Supplementary information

1) This paper compares and discusses five methods: PMRR, GRS, GAUC, SS, and GHS. At the very least, a brief explanation of each method should be written in order to allow the reader to follow the arguments of this paper. Unless this point is clearly stated, it is difficult to properly review and comment on the results and discussion of this paper. So that I believe that a re-review is necessary.

2. Overview of Federal Risk Assessment Surveys in Brazil

Since 2004, five different federal risk assessment surveys have been conducted in Brazil, each initiated at different times. The Municipal Risk Reduction Plan (PMRR) represents Brazil's first nationwide initiative aimed at establishing a standardized framework for local-scale risk assessment and disaster mitigation planning. Developed in alignment with the National Policy for Civil Protection and Defense (PNPDEC; Law No. 12,608/2012), the PMRR promotes a paradigm shift from reactive post-disaster responses to proactive risk prevention (Mendonça et al., 2023). Its methodology involves a series of structured phases, including the assessment of geohydrological risk areas, the design of structural countermeasures, cost estimation, and structural and non-structural action plans (Alheiros, 2006). Implementation is coordinated through the Union Resources Decentralized Execution Agreement, typically executed in partnership with universities, public agencies, or private entities (*e.g.,* UFSC, 2007; Souza et al., 2008; IPPLAN, 2016), ensuring technical rigor and local contextualization.

While the PMRR offers a comprehensive and structured framework, the Geological Risk Survey (GRS) was developed as a more responsive diagnostic tool to rapidly assess geohydrological risks in urban environments. Grounded in the conceptual understanding of risk as the interaction among hazard, vulnerability, and potential damage (Tominaga, 2012), the GRS focuses on phenomena such as landslides, debris flows, rockfalls, floods, and flash floods (Lana et al., 2021). Supported by national legislation, it serves both as a strategic input for early warning systems at the federal level and as a technical resource for local land-use regulation, preparedness measures, and emergency response planning (Pozzobon et al., 2018). Its methodology comprises a desk-based analysis using geospatial and thematic data, followed by fieldwork to validate and classify risk areas based on terrain morphology and physical vulnerability of existing infrastructure (Pimentel et al., 2018). Although various state and municipal institutions—such as the Institute for Technological Research (IPT) in São Paulo and the Geotechnical Institute Foundation (GeoRio) in Rio de Janeiro—initially developed their own methodologies, the responsibility for standardizing and implementing the survey nationwide was later delegated to the Geological Survey of Brazil (GSB), a federal agency under the Ministry of Mines and Energy, by directive of the Civil House of the Presidency (*e.g.,* Pascarelli et al., 2013; Lamberty & Binotto, 2022; DRM, 2023) .

Whereas the GRS centers on the delineation of existing risk zones, the Susceptibility Survey (SS) seeks to anticipate where future hazards are likely to occur by evaluating the intrinsic predisposition of terrain to trigger geohydrological processes. Officially recognized in Brazil's legal framework, the SS provides municipalities with technical input to inform land-use regulation and long-term urban planning (SGB, 2023b). This methodology encompasses a range of phenomena, including landslides, debris flows, floods, and flash floods (Antonelli et al., 2020). Its primary objective is to provide municipalities with technical support for territorial management and risk mitigation strategies. The approach is grounded in geospatial modeling techniques, which integrate historical inventory data with geological, hydrological, and geomorphological variables to produce susceptibility maps and classify terrain into distinct levels (Bittar, 2014). Fieldwork is carried out for validating the modeled results. While various academic institutions have proposed alternative approaches for conducting this type of assessment, the GSB is the officially designated authority responsible for implementing SS at the national level (*e.g.,* Lorentz et al., 2016; Dias et al., 2021).

Building upon susceptibility assessments, the Geotechnical Aptitude for Urbanization Chart (GAUC) is a technical survey designed to evaluate the suitability of terrain for supporting various forms of land use, thereby guiding safe and sustainable urban development (Antonelli et al., 2021). Intended to inform municipal planning decisions, GAUC supports territorial management, land-use regulation, and disaster risk reduction policies by identifying geotechnical favorable zones for urban expansion (SGB, 2023c). The methodology involves integrating geological, geomorphological, pedological, and topographic data with historical records, complemented by detailed field and laboratory investigations to delineate homogeneous geotechnical units suitable for urbanization (Antonelli et al., 2021). Like the previous surveys, GAUC is endorsed by Law No. 12,608/2012 and serves as a planning instrument under the National Policy for Civil Protection and Defense. Although several academic institutions contribute to GAUC development, its systematic national implementation is carried out by the GSB (*e.g.,* Ribeiro & Dias, 2020; Polivanov et al., 2024).

