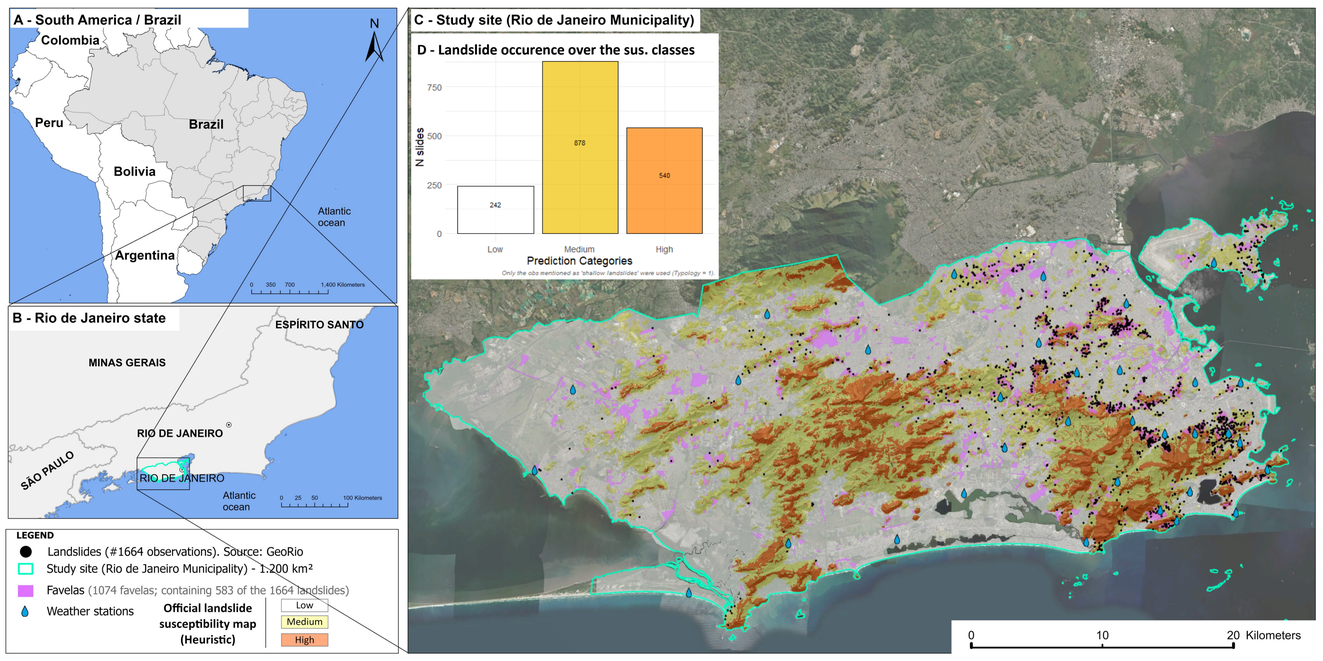

Fig. 1: Study site and official Landslide Susceptibility for Rio de Janeiro Municipality. **A)** Showcases the location of Brazil within South America, with a focus on Rio de Janeiro state. **B)** Zooms in on the state of Rio de Janeiro, highlighting its capital. **C)** Detailed satellite image of Rio de Janeiro Municipality, overlaid with data points indicating recorded landslide occurrences and the heuristic landslide susceptibility classes. The pink areas shows the distribution of informal settlements known as favelas. **D)** Landslide occurence over the susceptibility classes (https://www.data.rio/apps/PCRJ::suscetibilidade-a-deslizamentos/explore).

II Data & Methods

Landslide inventory

Fig. 2: Geotechnical occurrence report example.
Source: Rio de Janeiro Geological Survey (Geo-Rio).

Table 1: Number of reports and actual landslides per year.

Year	Number of reports	Actual landslides	Landslides with date Information
2009	NA	2	167
2010	1080	909	408
2011	959	162	24
2012	582	80	11
2013	949	196	69
2014	542	111	6
2015	410	78	12
2016	509	123	3
Total	**5031**	**1664**	**700**

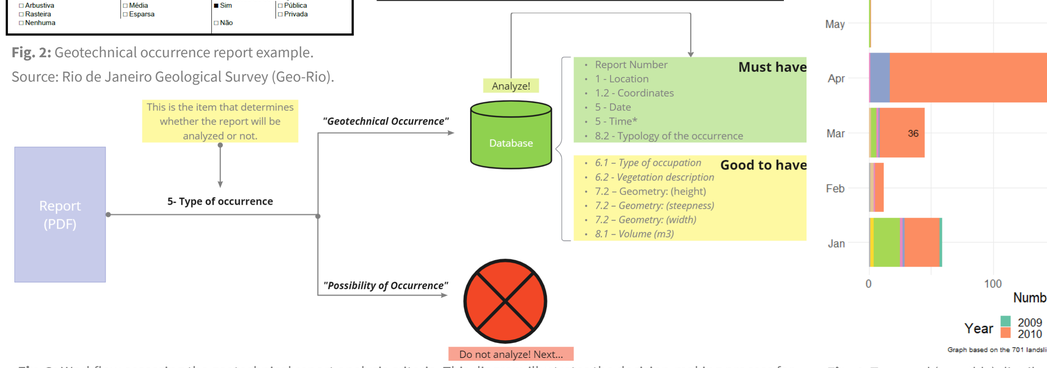

Fig. 3: Workflow assessing the geotechnical report analysis criteria. This diagram illustrates the decision-making process for the analysis of geotechnical reports based on predefined criteria.

