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MAPEAMENTO E CARACTERIZAÇÃO DE ÁREAS DE RISCO DO MUNICÍPIO DE CARAGUATATUBA - SP

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A cada etapa concluída em nossas vidas, é importante realizar uma reflexão sobre as relações criadas ou mantidas no processo, uma vez que os acontecimentos mundiais nos últimos tempos nos provam que sozinhos não chegamos a lugar algum.

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RESUMO

ROCHA, Daiana Tabosa. **Mapeamento e caracterização de áreas de risco do município de Caraguatatuba - SP**. 2022. Dissertação (Mestrado em Desastres Naturais) - Universidade Estadual Paulista (Unesp), Instituto de Ciência e Tecnologia; Centro Nacional de Monitoramento e Alertas de Desastres Naturais (Cemaden), São José dos Campos, 2022.

O município de Caraguatatuba, localizado no Litoral Norte do Estado de São Paulo, Brasil, área de estudo da presente pesquisa, apresenta um modelo de crescimento desordenado, com ocupação em áreas de risco e falta de infraestrutura urbana, além de uma tendência histórica na ocorrência de desastres. Indícios da possibilidade de reincidência de eventos extremos torna necessária a busca por novas perspectivas sobre os riscos e vulnerabilidades da população exposta. Esta pesquisa consistiu em validar o potencial de uso do Modelo Normalizado de Terreno HAND (do inglês, Height Above the Nearest Drainage) para o mapeamento de áreas de risco hidrogeológico, a partir da disponibilidade de dados topográficos de diferentes resoluções espaciais como entrada, para (i) observar as variabilidades de representação do relevo nos mapas normalizados; (ii) elencar a resolução que oferece melhores condições de representação do relevo; e (iii) a factibilidade de produção desses mapeamentos somente partir da utilização dados de livre acesso, diante das dificuldades de acesso a dados topográficos de qualidade enfrentados pelas municipalidades em geral. Os resultados demonstraram a existente possibilidade de um dado geoespacial com resolução mais grosseira ser capaz de gerar informações similares às produzidas pelo dado de alta resolução, com certo grau de precisão; viabilizando o uso de dados e softwares disponíveis gratuitamente na elaboração de mapeamentos, contribuindo com gestores nas ações para construção de cidades resilientes.

Palavras-chave: hidrogeologia; inundações; modelo HAND; áreas de risco; vulnerabilidade.

ABSTRACT

ROCHA, Daiana Tabosa. ***Mapping and characterization of risk areas in the municipality of Caraguatatuba - SP****. 2022. Dissertation (Master's degree in Natural Disaster) - São Paulo State University (Unesp), Institute of Science and Technology, National Center for Monitoring and Early Warning of Natural Disasters (Cemaden), São José dos Campos, 2022.*

Caraguatatuba municipality, located in the northern coast of São Paulo State, study area of this research, presents a disordered urban growth, with occupation in risk areas and lacks urban infrastructure, in addition to a historical tendency to disaster events occurrence. Evidence of possible recurrence of extreme events motivate the search for new perspectives on the risks and vulnerabilities of the exposed population. This research consisted of validating the potential use of the HAND Normalized Terrain Model for hydrogeological risk areas mapping, based on the availability of different resolutions of topographic data to use as input, and from HAND products, to (i) evaluate the relief representation variability in normalized topology; (ii) highlight the resolution that offers better conditions to surface representation; and (iii) the feasibility of producing these mappings solely from free access data input, given the difficulties of access to quality topographic data faced by municipalities in general. The results satisfactorily demonstrated the existing possibility of a less robust resolution data being able to generate information similar to those reproduced by the high resolution data, at some precision level; therefore enabling the use of freely accessible data and software for mapping purposes, collaborating with governances and policymakers actions to build resilient cities.

Keywords: hydrogeology; floods; HAND model; risk areas; vulnerability.

SUMÁRIO

1 INTRODUÇÃO

A percepção humana com relação aos acontecimentos ao seu redor produz a necessidade de intervenções e modificações no espaço, de tal forma a adaptar-se constantemente ao mundo real (NUNES, 2015). Essas configurações são temporais e em constante mudança, e acabam por contribuir fortemente para criação e ampliação de riscos que, por muitas vezes, transformam-se em desastres.

Os desastres naturais decorrem de fenômenos extremos de diferentes origens (e.g. biológicos, climatológicos, geofísicos) e intensidades, e ocorrem sobre um sistema social, cujo impacto excede a capacidade dessa comunidade ou sociedade de enfrentar a situação com recursos próprios. Já o risco, a partir da conceituação definida pela UNDRR (2017), é caracterizado pelo potencial de perda de vidas e propriedades, além de pessoas feridas, e meios de subsistência, meio ambiente e economia afetados, onde o risco de desastres é determinado em função da exposição a condições de risco (SAITO et al., 2019).

Para além de definições, é possível estender a análise de riscos e o que eles representaram ao longo do tempo, considerando formulações a partir de diferentes estudos de caso. Para Mattedi (1999) o "agravamento dos problemas ambientais parecem ser o resultado paradoxal da própria dinâmica do desenvolvimento", sendo tal asserção válida quando se cria uma conexão com os fenômenos de desastres, o que permite considerar os problemas ambientais como processos generalizados pontuados em todas as esferas sociais, que culminam para a geração de algum tipo de risco ao acontecimento de eventos desastrosos.

Ao identificar a existência de um cenário que risco, desenvolver metodologias para gestão e gerenciamento desses riscos que ameaçam uma população é de suma importância, uma vez que o gerenciamento de riscos de desastres opera principalmente na redução dos impactos causados por eventos extremos, a partir da modificação do padrão em que se estabelecem os propulsores do risco (i.e., perigo, exposição e vulnerabilidade) (KREIBICH et al., 2022). Além disso, entende-se que a gestão dos riscos compreende o conjunto de medidas de organização e operação institucional para o tratamento das situações de risco existentes (FUNEP, 2006), mas sua eficiência é diferenciadamente maior quando estas ações fazem parte da gestão urbana, e compreendem, além do gerenciamento dos riscos, políticas públicas de desenvolvimento urbano, tais como provisão habitacional, proteção e recuperação ambiental, e inclusão social, sempre contando com mecanismos de regulação e aplicação dessas políticas.

Associados à gestão, o emprego e busca de tecnologias para subsidiar mapeamentos de diversos tipos de variáveis acerca dos perigos e vulnerabilidades dos quais uma população está exposta, se apresenta como base para subsidiar a criação e implantação de medidas estruturais (i.e. ações do Poder Público nas esferas federal, estadual e municipal) e não estruturais (i.e. ações educacionais e de conscientização, políticas públicas no âmbito municipal e planejamento territorial), ações estas essenciais para a construção da resiliência (SAITO, 2008).

A importância do investimento nesses processos é reforçada no Marco de Ação de Sendai (UNDRR, 2015), que oferece diretrizes para o gerenciamento do risco de desastres e trata dos mapeamentos em suas prioridades de ação, como parte essencial na compreensão e fortalecimento da governança para o gerenciamento do risco, assim como sua mitigação. Neste contexto, o mapeamento de áreas de riscos hidrogeológicos cumpre um papel indispensável na análise de riscos, por subsidiar o monitoramento da ocorrência de eventos extremos, permitindo a emissão acurada de alertas, ferramenta essencial para mitigação dos seus impactos em situações de emergência.

Em geral os mapeamentos são conduzidos por uma abordagem técnica para identificar os graus de risco que determinadas áreas possuem, e classificá-los, a partir de indicadores de risco estabelecidos para um evento específico, ou ainda estabelecidos a partir de características geomorfológicas e/ou recorrência de eventos extremos sob uma área, expandindo as possibilidades de monitoramento de uma região (SHADECK et al., 2013; MARCELINO et al., 2006). Especificamente, a produção de mapeamentos de áreas de risco (e.g. mapas de setorização de riscos, mapas de suscetibilidade e cartas geotécnicas) compõe um dos eixos projetados pelo Plano Nacional de Gestão de Riscos e Resposta a Desastres, com diretrizes estabelecidas pela Lei Federal 12.608/2012, que visam balizar a atuação do governo brasileiro (em todas as esferas de poder) na prevenção contra desastres (BRASIL, 2012).

O resultado da pesquisa desenvolvida neste trabalho, artigo científico, é apresentado no Capítulo 2, e teve como área de estudo o município de Caraguatatuba, localizado no Litoral Norte do Estado de São Paulo, Brasil. A área foi escolhida por possuir um modelo de crescimento desordenado, com ocupação em áreas de risco, e falta de infraestrutura urbana, que combinados com a fragilidade e tendência histórica da região para a ocorrência de desastres, dá indícios de possível reincidência de eventos extremos, tornando a busca por novas perspectivas sobre os riscos e vulnerabilidades da população local necessária

(CAMPOS, 2000; CASTRO et al., 2011). Na Tabela 1 são apresentadas algumas medidas compensatórias empregadas ao longo do tempo pelos governos federal, estadual e municipal, em escala regional, diante dos impactos sofridos pela população local de Caraguatatuba, em decorrência de eventos de precipitação intensa, que desencadearam enchentes e deslizamentos de terra.