Completing the Brazilian risk assessment framework, the Geological Hazard Survey (GHS) was introduced to enhance the objectivity of hazard detection and provide predictive insight into potential runout distances of sediment-related events. Developed by the GSB, the GHS uses topographic thresholds derived from statistical analyses of historical events to identify susceptible areas and estimate the potential trajectory and runout extent (Pimentel et al., 2020). It is intended to support various stakeholders—including urban planners, civil defense authorities, and policymakers—by offering standardized and spatial outputs that inform land-use regulation, emergency preparedness, and risk mitigation strategies. Its methodological structure encompasses four key stages: compilation of spatial and thematic data, identification of strategic areas, desk-based hazard modeling using topographic conditioning factors, and final field validation to assign hazard classifications (Pimentel et al., 2018). The GHS has been applied in several municipal studies to support land-use planning and disaster risk management (*e.g.,* Facuri & De Lima Picanço, 2021; Ribeiro et al., 2021; Rocha et al., 2021).

These five federal methodologies constitute the backbone of Brazil's national strategy for assessing and managing geohydrological risks. Although they operate under a shared legal framework and pursue similar overarching goals, each survey differs substantially in scale, technical scope, practical applicability, and intended outcomes. These methodological distinctions raise critical questions regarding their complementarity, integration, and overall effectiveness in supporting disaster risk reduction (DRR) initiatives across multiple levels of governance. The following sections present a systematic comparative analysis to explore these issues, examining key dimensions such as survey design, territorial coverage, operational scale, suitability and alignment with DRR implementation, and relative cost per beneficiary.

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17) Line 384 – 402: The percentage values in the text cannot be found in Figure 4. Please either add a figure or discuss only the values that can be found in the figure.

5.2 Examining the correlation between risk assessment surveys and the implementation of disaster reduction countermeasures

Risk assessment surveys are vital resources for various risk-management initiatives. Therefore, the effectiveness of these surveys can be evaluated by examining the activities and initiatives developed from the basic information provided by them. Figure 4 illustrates the distribution of municipalities across the Brazilian states that have adopted various DRR initiatives, such as master plans (MP), landslide–specific laws (SL), land-use and land-occupation laws (LULOL), early warning systems (EWS), emergency response plans (ERP), and structural countermeasures (SC). The regional distribution of DRR initiatives across Brazilian states reveals notable contrasts in implementation levels. First, excluding the Federal District, the implementation of landslide-specific laws (LSL) remains notably low across all states. Only Rio de Janeiro and Pará exceed the 5% threshold, standing out as the exceptions in this category. In the Northern region, most states exhibit relatively low adoption of disaster risk reduction measures (Fig. 4). However, Amazonas, Pará, and Amapá present higher percentages in certain indicators in this region. Amazonas, for instance, shows considerable efforts in implementing emergency response plans (23%) and early warning systems (11%). Pará demonstrates moderate values across all initiatives, particularly in master plans (13%) and LULOL (12%). Amapá also stands out with 31% of municipalities having ERP and 19% implementing LULOL. In contrast, Roraima and Tocantins register the lowest levels in the region, with most indicators below 5%, and complete absence of early warning systems, emergency plans, and structural countermeasures in Roraima. In the Northeastern region, the implementation pattern is more heterogeneous (Fig. 4). States such as Pernambuco and Alagoas lead in most indicators. Pernambuco exhibits significant adoption of master plans (20%), emergency response plans (25%), and structural countermeasures (11%), while Alagoas shows high percentages in early warning systems (14%) and ERP (18%). Other states, such as Ceará and Bahia, demonstrate moderate values across all initiatives. In contrast, Piauí and Paraíba appear among the least engaged in the region, with consistently low percentages for specific plans, early warning systems, and structural countermeasures. In the Midwestern region, results vary significantly (Fig. 4). The Federal District represents a clear outlier, reporting 100% implementation for all DRR categories except for structural countermeasures. Mato Grosso do Sul follows with comparatively high adoption of master plans (13%), LULOL (14%), and EWS (8%). Meanwhile, Mato Grosso and Goiás exhibit limited implementation, with most indicators—particularly EWS, ERP, and SC—remaining below 5%.