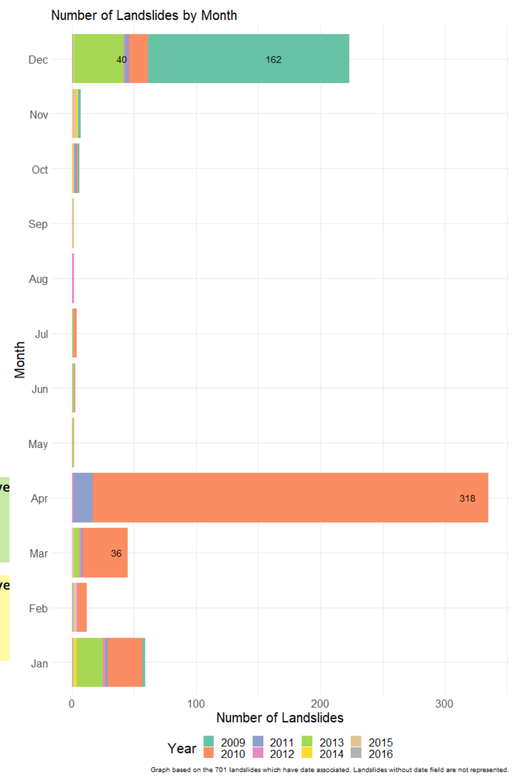

Fig. 4: Temporal (monthly) distribution of the landslides.

Summarized Work Plan

Data collection and preparation

Stage 1

Landslide inventory
- GeoRio inventory
- Coelho Netto et al. (2009), Coelho Netto et al. (2007), Silva (2000) e Negreiros et al. (2012).
- NASA global landslide inventory (Kirschbaum et al. (2015))

Predictors
- Digital Elevation Model (IPP/RJ)
- Geomorphological Variables
- Land Cover Map
- Geology
- Geomorphological map

Rainfall data
- Rainfall data, with a 15-minute temporal resolution. [Available from 1997 - 2023].

Available at: http://alertario.rio.rj.gov.br/download/dados-pluviometricos/

Modelling

Stage 2

Landslide Susceptibility Map (static map)
Statistical models and/or machine learning for the creation of spatial prediction models of landslides.

Integration with pluviometric data (dynamic map)
Identification of critical rainfall that triggered landslides and integration with the terrain susceptibility model.

Visualization of results and product availability

Stage 3

The products (static and dynamic maps) will be made available in the form of:
- Online dashboard?
- Provision of the code for modeling reproduction (e.g., GitHub).

Fig. 5: Three-stage workflow, detailing data collection, modeling techniques, and dissemination methods. Current stage: Stage 2.