Tabela 1 – Resumo de ações governamentais aplicadas à gestão de riscos com incidência sobre o município de Caraguatatuba

Ano	Descrição	Referência
1989	**Plano Preventivo de Defesa Civil (PPDC)** O plano considerou o histórico de escorregamentos, principalmente em taludes de corte, registrados a partir do evento de 1967 (Decreto Estadual nº 30.860 de 04/12/1989, redefinido pelo Decreto Estadual nº 42.565 de 01/12/1997)	SÃO PAULO, 1989
1999	**Relatório nº 39878/99 - Carta de risco de escorregamentos e inundações de Caraguatatuba, SP**	IPT, 1999
2006	**Plano Municipal de Redução de Riscos (PMRR)** A partir deste plano foram definidas estratégias e prioridades para implantação de intervenções estruturais de segurança nas 19 localidades mais vulneráveis, indicadas pela Prefeitura Municipal de Caraguatatuba	FUNEP, 2006
2010	**Parecer Técnico nº 18578-301** Mapeamento e proposta de plano de gerenciamento de áreas de risco de escorregamentos do municipio de Caraguatatuba, SP	IPT, 2010
2012	**Lei Federal nº 12.608/2012** Legislação onde é estabelecido o Plano Nacional de Gestão de Riscos e Resposta a Desastres, onde a Lei institui sobre a Política Nacional de Proteção e Defesa Civil (PNPDEC), sobre o Sistema Nacional de Proteção e Defesa Civil (SINPDEC), e o Conselho Nacional de Proteção e Defesa Civil (CONPDEC).	BRASIL, 2012
2017	**Carta de suscetibilidade a movimentos gravitacionais de massa e inundações - Município de Caraguatatuba - SP** Documento produzido com base na Nota Técnica Explicativa publicada em 2014 pela CPRM	IPT, 2014 CPRM, 2017

Fonte: elaborado pela autora.

Ademais, a área de estudo está inserida em uma região configurada por uma planície costeira com um território tomado por cursos hídricos onde, por consequência, predomina um solo muito encharcado, gerando naturalmente uma vulnerabilidade a eventos hidrometeorológicos extremos, que configuram riscos a partir da combinação da falta de planejamento territorial e o grande adensamento populacional. Além disso, regiões costeiras revelam maior sensibilidade aos impactos sociais e econômicos, em face das constantes mudanças ambientais globais, em especial àquelas sob o efeito das mudanças climáticas (SEIXAS et al., 2011, CAMPOS, 2000). Mata-Lima et al. (2013) afirma que "nas duas últimas décadas, muitos estudos têm apresentado consistentes demonstrações e previsões do aumento da frequência de ocorrência e da intensidade dos desastres naturais [...] sobretudo os relacionados com os fatores climáticos", impulsionando a promoção, em caráter essencial, da busca por medidas que possam monitorar, projetar e alertar sobre a ocorrência de eventos extremos.

2 ARTIGO

2.1 Artigo – Tabosa, D., Cuartas, L. A., Amore, D. Mapping and characterizing hydrogeological risk areas at different spatial scales using HAND normalized terrain model / Mapeamento e caracterização de áreas de risco hidrogeológico em diferentes escalas espaciais usando o modelo normalizado de terrenos HAND

The following paper is currently under consideration by a Frontiers Journal. Submission completed on November 3rd, 2022.

MAPPING AND CHARACTERIZING HYDROGEOLOGICAL RISK AREAS AT DIFFERENT SPATIAL SCALES USING HAND NORMALIZED TERRAIN MODEL

ABSTRACT

Structural and non-structural measures development are essential to build disaster resilience. The search for technologies applicable for different types of risk mapping is fundamental, whereas hydrogeological risk mappings play a crucial role in risk assessment and analysis, once a tool supporting compensatory measures procedures. The HAND (Height Above the Nearest Drainage) Normalized Terrain Model has the potential to describe the landscape as a normalized topology, and its proven applicability in natural disasters research enabled testing the model's ability at different spatial scales. The objective of this study was to validate its use as a simplified mapping method, for information regarding settlements in susceptible areas to floods or landslides events, and to enable analyses of infrastructure and population data available. The municipality of Caraguatatuba, located in São Paulo state, Brazil, was selected as the study area, based on its historical background facing disasters impacts, and the availability of high resolution geospatial data for the region. Combined with the acquired municipal information, other Digital Elevation Model (DEM) data were incorporated, using images from ALOS PALSAR-2 and the Shuttle Radar Topography Mission (SRTM), totalizing four different resolutions of DEMs used in processing. It was also evaluated the potential of optimizing available data for municipalities that cannot acquire high-resolution topographic data, by using correlation and intersection tests; the results indicated that the more refined resolution DEM among the selected data grants better odds to risk areas identification; but also, the DEM with less resolution is capable of reproducing features similar to those of the latter.

Keywords: hydrogeology; floods; HAND model; risk areas; vulnerability.

1 INTRODUCTION

As a result of territorial, population, and economic growth of cities, the urban form culminates in the implementation of various models of urban settlement, whilst preserving its design and complexity, which in turn increases, for example, the emergence of centrality axis in peripheries, logistic and industrial equipment along roads, and permanent preservation areas involved by the city. Provided by analyzing these scenarios from an urban infrastructure perspective, a significant impermeabilization of urban areas is presented as a result, specially due to neglected knowledge and control over the urban drainage system, shedding light to a heated debate among Brazilian municipalities with poorly managed and/or inadequate systems for urban water drainage (GORSKI, 2010; MACEDO et al., 2012).

Although concepts are not standardized, according to the UNDRR Terminology, disaster risk reflects extreme/hazardous events as a result of risk conditions; consequently, hydrogeological risk combines hazardous events capable of causing damage to a socioeconomical system, which is exposed and vulnerable particularly to flood events (UNDRR, 2017). Therefore, acknowledging risks must take into account that they are not only the result of decision-making (or lack thereof), but also a combination of factors that have been incorporated into the environment over time, and then to use them as indicators of the potential disaster triggers (MIGUEZ et al., 2017; MATTEDI, 1999). Concerning risk drivers, Kreibich et al. (2022) presents in their study that changes in flood impacts are significantly and positively correlated with changes in hazard, exposure and vulnerability. Also, the dataset presented in the study suggests that these three risk drivers are equally important to flood impact reduction, given how they strongly correlate in different scenarios.
Other studies have addressed the risk perception of natural disasters; however, given the constant changes in the environment, and the demand for adaptive development, studies ought to focus on this broader scale of disaster risk construction, i.e., to consider areas that are not vulnerable to disaster occurrence, but are within the same municipal limits, as a cooperative strategy for Disaster Risk Reduction (DRR) strategies.

According to the recent Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (published in 2021), the climate has become progressively warmer since 1850, and despite the fact that climate change does not unfold uniformly, its effects are visible in every region of the world. In terms of alterations in precipitation patterns, climate change has been identified as a major contributor to increases in frequency and intensity of heavy precipitation events over decades (IPCC, 2021; UNDRR, 2019). The United Nations Office for Disaster Risk Reduction (UNDRR) Global Assessment Report on Disaster Risk Reduction (GAR), acknowledges that climate change alone is not a source of disaster risk, but its interactions with geological, environmental, biological and technological hazards contributes to the occurrence of extreme events, thereby increasing the risk of future disaster impacts on human systems in short, medium, and long terms (UNDRR, 2019).

According to the Centre for Research on the Epidemiology of Disasters (CRED), from the 432 recorded disaster events worldwide in the Emergency Event Database (EM-

DAT) 2021 report (CRED, 2021), nearly 54% corresponded to flood events (233 total occurrences). It is highlighted that the numbers shown in the current EM-DAT report presented to be higher than the annual average disaster numbers for the 2001-2020 period.

Also according to the EM-DAT database, from 1948-2022 a total of 188 hydrological disaster events were recorded in Brazil, with 163 cases of floods and 25 cases of landslides. Furthermore, according to the Brazilian Atlas of Natural Disasters (CEPED, 2013), from 1991 to 2012, 96.2 million Brazilians were affected by natural disasters, with many of these tragedies triggered by climate extremes. During the same time period, 4,691 floods and 699 landslides were officially recorded, accounting for 12 % and 1.79 % of the total number of disaster records in the country. Also, 34 % of all flood events and 79.8 % of all landslide records are located in the Southeast region of the country.

In this context, the recurrence of disasters associated with floods is one of the characteristics of Brazil’s risk profile (LONDE et al., 2014), and therefore, the search for applicable technologies to promote different types of risk and vulnerability assessment, considering different variables, is fundamental to serve as a foundation for the development of structural (Public authority actions in federal, regional and municipal spheres) and non-structural (educational and awareness actions, local public policies and territorial planning) measures, essential to strengthening resilience (SAITO, 2008). The Sendai Framework for Disaster Risk Reduction (UNDRR, 2015) provides guidelines for disaster risk management, and addresses risk mapping in its priority actions for understanding and bolstering governance in risk management, as well as risk mitigation, by reinforcing the need for investments in these processes.

Hydrogeological risk mapping is capable of playing a crucial role in risk assessment and analysis, due to its utility as a tool in compensatory measures application, once it subsidizes monitoring the occurrence of extreme events. In addition, the production of risk areas mappings (e.g. sectorization, susceptibility, and geotechnical/topographic maps, etc.) is addressed in the National Agenda for Risk Management and Disaster Response in Brazil, in accordance with guidelines implemented by Federal Law No. 12608-2012. The agenda is based on four axis to model government actions on disaster prevention, and comprises: mapping, monitoring and alert, prevention, and response (BRASIL, 2012). The mapping axis works primarily in the identification, assessment and mapping of susceptibilities, vulnerabilities and risks, an essential process for decision-making and prioritization of risk reduction interventions (SHADECK et al., 2013).

Various models can represent the hydrogeological risks of a particular region. The HAND (Height Above the Nearest Drainage (HAND) Normalized Terrain Model has the potential to describe the landscape as a normalized topology that adheres to the hydrostatic principle, which is normalized by drainage channels. The HAND Model was entirely produced and developed in Brazil, and is coordinated by its authors alongside INPE's Center for Earth System Sciences (CCST/INPE) and the National Center for Monitoring and Early Warning of Natural Disasters (Cemaden). The model can be extensively applied in natural disasters research, either on mapping with the use of HAND topology classification to create hydrological/terrain homogeneity (NOBRE et al., 2011) or in the predictive mapping for hydrological risks, generating contours to indicate potential flood risk zones (NOBRE et al., 2015).