The Southeastern region stands out as the most advanced in DRR implementation (Fig. 4). Rio de Janeiro and Espírito Santo lead the country, with exceptionally high percentages across nearly all indicators. Rio de Janeiro, for example, reports 77% of municipalities with ERP, 41% with EWS, and 30% with SC. Espírito Santo shows similar results, including 63% ERP and 26% EWS. São Paulo and Minas Gerais also demonstrate widespread adoption, with São Paulo exceeding 10% in all indicators and Minas Gerais registering 20% for ERP and 18%

for SC. In the Southern region, DRR measures are generally well adopted (Fig. 4). Paraná shows the highest percentages for master plans (31%) and LULOL (31%) among all states in the region. Santa Catarina also performs well, particularly in EWS (16%) and ERP (32%). Rio Grande do Sul, while displaying lower values compared to its southern counterparts, still achieves notable implementation for ERP (30%). Overall, the Southeast and South regions exhibit the highest concentration of municipalities with DRR measures, while the North and Midwestern—excluding the Federal District—tend to lag behind, with considerable disparities within and between regions.

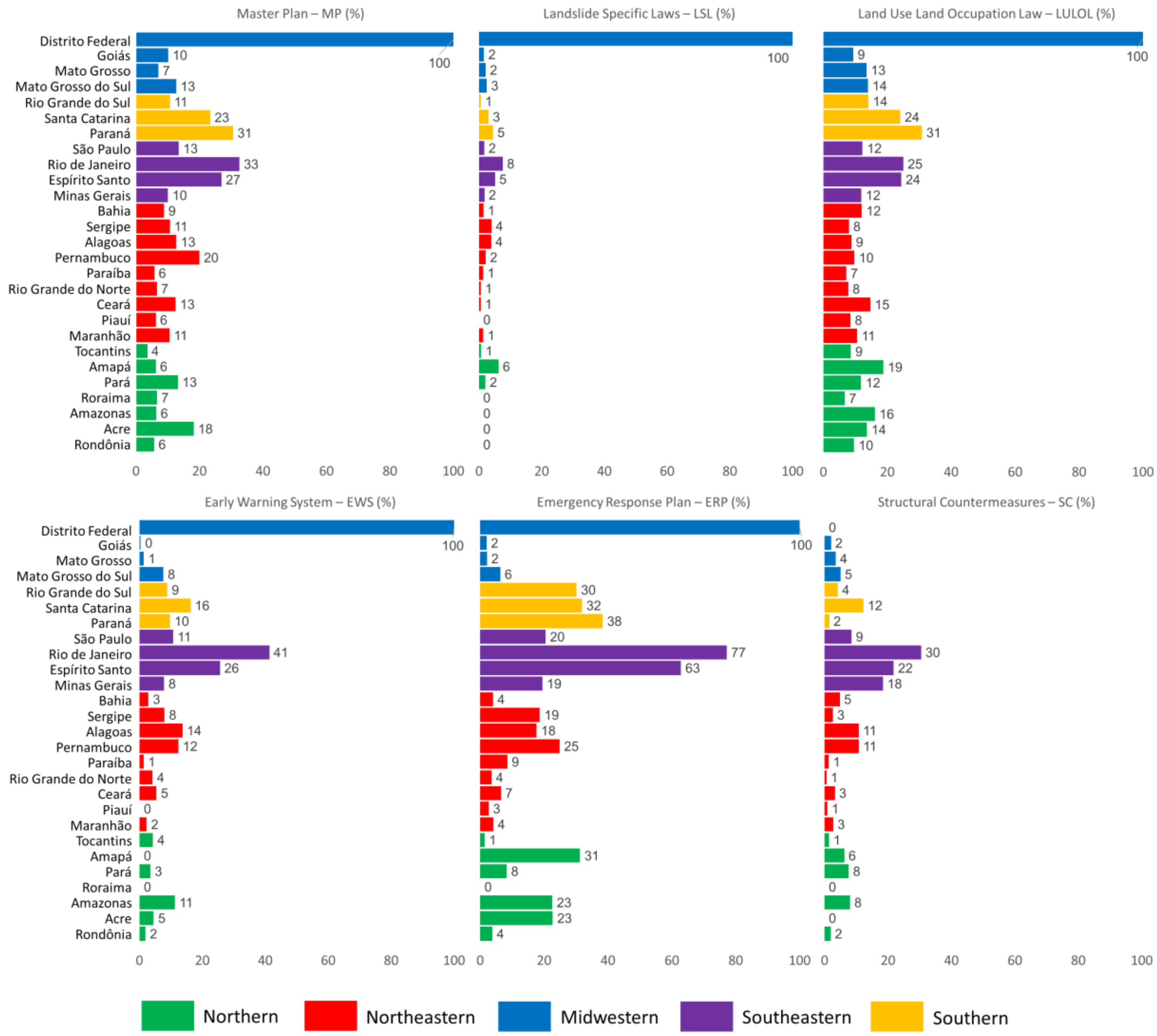

Figure 4: Distribution of municipalities in Brazilian states implementing sediment-related DRR initiatives (in percentages). Analysis based on IBGE (2020) DRR dataset. Bars are color-coded to represent Brazil's five macro-regions.

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19) Figure 6: The correspondence with the six initiatives written in section 2.3.3 is unclear.

5.3 Applicability for disaster reduction initiatives

To complement the operational analysis presented in Section 5.2, a relevance matrix (Fig. 6) was developed to explore the applicability of federal risk assessment surveys across multiple dimensions of disaster risk reduction. While the previous section focused on the implementation status of key DRR initiatives based on official