Urban Risk Assessment: Mapping Socioeconomic Vulnerability to Landslide Hazards on São Paulo's Northern Coastline

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Abstract

Increasingly salient, the threat of natural hazards poses a risk to communities, disproportionately affecting socially and economically vulnerable populations. In Brazil, recent precipitation trends have escalated the incidence of flooding and landslides, with the Northern coast of São Paulo experiencing, in 2023, 682mm of downpour. As a consequence, 1,730 people were displaced and 1,810 left homeless.[7] However, as discussed in Dantas et al.(2025), negative impacts of hydrological extremes are unevenly distributed across socioeconomic variables, with more severe consequences concentrated in areas with limited resources. We then investigate the negative correlation between the allocation of high income housing —proxied by mapping luxury condominiums—and areas most vulnerable to climate change, emphasizing the impacts of extreme precipitation through employing change identification techniques in satellite rasters.

Introduction

In 2023, São Paulo's Northern coastline was hit by 682 mm of downpour, resulting in landslides and floods that caused great damage.[7] However, fatalities were localized, with all 64 deaths occurring in Vila Sahy, a hillside favela.[8,9] Existing research in the field describes said phenomenon, highlighting differential impacts on distinct economic segments of the population. That is, while rich neighborhoods feature luxury condos and high-rise beach fronts, with reinforced concrete walls and strong foundations that remained structurally intact post the landslides, poorer neighborhoods house service workers of luxury apartments and faced the brunt of the impact.

(a) February 19, 2023 (b) February 26, 2023

Figure 1. Sao Paulo before and after.
Source: Operational Land Imager (OLI) on Landsat 8

Methods

Step One: Identifying High-Income Areas

- The OSMDownloader plugin and XYZ tiles (provided by GoogleMaps) were used to identify condominiums listed as points of interest in Open StreetMap. We verified the accuracy of these points using Google Earth Street View. An example of the profile of low and high income areas is displayed in Figure 1.
- A new shapefile polygon layer was created using toggle editing to manually outline high-income gated communities (condominiums).
- Each observation included three attributes: **ID, description, and tourism classification**. Tourism areas include cities with high-income tourism infrastructure, not limited to condominiums alone.

(a) Low income area, Praia de Boraceia (b) High income area, Praia da Baleia

Figure 2. Example of low and high income areas.
Source: Google Earth, Street View

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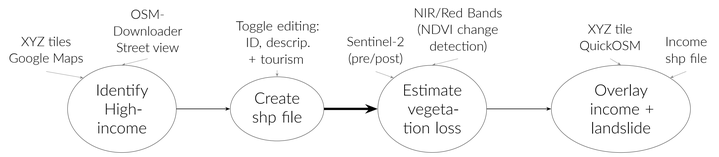
Step Two: NDVI Analysis of Landslide Impact

- We downloaded two Copernicus Sentinel-2 images: one from January 26, 2023 (pre-landslide) and one from February 25, 2023 (post-landslide). In a new QGIS project with CRS set to EPSG:32723, we opened the red band (10m resolution) and NIR band (10m resolution) for both dates.
- To estimate vegetation loss, we calculate the **Normalized Difference Vegetation Index** for each date using:

$$NDVI_i = \frac{NIR_i - Red_i}{NIR_i + Red_i}$$

- We added an OpenStreetMap base map via XYZ Tiles.
- Using the QuickOSM plugin, we downloaded building points of interest and overlaid the socioeconomic vector layer for analysis.



Results

After overlaying polygons of high-income neighborhoods —highlighted in blue —onto landslide incidence data —calculated with NDVI —a clear spatial pattern of the segregation emerges: high income areas correspond to zones of minimal vegetation loss, our proxy for landslide impact, as showcased in Figure 3. In contrast, low-income neighborhoods, located outside blue polygons, overlap significantly areas with the greatest vegetation loss (in red), and, therefore, the highest landslide impact. Moreover, we find no correlation between income levels and level of land coverage. Thus, it is unlikely that low-income would have more vegetation and, consequently, more landslide incidence.

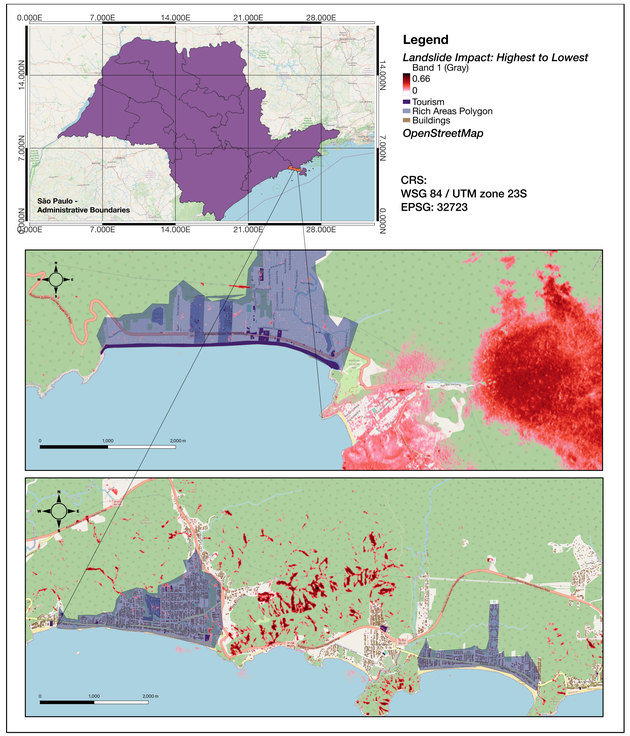


Figure 3: Mapping High Income Neighborhoods to Landslide Risk - Maresias and Praia da Baleia

Conclusion

Given the context of extreme rainfall in the Northern coast of São Paulo, our research then strengthens the hypothesis that negative impacts of climate change are correlated with economic dimensions. Specifically, this study showcases a negative correlation between landslide incidence —calculated via NDVI change detection —and high-income areas —proxied by mapping luxury condominiums. However, to infer the specifics of different income levels, future research should attempt to link change detection with submunicipal-level economic data, not publicly available.

References

[1] 3liz. Osmdownloader: Qgis plugin, 2023. URL `https://plugins.qgis.org/plugins/osmdownloader/`. QGIS plugin.

[2] European Space Agency. Sentinel-2 satellite imagery, February 2023. URL `https://scihub.copernicus.eu/`. Data set.

[3] European Space Agency. Sentinel-2 satellite imagery, January 2023. URL `https://scihub.copernicus.eu/`. Data set.

[4] Dantas et al. Projections of extreme weather events according to climate change scenarios and populations at-risk in brazil. 178(152), 2025. doi:10.1007/s10584-025-03989-2.

[5] Julien Girres. Quickosm: Qgis plugin, 2023. URL `https://plugins.qgis.org/plugins/QuickOSM/`.

[6] Google. Google earth pro, 2023. URL `https://www.google.com/earth/`. Software.

[7] The Guardian. Brazil floods: death toll rises to 48 as landslides and looters prevent aid reaching survivors. *The Guardian*, 2023. URL `https://www.theguardian.com/world/2023/feb/23/brazil-floods-death-toll-flooding-landslides-looters-sao-paulo-state`.

[8] Kathryn Hansen. Landslides in são paulo, brazil, October 2022. URL `https://earthobservatory.nasa.gov/images/151051/landslides-in-sao-paulo-brazil`.

[9] Dave Petley. Vila sahy, são paulo: Extreme rainfall in brazil has triggered multiple fatal landslides, February 2023. URL `https://blogs.agu.org/landslideblog/`