Perceptions about environment behavior as a response mechanism to population densification and human interventions in the environment, corroborate to the purpose of this work, which is to map hydrogeological risk areas in the municipality of Caraguatatuba, located in São Paulo state, Brazil, using the HAND Normalized Terrain Model. The validation of the applicability of the proposed methodology for risk mapping aims not only to identify flood and landslide prone areas, but also to examine some social factors associated with these regions. In addition, this study discusses not only the implications of data quality and availability for processing the model, but also addresses the implications of using DEMs with different spatial resolutions for mapping hydrogeological risk areas.

2 MATERIALS AND METHODS

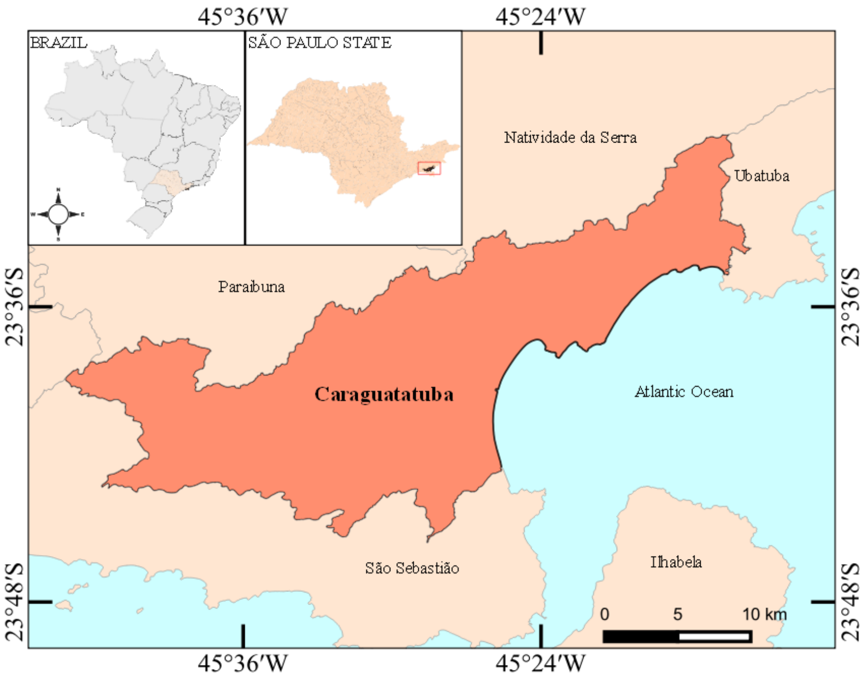
2.1 Study Area

The municipality of Caraguatatuba is located on the northern coast of São Paulo State (Figure 1), with a territorial area of 484.947 km², and estimated population (in 2021) of 125,194 inhabitants (IBGE, 2022). Territorial occupation in the municipality was, at first, mainly established in the central region of the city, whilst in the 1950-2000 period, immigrants began the occupation of areas in peripheral regions and hillsides, due to the advent of buildings verticalization both centrally and shore side (GIGLIOTTI and SANTOS, 2013). Population numbers increased significantly after the 1967 disaster event (the "Catastrophe of 1967"), where in the 1970-2021 period population has increased approximately 830% compared to current numbers (IPEA, 2022).

Its configuration is characterized by the confinement of the plain within the Serra do Mar scarps, which acts as a barrier to atmospheric air flow from the ocean, thus contributing to changes in the region's atmospheric and pluviometric dynamics (BRIGATTI and SANT'ANNA, 2011; BORTOLETTO, 2016). The Köppen-Geiger climate classification indicates tropical and rainy climate, with an undefined dry season and heavy precipitation in the summer. Due to the high altitude of the Serra do Mar mountains and proximity to the ocean, it is located in one of the wettest regions in Brazil, which contributes to the occurrence of floods, considering additional factors such as the influence of tide, low slope and elevation, high drainage density, and hydraulic conductivity (BOULOMYTIS et al., 2017; SOUZA, 2005).

The municipality is part of the Juqueriquere River Basin, the region's largest in terms of area and length, 419.36 km² by 135.25 km, respectively. This configuration merits special consideration for a number of reasons, but primarily due a substantial portion of its total area being located within Caraguatatuba's urban limits, in close proximity to important interventions and facilities such as the Monteiro Lobato Gas Treatment Unit (UTGCA), the Regional Hospital of the North Coast, and Nova Tamoios Highway Contours (CARAGUATATUBA, 2017; CBH-LN, 2016; MOURA, 2013).

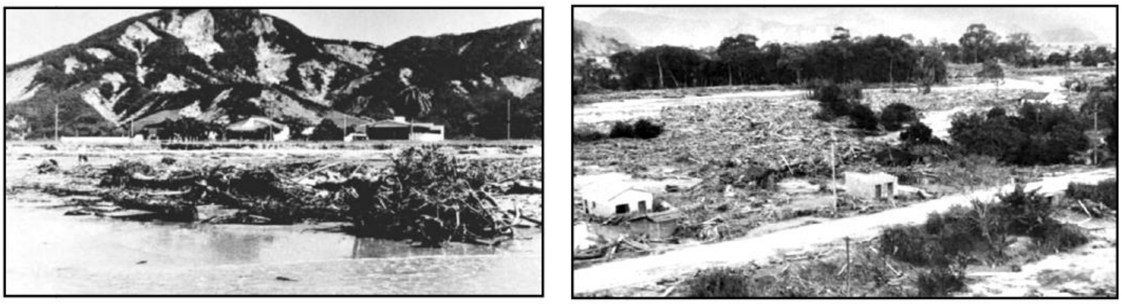
Figure 1 – Location of the study area



Numerous authors have referred to the Caraguatatuba municipality as "the one who refused to die" in literature, due to its struggles with natural disasters since its founding years. The "Catastrophe of 1967" refers to the natural disaster that occurred on March 18, 1967, which was the worst in the municipality's history and one of the greatest in the country. After 13 hours of rainfall, different heights of debris-flow detachment sites occurred upon the surrounding mountains, where two meters of mud and sediments covered nearly 200 km² of Serra do Mar's plains (Figure 2). It was estimated that, on this day, over 450 Caraguatatuba residents lost their lives (CAMPOS, 2000). In comparison, currently the state of São Paulo registers numbers between 1,450 and 1,477 mm for average annual accumulated rainfall, considering the 1961-2020 period, which the Caraguatatuba region alone accumulated 580 mm in two days in 1967 (CRUZ, 1975; INMET, 1992, 2022).

According to Campos (2000), from the municipalities composing the Northern Coast, Caraguatatuba has always attracted attention for presenting favorable conditions for habitation expansion. However, despite the fact that the implementation of intermunicipal connections through federal highways between 1938 and 1939 resulted in greater investments, the city did not experience a significant development boost until after 1970, when it was rebuilt following a catastrophic event that occurred in 1967.

Figure 2 – Catastrophe of 1967: (a) Debris-flow from Serra do Mar Mountains; (b) Juqueriquere River basin plains covered with debris.



(a) (b)

Source: Images courtesy of Arquivo Público do Município de Caraguatatuba “Arino Sant’ana de Barros”.

In the last 10 years, damages and risk alerts due to extreme rainfall periods in Caraguatatuba have been reported. The National Center for Monitoring and Early Warning of Natural Disasters, CEMADEN, monitors the municipality since 2014, and up until 2022 has reported 115 alerts concerning hydrological risk (50 alerts) and mass movements (65 alerts) in the region. From those, according to risk levels established by the agency, 90 were of moderate potential impact, 20 of high potential impact, and 5 of very high potential impact (CEMADEN, 2022). Specifically in 2013, the damage report from the National Integrated System for Disaster Information (S2ID) documented 4 records, from January to March, regarding floods and landslides events, which registered 203 lives lost and 129 people affected (S2ID, 2013).

Once the lack of concern with compensatory measures prior to the 1967 event in Caraguatatuba, afterwards some measures regarding the city vulnerability were implemented by federal, regional and municipal spheres, such as: the Preventative Plan for Civil Defense (SÃO PAULO, 1989); IPT Landslides and Floods Report (IPT, 1999); MUNICIPAL PLAN FOR RISK REDUCTION (FUNEP, 2006); FEDERAL LAW NO. 12608-2012 (BRASIL, 2012); and Susceptibility Chart to Gravitational Mass Movements and Floodings (CPRM, 2017; IPT, 2014).

The study area was therefore selected based on the aforementioned historical disaster events occurrence in Caraguatatuba, and also due to its configuration with disordered urban sprawl with precarious settlements, which combined with deficiencies in urban infrastructure, and its fragility and historical susceptibility to disasters episodes, indicates susceptibility to extreme events recurrence, thereby necessitating the search for new perspectives on risks and vulnerabilities locals face (CAMPOS, 2000; CASTRO et al., 2011).

2.2 Data

The topographic and hydrological data were all acquired through competent agencies holding ownership of the files. In particular, some files were acquired through management departments of Caraguatatuba city hall, upon established cooperation agreement. Department negotiations were conducted in all cases to ensure that the research would be based solely on accurate, applicable, and mostly widely dispersed data, where such files and byproducts of this study can be used by municipal administrations in its own management and strategic planning initiatives.