III Preliminary results & perspectives

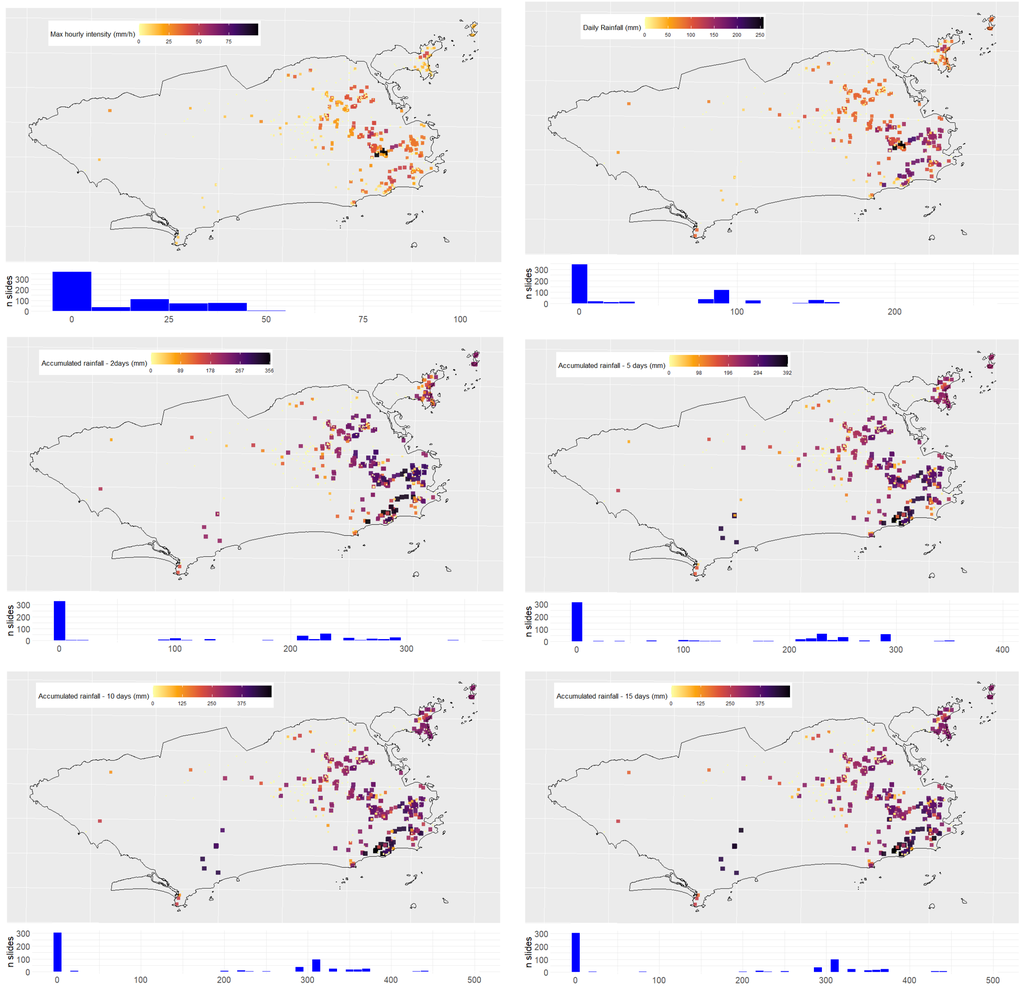

Fig. 6: Distribution and precipitation patterns related to landslides occurences (max hourly intensity, daily totals, and accumulated rainfall over 3-, 5-, and 10-day periods).

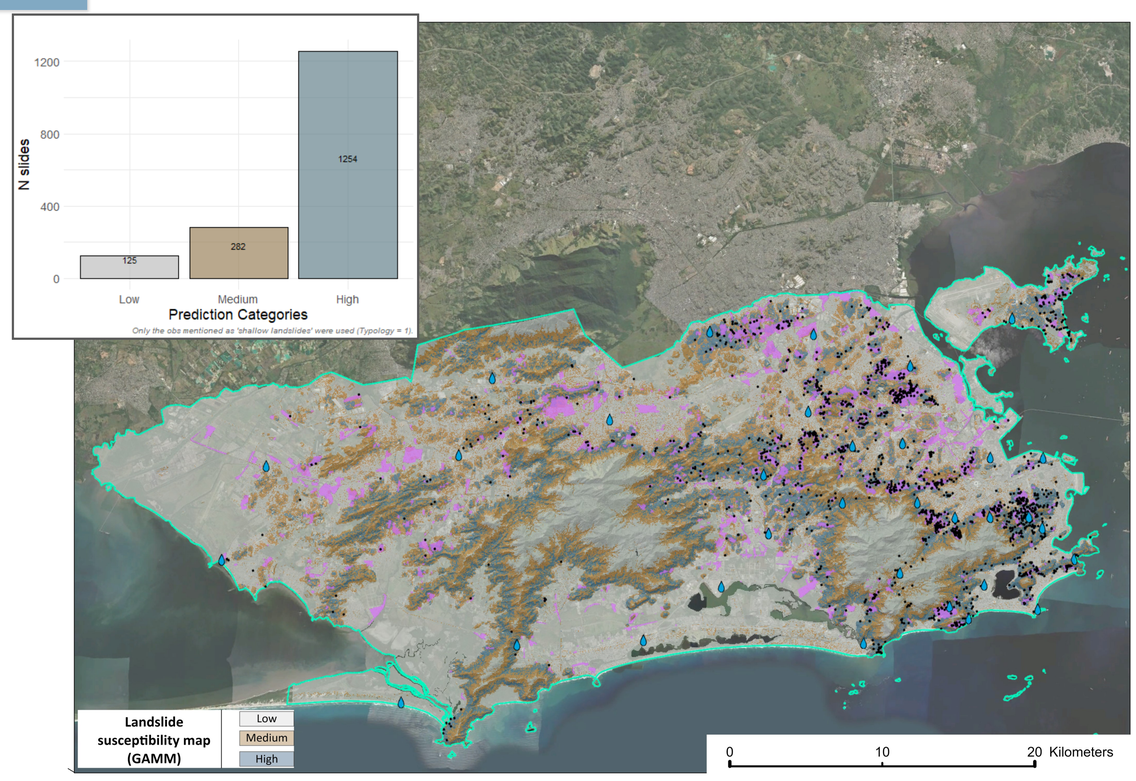

Fig. 7: Data-driven landslide susceptibility map. Model created using GAMM: *fo1 <- slide ~ s(dtm) + s(prof_curv) + s(slope) + geomorph_rec + geol_rec + fav_res* . The "*fav_res*" was introduces as a random intercept.

Moving towards...

Alternative mapping unit –> Slope unit.

Sampling strategy adaptation -> In terms of time balance and excluding non-landslide observations in trivial terrain.

Bias handling -> Mixed effects. Given the high number of occurrences (reports) in the favelas, these were added (together with the residential areas) as random intercept.

Landslide occurrences x Rainfall patterns -> Still needs to be better comprehended.

Space-time prediction -> Similar as performed in Steger et al., 2023 and Moreno et al., 2023.

Literature

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