indicators from the municipal profiles (IBGE, 2020), the matrix presented here evaluate the suitability of these DRR derived from internationally recognized methodological frameworks (Hungr et al., 2005; Fell et al., 2008; Corominas et al., 2014). The matrix displays the degree to which each survey supports different DRR elements, using a gradient scale from dark blue (0—Not applicable) to dark red (4—Fully applicable). This classification reflects the functional alignment of each survey with best practices for its respective scale, taking into account its defined scope and the extent to which it is integrated into formal governance practices. The resulting overview highlights distinct differences in applicability among the methodologies.

The matrix reveals a clear differentiation in the breadth and depth of applicability among the five federal risk assessment methodologies. The PMRR and GRS exhibit consistently high applicability across a range of DRR initiatives, particularly in emergency response planning (ERP), early warning systems (EWS), and structural countermeasures (SC). Their operational versatility enables integration into a broad set of initiatives; however, their role in shaping legislative frameworks—particularly LSL and LULOL—remains limited. In contrast, the GAUC demonstrates strong alignment with legal instruments, though its contribution to ERP appears comparatively constrained. The SS similarly supports the legislative dimension, but its applicability is markedly lower in ERP and SC. Finally, the GHS stands out as the most applicable methodology, achieving either full (score 4) or substantial (score 3) relevance across all DRR categories. Its balanced integration emphasizes its utility as a comprehensive tool for multi-level risk governance.

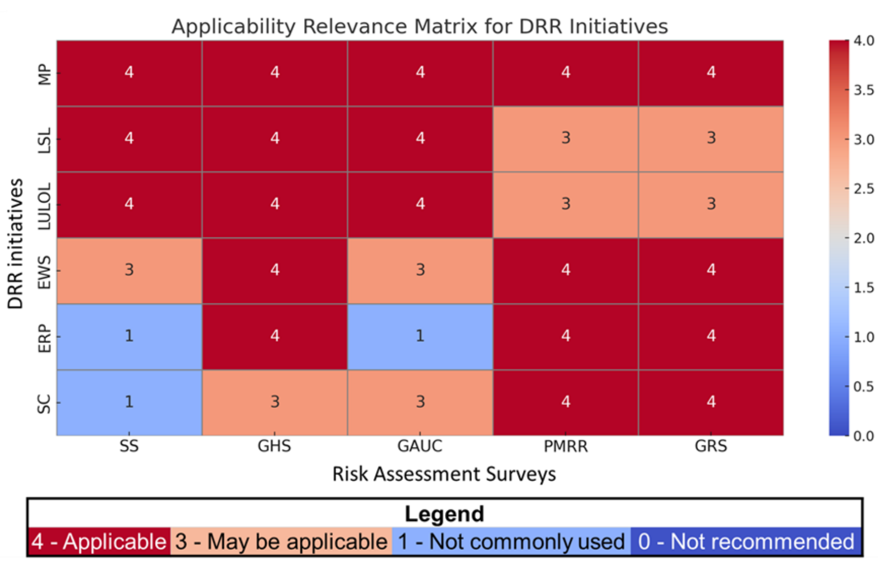

Figure 6: Brazilian DRR assessment relevance matrix based on applicability recommendations from Hungr et al. (2005), Fell et al. (2008), and Corominas et al. (2014).