Concerning topographic data, different resolutions of Digital Elevation Models (DEM) were incorporated in this study, such as: 30-m resolution DEM from Shuttle Radar Topography Mission (SRTM) images; 12.5-m resolution DEM from ALOS-PALSAR images; 5-m resolution DEM from Geological Survey of Brazil’s (CPRM) GISAT Project; 1.12-m Digital Surface Model (DSM) from Unmanned Aerial Vehicle (UAV) aerophotogrammetric images (Caraguatatuba city ownership). Also, other data files were considered in the study: open access vector drainage networks from National Water and Sanitation Agency - ANA (ANA, 2019; 2017); Institute of Technological Research (IPT) data catalog of regional mappings of risk areas prone to gravitational mass movements and floods; and 2010 Census data from the Brazilian Institute of Geography and Statistics (IBGE).

2.3 The HAND Model

The Normalized Terrain Model HAND, whose application is proposed in this study as a method for hydrogeological mapping, allows the production of hydrologically relevant landscape-descriptive maps. The model can represent topographic data (Digital Elevation Models, DEMs) as maps of soil water saturation (NOBRE et al., 2011; CUARTAS et al., 2012). The spatial description of the model's high water table and inundation potential information supports a risk assessment of the studied region (NOBRE et al., 2011). Recent studies (NOBRE et al., 2015; MOMO et al., 2016) demonstrate the applicability and utility of the HAND Model for flood mapping.

To summarize, the HAND Model establishes procedures for DEM processing (in raster format), where "the z axis variable of the HAND model is the normalized local height, defined as the vertical distance from a hillslope surface cell to a respective outlet-to-the-drainage cell, i.e. the level difference between such cells that belong to a mutually connecting flowpath" (NOBRE et al., 2011). The C++-written standalone software is available for free download upon registering in the project website (http://handmodel.ccst.inpe.br/).

The HAND maps generated were classified according to a classification criteria (Table 1), created based on the thresholds used by Nobre et al. (2011) adjusted to fit more classes, incorporating analysis criteria used by CPRM (2017) and other previously studied thresholds for slope stability for the region (i.e. COLANGELO, 2012; CRUZ, 1975).

Table 1 – Classification criteria for HAND Classes.

Classes Interpretation	**Absolute values***
1	$0 \leq$ HAND ≤ 1.5 m
2	$1.5 <$ HAND ≤ 3 m
3	$3 <$ HAND ≤ 5 m
4	$5 <$ HAND ≤ 15 m
5	HAND > 15 m & *slope* 36% ($\geq$)
6	HAND > 15 m & *slope* 36% ($<$)

**HAND = value of normalized hypsometric heights.*

The classification criteria contains field verified information for accurate application for Caraguatatuba region, concatenated to match with environments classification defined in Nobre et al. (2011) study, that validated four categories divided in (a) waterlogged, meaning water table is constant presented very close to the surface; (b) ecotone, a transition zone; (c) slope, when the vadose layer becomes progressively dominant; and (d) plateau. The correspondences verified to match HAND Classes 1 to 6 used in this study (Table 1) are: 1 - streams/waterlogged; 2-3 - waterlogged; 4 - ecotone; 5 - slope; 6 – plateau.

Furthermore, a precise and accurate drainage network enables the model to transform the landscape into the corresponding topology while adhering to the physical principles that govern the model. In this study, rather than producing a separate drainage for each of the four different spatial resolution DEMs used, a single drainage data from ANA's Ottocoded Hydrographic database was incorporated.

Thus, the four DEM files with varying spatial resolutions selected (Data, section 2.2) were processed using the HAND model. The products were concatenated with vulnerability information derived from metrics comprising infrastructure, social, and population data. Aside from the application of the HAND Model in map generation, for data systematization Geographic Information System (GIS) tools such as QGis were used for spatialization and geoprocessing.

2.4 Statistical test

Pearson’s (PCC) and Spearman’s (SCC) correlation coefficients were used (CHEN and POPOVICH, 2002; WHERRY, 1984) to support a descriptive analysis of area segmentation by HAND Classes, from the HAND-classes maps, aimed at identifying similarities among the different resolution images generated. Estimations consisted in analyzing local averages of area deposits of the four different resolutions of HAND maps, that were categorized according to six variables (six listed HAND Classes, Table 1); and then its correlation with the highest resolution results. The adopted significance level considers *p-value*<0.05 for general assertion, but also *p-value*<0.01 for discussions. The *r* correlation value measures the strength of a linear relationship, and varies from -1 to 1. Results closer to 1 (originally) indicate great correlation; and closer to 0 (center point of the bivariate correlation) indicate that there is no correlation.

2.5 Social-spatial analyses

Temporal sequences are capable of revealing urban sprawl statistics for a region (PEREIRA and SILVA, 2001), whose results can be dynamically observed using GIS tools (COSTA and SILVA, 2007; CORDOVEZ, 2002; CÂMARA, 1995).

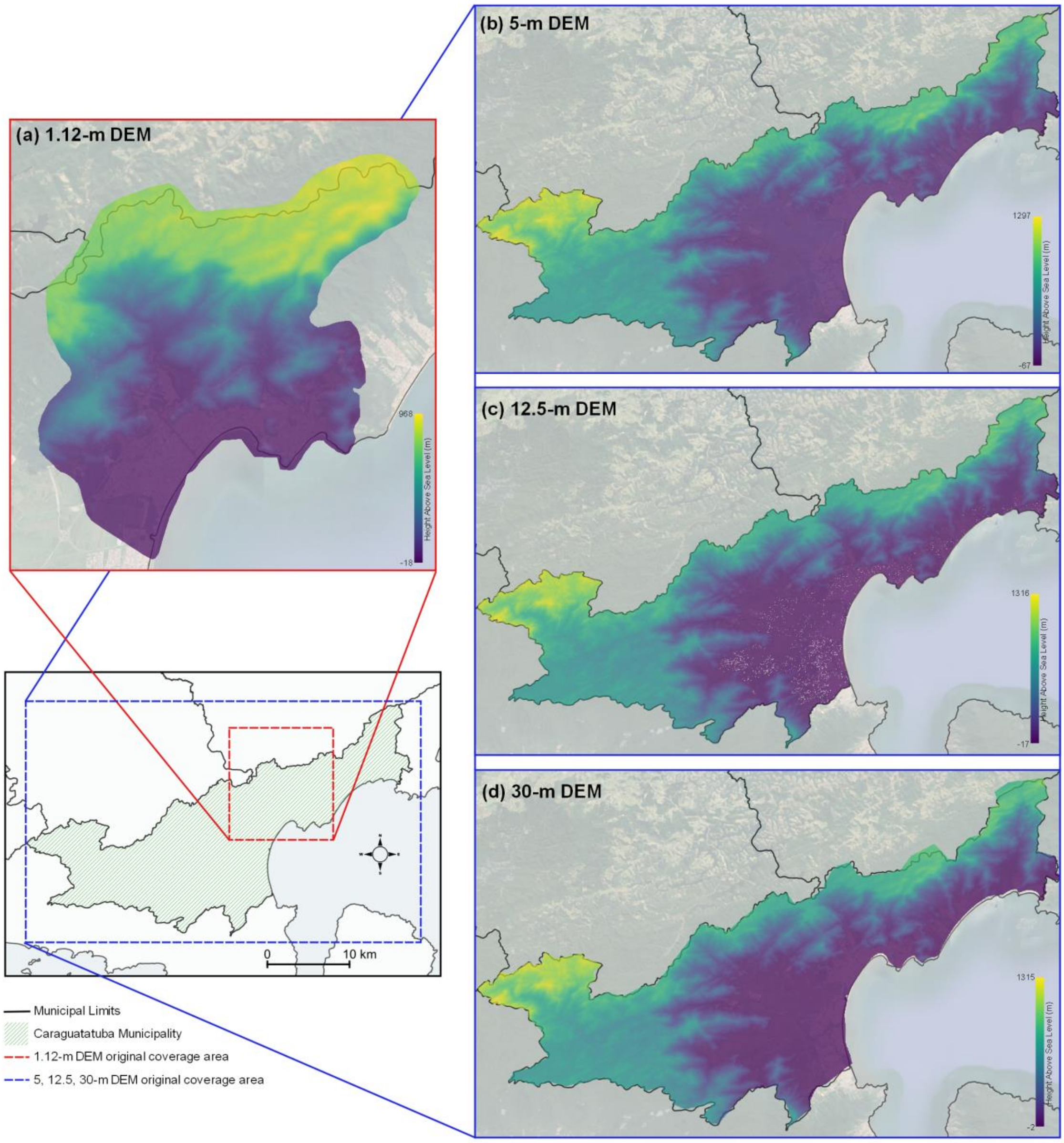
To this extent, three sets of processing were conducted for social-spatial analyses purposes. The processing consisted in using the intersection tool available in the internal geoprocessing library of the software QGis. The generated HAND Classes maps were used as overlay layers to different overlap layers containing socio-economic and spatial information (details in section 3.2). The goal was to obtain estimations about: in first set, annual urban areas growth rates ($gr = \{[((Npresent/Npast)^{\wedge}(1/n))-1]*100\}$; gr = growth rate; N = measured area value; n = years) for each HAND-class in four different resolutions of HAND maps; in second set, observations of previously mapped risk areas allocation in urban settlements (incorporates results from the first set); and third set, the differences in the allocation of population census data in different resolution of HAND maps.

3 RESULTS AND DISCUSSION

In the course of this study, mappings based on prior research were examined, such as the risk sectors mapping by IPT based on Geoeye satellite aerial imagery plotted in 2010 (CPRM, 2017); and the mapping for physiographic compartments by Souza (2006b) from the SIIGAL Project, which was later incorporated into the 2016-2019 Basin Plan from North Coast Hydrographic Basin Committee (CBH-LN) (CBH-LN, 2016).

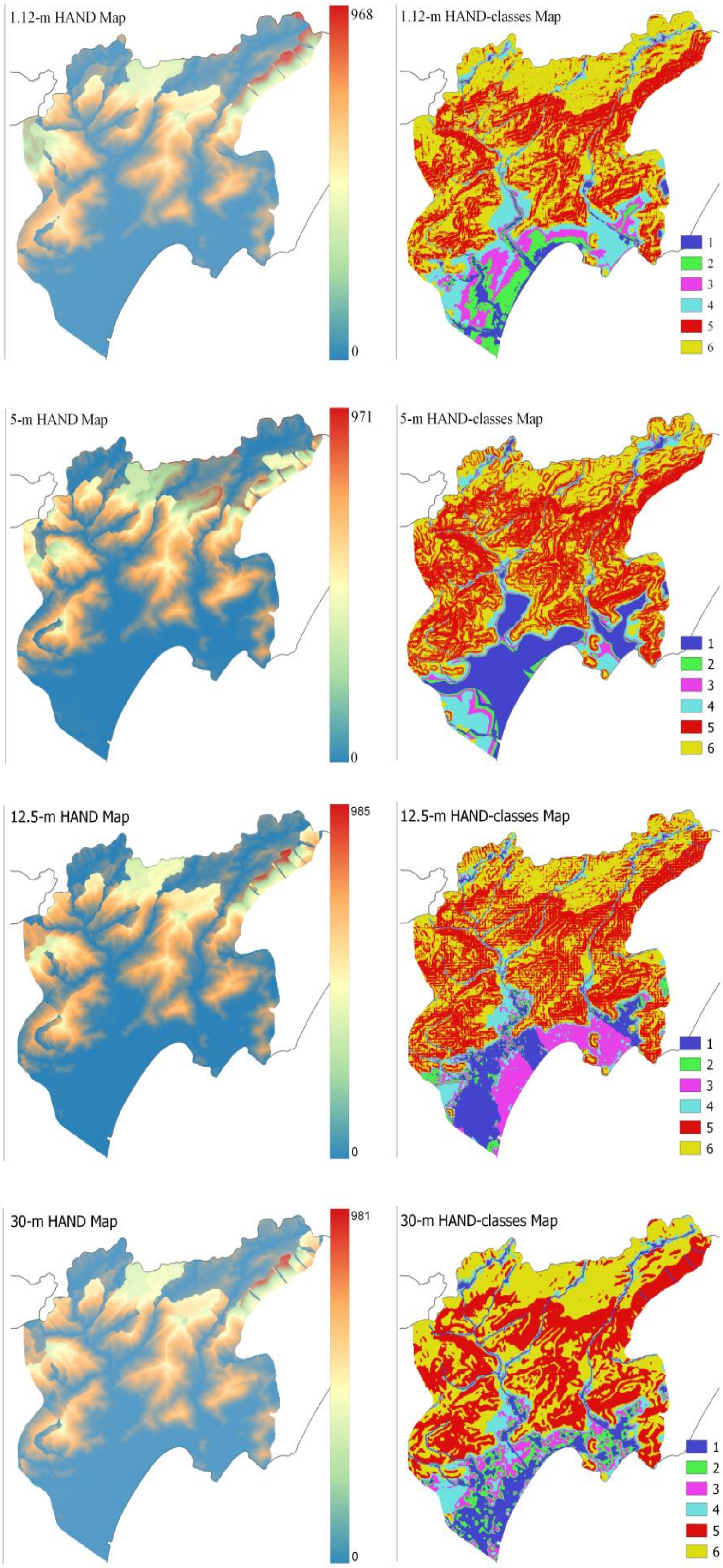
All data presented in Section 2.2 have been processed and adapted to the coordinate reference system (SRC) World Geodetic System 1984 (WGS94, EPSG:4326). Considering a substantial portion of the proposed methodology for this study, the data processing phase served as a starting point to provide information for data refinement, which, as shown in Figure 3, led to the selection of (a) DSM raster image product from an aerophotogrammetric imaging through unmanned aerial vehicle with a 1.12-m spatial resolution, and coverage area of 171.85 km², representing 36.18% out of the municipal territorial area (MTA = 484.847 km²); (b) Digital Terrain Model (DTM) raster image product with a 5-m spatial resolution from IPT/CPRM GISAT Project using 1:50,000 scale topographic sheets (CPRM, 2017; DAEE, 2008); (c) raster images from the ALOS PALSAR-2 sensor with a 12.5-m resolution, in clipped masks for fitted coverage of the study area; and (d) DEM raster image from SRTM mission with a 30-m spatial resolution, refined to TOPODATA database (VALERIANO, 2011).

Figure 3 – Original DEMs spatialization according to pixel resolution, in which (a) shows the 1.12-m resolution; (b) 5-m resolution; (c) 12.5-m resolution; and (d) 30-m resolution.



The original DEM files were, then, clipped based on the 1.12-m resolution DEM mask to normalize the spatial extent of all four DEMs. Hereafter, the selected DEMs were processed to generate the respective HAND models. The normalized HAND maps and maps of HAND Classes maps are depicted in Figure 4.

Figure 4 – Normalized HAND maps and respective HAND-classes maps.



3.1 Different spatial scales

Pereira and Silva (2001) and Cordovez (2002) present discussions on how (practically) all areas of government actions can find in geoprocessing an important ally in the stages of urban planning. Therefore, to adapt in time and optimize urban planning/management, concerns ought to be expected regarding data availability for mappings.

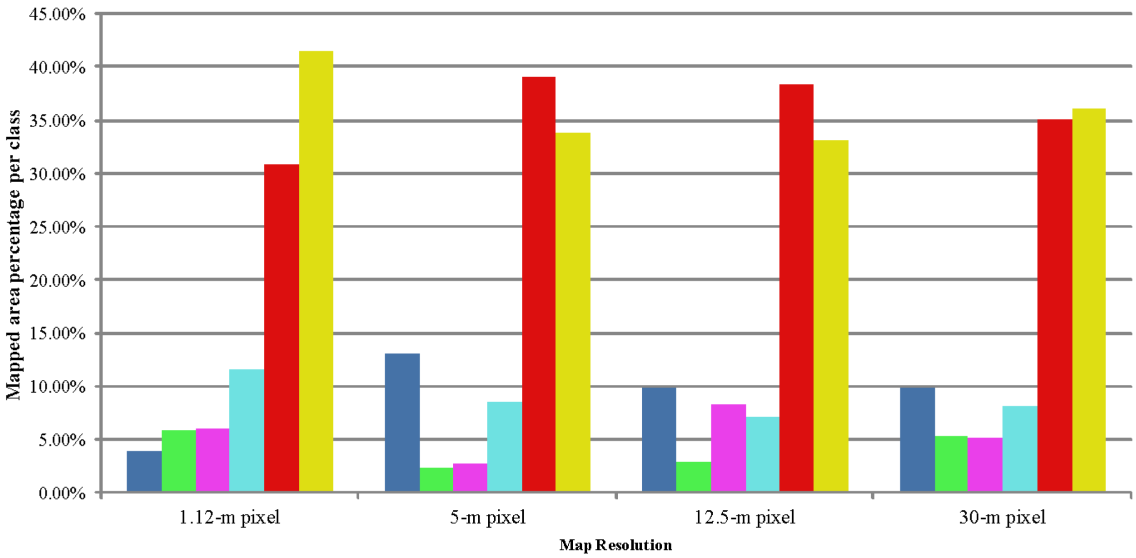
The HAND Model's applicability for different geospatial resolution data allows exploring any available data; although, the feasibility of this type of hydrological modeling application is contingent on the availability of high-quality topographic data.

Exploring the HAND products presented, comparative area segmentation according to respective HAND Classes maps (shown in Figure 4) is presented in Table 2 and Figure 5. It was observed that the results drew attention to a significant difference between the 1.12-m resolution and the other resolutions, with the 1.12-m resolution presenting a gradual ascending percentage value of the mapped area for each class, whereas the other resolutions emphasize class 1 deposits (0 to 1.5 meter gauge).

Table 2 – Comparative information of mapped areas in HAND maps according to height distribution (HAND-Classes)

		Mapped Area Estatistics (per spatial resolution/HAND-class)							
		1.12-m pixel		5-m pixel		12.5-m pixel		30-m pixel	
RGB	Class #	[hectares]	[%]	[hectares]	[%]	[hectares]	[%]	[hectares]	[%]
	1	343.67	3.90%	1159.61	13.21%	877.57	9.96%	876.09	9.94%
	2	524.22	5.95%	211.71	2.41%	254.85	2.89%	475.94	5.40%
	3	536.11	6.09%	245.79	2.80%	732.20	8.31%	459.72	5.22%
	4	1019.77	11.58%	754.01	8.59%	630.34	7.15%	716.92	8.14%
	5	2726.05	30.94%	3435.76	39.14%	3391.12	38.48%	3094.69	35.12%
	6	3659.68	41.54%	2970.71	33.84%	2927.01	33.21%	3188.38	36.18%
	Σ	8809.51	100.00%	8777.61	100.00%	8813.10	100.00%	8811.73	100.00%

Figure 5 – Graphical representation of HAND-classes mapped areas variability according different spatial resolutions



For each different resolution, the respective area deposits in each HAND class are listed. The left column shows the respective area value; the right column shows these area values in a corresponding percentage rate of the respective total mapped area. Disparities in totals of area coverage were unavoidable, with an average of 8.45% distortion in area boundaries due to different North coverage encountered in between files.

The area values (presented in Table 2) were calculated using an internal tool of the software QGis, set to report statistics in hectares units of measure. To test for possible limitations of area calculation using QGis, the stats were compared to results from another area calculation method. The cloud-based computing platform Google Earth Engine (GEE) was used, with an adapted script for area calculation. GEE can be used in a wide range of applications (GORELICK et al., 2017); Coltin (2016) showed great results for GEE applicability for flood mapping variables analyses. Therefore, the resampled data showed that there are no relevant discrepancies in area values, regarding QGis statistical measurements, thus securing *high confidence level* in the numbers presented.

The graphical representation of results enabled visualizing area deposits transitioning between soil-environment classes in all different resolution files. Observations highlighted that the 5-m pixel resolution file presents great homogeneities in parts of the mapped surface, which reproduced contrasting class 1 numbers. Such discrepancies in surface representation compromise the map’s accurate class segmentation and its individual analysis per class; and impacts an analogous analysis of all gathered results. Nevertheless, the anomalies do not impact conducting this study, hence the totals of areas for classes 1 to 3 being similar in all 4 resolutions. Classes 1 to 3, with 0 to 5 meter gauge range, comprise the waterlogged category, which according Nobre et al. (2015) represents the floodplain.

The Geological Survey of Brazil – CPRM elucidated that the 5-m DEM was generated based solely on topographic maps in a 1:50,000 scale, using *topo to raster* interpolation in ArcGIS. According to Souza and Furrier (2019) homogeneities in (original) DEM files may mainly be related to its generation form; Neuman et al. (2018) elaborate that the use of only topographic data in elevation models conception might cause interferences in surface representations; hence incorporating radar/satellite information would prevent failures when concatenating geomorphologic detailing to the model.

Maximum slope values tend to decrease as spatial resolution increases (in all files), and due to a more robust pixel resolution, average topographic values are plotted to smooth out extreme slope numbers. Hence the disparities in area coverage among mapped classes among the DEM files previously presented.

To enhance the analysis of the different spatial resolution files processed in HAND Model, basic statistics correlation test (NETO, 2013; NETER et al., 1996) was applied to mapped areas results presented above, to test for patterns/similarities among 4 different samples of HAND-maps. The variable values correspond to HAND-class segmentation criteria (Table 1, criteria; Figure 4, HAND-classes maps). Results are assembled in Table 3.

Table 3 – Estimations of linear correlation coefficient r between different resolutions of normalized DEM maps according to HAND Classes area segmentation

Dem files[1]	**DEM1**	**DEM5**	**DEM12**	**DEM30**
DEM1	1			
DEM5	0.902* 0.901** p=0.014	1		
DEM12	0.918* 0.837** p=0.038	0.961* 0.956** p=0.003	1	
DEM30	0.961* 0.901** p=0.002	0.983* 0.912** p=0.011	0.984* 0.825** p=0.043	1

**Pearsons correlation coefficient (PCC); **Spearmans correlation coefficient (SCC); p: p-value; blue shade: significance level α= 5%; green shade: significance level α= 1%; (1) DEM1, 1.12-m resolution map; DEM5, 5-m resolution map; DEM12, 12.5-m resolution map; DEM30, 30-m resolution map.*

Aside from the aforementioned correlation estimation purpose for this study, the main goal was to identify which sample better associates with the most robust DEM resolution amongst them (the 1.12-m resolution normalized map), i.e. capable of reproducing similar information at some precision level. Therefore, it was observed that only *DEM30* presented very similar *r* values (for both PCC and SCC coefficients) compared to *DEM1*; also, p-value shows this correlation is significant also at both $\alpha = 5\%$ and $\alpha = 1\%$.

Note that *DEM5* versus *DEM12* also present p-value significant at 1%, but due to the inconsistencies with the individual classes area values aforementioned (section 3.1), we have chosen to ignore this result for now, to prevent the overestimation of areas at high exposure to flood risk zones to be interpreted from these results.

Moreover, the results presented in Table 3 indicate existent similarities in between all samples, regarding the area deposits according class segmentation; even though these similarities indicate a proportional distribution, *r* values pattern enables investigating the effects of the spatial resolution variability reflecting in the original DEMs, and consequently, in the normalized maps.

Thereby, observations lead to conclusions that the most robust resolution file (1.12-m pixel) shows better odds to the identification of flood risk areas, due to finer delineations of streams/river areas, granted its high resolution images; its more accurate features representation enables to analyze directly the areas for classes with 0 to 5 meter gauge range, that concentrate around the normalized drainage network. Also, correlation results interpretation indicated that the strongest positive correlation ($y = 0.905x - 140.21$; $R^2 = 0.923$) to 1.12-m maps settled for the SRTM-DEM originated 30-m HAND maps.

3.2 Social information

The rapid establishment of urban sprawl in the Caraguatatuba region after the 1970s (2.1, study area, after the 1967' Catastrophe) is indicated by the significant increase in urban area settlements. The demographic census data compiled in the Litoral Sustentável programme (INSTITUTO POLIS, 2012), which is a sustainable development program based on a participatory socio-environmental urban diagnosis, revealed a geometric growth rate (TGCA, Portuguese acronym) of 4.55 % per year, with urbanization fitting into the plains situated between the sea and the mountains.

Thereby, the first set of socio-spatial analyses consisted in observing the intersection results using the aforementioned study products as the overlay layer, to overlap HAND

Classes maps. The trend analysis showed an approximated average growth rate of 122.87 % for the mapped area in this study (considering respective growth rates for the four different-resolution maps), for the 1979 to 2010 time series data. Trend analysis is presented in Figure 6, and Intersection results are presented in Table 5.

Figure 6 – Trend analysis of HAND-classes maps intersection with the 1979-2011 time-series urban sprawl map by Litoral Sustentável

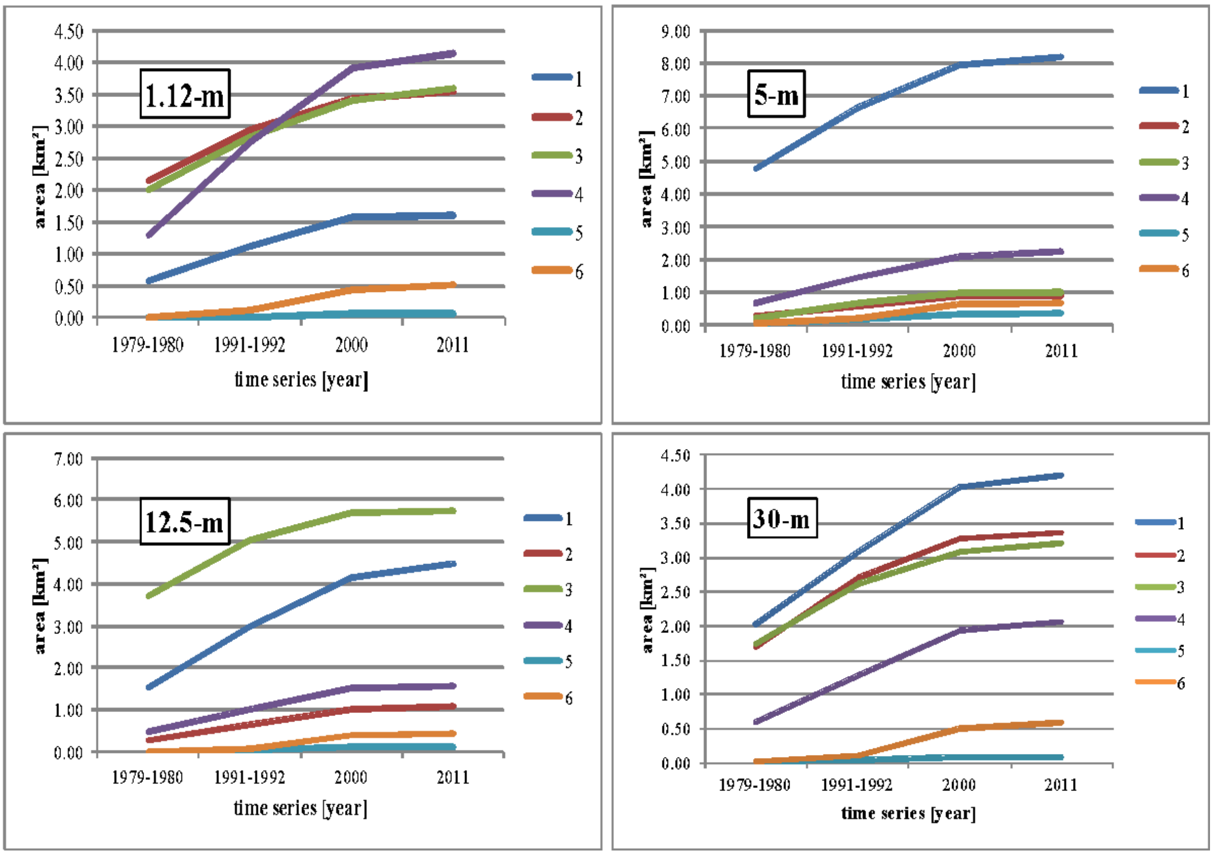


Table 5 – Results of HAND-classes maps intersection with the 1979-2011 time-series urban sprawl map by Litoral Sustentável.

1.12-m pixel area values [km²]						
Class #	1979-1980	1991-1992	2000	2011	anual growth rate [%]	total growth [%]
1	0.580	1.136	1.571	1.606	3.23%	176.90%
2	2.157	2.945	3.445	3.559	1.58%	65.00%
3	2.003	2.834	3.421	3.597	1.85%	79.58%
4	1.283	2.752	3.935	4.142	3.73%	222.84%
5	0.005	0.021	0.068	0.071	8.64%	1320.00%
6	0.019	0.110	0.451	0.513	10.85%	2600.00%
Σ	**6.047**	**9.798**	**12.891**	**13.488**	**2.54%**	**123.05%**

5-m pixel area values [km²]						
Class #	1979-1980	1991-1992	2000	2011	anual growth rate [%]	total growth [%]
1	4.791	6.649	7.918	8.214	1.70%	71.45%
2	0.261	0.583	0.890	0.901	3.95%	245.21%
3	0.220	0.705	0.979	1.018	4.90%	362.73%
4	0.686	1.470	2.103	2.264	3.80%	230.03%
5	0.037	0.160	0.347	0.356	7.33%	862.16%
6	0.050	0.210	0.611	0.691	8.55%	1282.00%
Σ	**6.045**	**9.777**	**12.848**	**13.444**	**2.53%**	**122.40%**

12.5-m area values [km²]						
Class #	1979-1980	1991-1992	2000	2011	anual growth rate [%]	total growth [%]
1	1.533	2.996	4.149	4.481	3.41%	192.30%
2	0.269	0.643	1.007	1.106	4.52%	311.15%
3	3.719	5.031	5.689	5.744	1.37%	54.45%
4	0.501	1.008	1.534	1.584	3.66%	216.17%
5	0.008	0.029	0.105	0.114	8.66%	1325.00%
6	0.016	0.090	0.404	0.457	11.04%	2756.25%
Σ	**6.046**	**9.797**	**12.888**	**13.486**	**2.54%**	**123.06%**

30-m pixel area values [km²]						
Class #	1979-1980	1991-1992	2000	2011	anual growth rate [%]	total growth [%]
1	2.010	3.071	4.029	4.202	2.33%	109.05%
2	1.700	2.702	3.283	3.371	2.16%	98.29%
3	1.735	2.617	3.074	3.203	1.93%	84.61%
4	0.583	1.271	1.926	2.053	4.01%	252.14%
5	0.006	0.031	0.070	0.074	8.17%	1133.33%
6	0.013	0.102	0.502	0.579	12.60%	4353.85%
Σ	**6.047**	**9.794**	**12.884**	**13.482**	**2.54%**	**122.95%**

The graphic numbers showed higher urban sprawl values for lowland classes; but, the area versus time-series trend analysis, and the growth rates numbers, showed that the upland classes sustained greater changes over time. Observations showed urban areas expansion has predominantly settled in segmented classes 5 and 6 (HAND > 15 m; slope and plateau areas).

Gigliotti and Santos (2013) indicate that Caraguatatuba urban territory expansion can be qualified as the result of tourist urbanization and strong real estate speculation. These characteristics, combined with the natural dynamics of resources and predominant spaces appropriation by population (CASSETI, 1991), contribute to the arising of significant problems due to irregular occupation of space, lack of urban infrastructure and socio-spatial segregation.

Additional to the considerations presented above, it is possible to correlate that this predominance of urban growth in upland classes indicates direct correlation with areas that have experienced previous disasters. Instituto Polis (2012) combined existing precarious residential settlements information from IBGE and IPT (IPT, 2010) for Caraguatatuba city, in which 19 precarious settlements points were registered within municipal limits, affecting a total area of 0.928 km²; 14 out 19 points are comprised within the mapped area presented in our study, encompassing 14 districts and a total of 0.528 km², where an average of 34 % and 44 % of this area is located in classes 5 and 6, respectively. The quantitative characteristics presented for this type of occupation reinforces a hazardous environment, from the functional relationship of disordered urban settlements and the local established population exposure to disaster risk.

To enhance the context presented in the aforementioned first set, hereafter the second set consisted in processing the intersection of mass movement risk areas mapped by IPT (2010; CPRM, 2017) with different-resolution maps of HAND Classes; compared to temporal urban growth delineations.

According to IPT (2010, 2014) the criterion to determine the degree of probability to mass movements events establishes 4 types of risks: R1, R2, R3 and R4; R3-type risk areas presents a *high degree of probability*, and are areas where significant evidence of instability is observed (e.g. ground cracks, slope abatement degrees), creating a *perfectly possible* condition for the occurrence of a disaster event during intense and prolonged rainfall, in a 1-year return period; and R4-type risk areas presents *very high degree of probability*, where the evidence of instability is expressive and in large number/magnitude, being then the most critical condition, *very likely* condition for the occurrence of a disaster event during intense and prolonged rainfall, in a 1-year return period.

Intersection results returned positive for the existence of predominant occupation of mapped risk areas in upland classes, i.e. along HAND-classes 4, 5 and 6, especially 5 and 6. From the total 56 areas at risk mapped for Caraguatatuba municipality (CPRM, 2017), 48 are comprised in the mapped area presented in our study, where 55.62% of this number corresponds to risk areas type R3, and 21.93% to risk areas type R4.

The third socio-spatial analysis involved the intersection of the HAND Classes map and the IBGE 2010 demographic census indicators (available at http://www.ibge.gov.br/estatisticas/downloads-estatisticas.html). The results enabled the assignment of attributes such as the number of census sectors, residences, and inhabitants, thereby providing a comprehensive view of population distribution among the classes. According to IBGE statistics, 202 census sectors were mapped for Caraguatatuba municipality, 116 of which are included in the mapped area presented in this study and contain an estimated 18,359 dwellings and 56,701 inhabitants (according 2010 census numbers). These numbers represent 56.23% of the total population as reported by the 2010 census and 45.29% of the estimated population in 2021 (IBGE, 2022). The results are presented in sets of (transitioning) classes (Table 6), in which census sectors are grouped according to their placement, and the number of residences and inhabitants residing in each class is indicated according to clustered HAND-class classes.

Table 6 – Results of HAND-classes maps intersection with 2010 IBGE Indicators.

		Resolutions of HAND-classes maps											
		1.12-m			**5-m**			**12.5-m**			**30-m**		
Clusters	**Corresponding gauge range [m]**	**Number of sectors**	**Dwellings**	**Inhabitants**	**Number of sectors**	**Dwellings**	**Inhabitants**	**Number of sectors**	**Dwellings**	**Inhabitants**	**Number of sectors**	**Dwellings**	**Inhabitants**
1	0 to 1.5	2	295	825	35	5132	15772	3	522	1759	1	117	304
1-2	0 to 3	1	1183	3284	1	722	2225	8	1558	4925	1	182	560
1-2-3	0 to 5	1	2611	7931	6	990	2752	9	1361	4299	19	2985	9353
1-2-3-4	0 to 15	1	3867	11709	8	2956	8738	31	5385	16209	47	6904	20496
1-2-3-4-5-6	0 to 15+*slope%*	10	3342	10684	19	6257	19977	26	4260	13989	27	4854	15495
1-2-3-4-6	0 to 15 & 15+<*slope%*	-	-	-	34	730	2325	-	-	-	1	293	969
1-3	0 to 1.5 & 3 to 5	18	182	560	-	-	-	1	172	529	-	-	-
1-3-4-5-6	0 to 1.5 & 3 to 15+*slope%*	-	-	-	-	-	-	-	-	-	1	7	20
2-3	1.5 to 5	22	866	2766	-	-	-	3	141	422	-	-	-
2-3-4	1.5 to 15	20	2073	6260	-	-	-	22	2700	7601	6	911	2707
2-3-4-5-6	1.5 to 15+*slope%*	5	855	2759	2	371	1173	8	1483	4431	6	1160	3608
3	3 to 5	14	126	410		-	-	-	-	-	-	-	-
3-4	3 to 15	4	696	2257	2	102	255	-	-	-	-	-	-
3-4-5-6	3 to 15+*slope%*	5	568	1884	1	248	837	2	505	1641	1	248	837
3-4-6	3 to 15 & 15+<*slope%*	-	-	-	-	-	-	-	-	-	1	283	962
4	5 to 15	3	203	592	1	182	560	-	-	-	-	-	-
4-5-6	5 to 15+*slope%*	8	1492	4780	4	669	2087	3	272	896	3	415	1390
4-6	5 to 15 & 15+<*slope%*	1	0	0	1	0	0	-	-	-	2	0	0
5-6	15+*slope%*	1	0	0	2	0	0	-	-	-	-	-	-
	Σ	**116**	**18359**	**56701**	**116**	**18359**	**56701**	**116**	**18359**	**56701**	**116**	**18359**	**56701**

The representation nature of IBGE Census data allocates socio-economic information in census sectors, which in spatial representation, have the attributes (data values) for each coverage-polygon; hence the precluded action of analyzing dwellings and inhabitants numbers according to singular classes 1 to 6 of HAND-classes criteria.

When contrasting with population information, topology spatial coverage variations may induce neglecting or overestimating data values, which affects all sorts of analyses, especially the social-economic. Thus, attention is drawn again to disparities in 5-m resolution maps, caused by DEM homogeneities (refer to section 3.1), for which overestimated dwellings/inhabitants numbers were expected, due to its irregularities in classification arrangements.

Results assembled in table 6 shows that higher numbers for dwellings settlements predominate in clusters containing upland classes, when compared to lowland clusters. In addition, using maximum slope values impressions (addressed in section 3.1), although with "0" inhabitants (meaning, no inhabitants were accounted for), the high resolution of the 1.12-m map allows identifying dwellings in high upland classes; also present for 30-m map results.

Lastly, the cluster of residences with classes moving from the plain to the valley (permeating classes 1 to 6) speculates on possible regions in vulnerable predisposition to the impacts of a disaster event occurrence, precisely because it compounds a large group of houses following the topology design.

4 CONCLUSIONS

The challenge imposed by the vertiginous abrupt and disordered urban expansion experience by Caraguatatuba, with both territorial and population growth in a short period of time, culminated in an increased locals vulnerability to the occurrence of disasters deflagrated by bad weather conditions (INSTITUTO POLIS, 2012).

Currently, the municipality still faces serious problems of popular housing, which comprehends irregular occupations and precarious housing. Therefore, the importance of validating the use of a simplified mapping method (in this case, the HAND Model) ensued good information regarding settlements in areas susceptible to floods or landslides events, with the possibility to better estimate these predispositions, and also cross analyze all infrastructure and population data available with the produced maps.

Our results showed that from all four different resolutions of DEMs processed, the most robust resolution, the 1.12-m pixel resolution, grants better odds to flood risk areas identification. The linear correlation coefficient tests provided verifying similarities in between areas totals deposited in each segmented class (among all files), and also to specifically identify which of the other resolutions best relates to the 1.12-m DEM features. It was concluded that, according to correlation numbers, the 30-m pixel resolution DEM being capable of reproducing features similar to those of the 1.12-m, at some precision level, in spite of possible quality variations in images.

By using different topographic resolution data as input in processing, it was also possible to evaluate the potential of using available data especially for cases where municipalities cannot acquire high-resolution topographic data. Therefore, the importance of this result, with the validation of a broad-specter HAND Model use, is to support technicians and policymakers in mapping developments, even as support in preliminary analyses of risk areas. Some possibilities are the use of terrain normalization and optimized calibrations of HAND Classes, with adjusted features according to the characteristics of the terrain (or specific points to be evaluated); and the use of procedures/tools applied in this study for indexation of points located in areas of vulnerability to floods and landslides events. In addition, its use grants simpler analysis with great results, provided it allows less robust resolutions to print significant results.

Given the purpose of risk management being the reduction of impacts from disasters events (KREIBICH et al., 2022), by managing the main risk drivers, the relevance of this study can navigate in different stages of risk management. The model’s tested applicability in a varied range of topographic data supports the call for updates in the database, for either refined topographic data or operations with open access information. Also, hence land occupation establishments and topology changes throughout time, up-to-date risk maps would provide accurate monitoring of risk areas and its surroundings, which consequently leads to more accurate issue of risk alerts. In addition, the study would also benefit studies working on vulnerability indices for early warning systems, especially with the need for regional-scale analysis (DE ASSIS DIAS et al., 2020).

Marchezini et al. (2017) have addressed in their study the need for updates in risk maps contained in the alerts issued nationally, once most of them were generated in emergency response in 2012 by CPRM, and therefore, may no longer express reality thoroughly. In addition, the need for improvements in data spatial accuracy were also addressed, as a measure to better indicate areas requiring special attention to civil defense actions.

Regardless of the considerations made in our study of open possibilities to optimize the existing open data, is important to emphasize the continuity to improvements of information available, to fully support governances and policymakers in the strengthening of resilience to disaster events, which makes it possible to improve information at an analytical level, by supporting mappings and structural measures needs, and therefore, monitoring and alerts issue.

Lastly, we highlight that the discussions addressed in this research do not intend to settle potential searches, especially from municipal governance sectors, for database enhancing with more accurate and refined data; it merely discusses alternatives in mapping risk areas, which could allow funding, e.g., to be redirected when needed, prioritizing physical and practical risk mitigation actions in municipalities with scarce financial resources for this purpose.

REFERENCES

AGÊNCIA NACIONAL DE ÁGUAS (ANA). Massas d'Água. 2019. Catálogo de Metadados ANA. Available from: https://metadados.snirh.gov.br/geonetwork/srv/por/catalog.search#/metadata/7d054e5a-8cc9-403c-9f1a-085fd933610c. Accessed: 02 April 2021.

______. Base Hidrográfica Ottocodificada Multiescalas 2017 (BHO 2017). 2017. Catálogo de Metadados ANA. Available from: https://metadados.snirh.gov.br/geonetwork/srv/por/catalog.search#/metadata/0c698205-6b59-48dc-8b5e-a58a5dfcc989. Accessed: 02 April 2021.

ARQUIVO PÚBLICO DO MUNICÍPIO DE CARAGUATATUBA “ARINO SANT’ANA DE BARROS”. Fundação Educacional e Cultural de Caraguatatuba (Fundacc). 94 images.

BORTOLETTO, K. C. Estudo das vulnerabilidades social e ambiental em áreas de riscos de desastres naturais no município de Caraguatatuba SP. 2016. 217 p. Tese (doutorado) - Universidade Estadual Paulista, Instituto de Geociências e Ciências Exatas, Rio Claro, SP. Available from: https://repositorio.unesp.br/handle/11449/148805. Accessed: 31 August 2020.

BOULOMYTIS, V. T. G., Zuffo, A. C. and Gireli, T. Z. WATERSHED SPATIAL DISCRETIZATION FOR THE ANALYSIS OF LAND USE CHANGE IN COASTAL REGIONS. Boletim de Ciências Geodésicas [online]. 2017, v. 23, n. 1. Available from: https://doi.org/10.1590/S1982-21702017000100007. Accessed: 30 April 2022.

BRASIL. Lei Federal nº 12.608, de 10 de abril de 2012. Institui a Política Nacional de Proteção e Defesa Civil – PNPDEC e dá outras providências. Available from: http://www.planalto.gov.br/ccivil_03/_Ato2011-2014/2012/Lei/L12608.htm. Accessed: 15 October 2020.

BRIGATTI, N.; SANT'ANNA NETO, J. L. Dinâmica climática e variações do nível do mar na geração de enchentes, inundações e ressacas no litoral norte paulista. Revista Formação, n.15, vol 2. p. 25-36. 2011.

CÂMARA, G. Modelos, linguagens e arquiteturas para bancos de dados geográficos. São José dos Campos: INPE, 1995. Tese de doutorado, 1995.

CAMPOS, J. F. Santo Antônio de Caraguatatuba: memória e tradições de um povo. [s.l.]: Fundacc, 2000.

CARAGUATATUBA. Sítio arqueológico da Fazenda dos Ingleses é tema de palestra na Rede Municipal de Ensino. 2017. Available from: https://www.caraguatatuba.sp.gov.br/pmc/2017/04/sitio-arqueologico-da-fazenda-dos-ingleses-e-tema-de-palestra-na-rede-municipal-de-ensino/. Accessed: 09 August 2020.

CASSETI, V. Ambiente e apropriação do relevo. São Paulo: Contexto, 1991.

CASTRO, L. M. F. B. et al. Mudança climática, riscos e vulnerabilidade: um estudo dos eventos ocorridos em 1967 e 1996 na planície litorânea de Caraguatatuba – SP. CLIMEP - Climatologia e Estudos da Paisagem, [S. l.], v. 6, n. 1–2, p. 22–43, 2011.

CEMADEN, Centro Nacional de Monitoramento e Alertas de Desastres Naturais. 2022. Dataset - Complete database of issued alerts for Caraguatatuba-SP. A. Cuartas, personal communication, September 9, 2022.

CENTRE FOR RESEARCH ON THE EPIDEMIOLOGY OF DISASTERS (CRED). 2021. Disasters in numbers. Brussels: CRED; 2022. Available from: https://cred.be/sites/default /files/2021_EMDAT_report.pdf. Accessed: 12 September 2022.

CEPED, Centro Universitário de Estudos e Pesquisas sobre Desastres. Atlas Brasileiro de Desastres Naturais: 1991 a 2012. 2. ed. rev. ampl. Volume Brasil. Florianópolis: Universidade Federal de Santa Catarina (UFSC), 2013. 126 p.

CHEN, P. Y.; POPOVICH, P. M. Correlation: parametric and nonparametric measures. London: Sage, 2002. 95p.

COLANGELO, A. C. Os parâmetros de resistência ao cisalhamento e a estabilidade das encostas no planalto de Paraibuna e Serra de Caraguatatuba. In: Revista do Departamento de Geografia, [S. l.], p. 112-129, 2012. DOI: 10.7154/RDG.2012.0112.0007. Available from: https://www.revistas.usp.br/rdg/article/view/53845. Accessed: 17 June 2021.

COLTIN, B. et al. Automatic boosted flood mapping from satellite data. International Journal of Remote Sensing, v. 37, n. 5, p. 993-1015, 2016. DOI: 10.1080/01431161.2016.1145366. Accessed: 15 July 2022.

COMITÊ DE BACIAS HIDROGRÁFICAS DO LITORAL NORTE (CBH-LN). Plano de Bacias Hidrográficas do Litoral Norte do Estado de São Paulo 2016-2019. Relatório II. Ubatuba – SP, 2017. Available from: http://www.sigrh.sp.gov.br/cbhln/documentos#.

Accessed: 02 December 2020.

______. Plano de Bacias Hidrográficas do Litoral Norte do Estado de São Paulo 2016-2019. Relatório I – Informações Básicas. Ubatuba – SP, 2016. Available from: http://www.sigrh.sp.gov.br/cbhln/documentos#. Accessed: 02 December 2020.

CORDOVEZ, J. C. G. Geoprocessamento como ferramenta de gestão urbana. Simpósio Regional de Geoprocessamento e Sensoriamento Remoto, v. 1, p. 1-19, 2002.

COSTA, S. M. F.; SILVA, D. C. Caracterização da dispersão residencial (Urban Sprawl) utilizando Geotecnologias. 2007. Available from: http://marte.sid.inpe.br/col/dpi.inpe.br/sbsr@80/2006/11.14.20.48/doc/5167-5174.pdf. Accessed: 03 August 2022.

CRUZ, O. A serra do mar e o litoral na área de Caraguatatuba - SP: contribuição à geomorfologia litorânea tropical - 2. Revista Brasileira de Geografia, [S. l.], 1975.

CUARTAS, L. A., NOBRE, A. D., HODNETT, M. et al., 2012. Distributed hydrological modeling of a micro-scale rainforest watershed in Amazonia: Model evaluation and advances in calibration using the new HAND terrain model. Journal of Hydrology: 404, 13–29. DOI: https://doi.org/10.1016/j.jhydrol.2011.12.047.

DE ASSIS DIAS, M. C. et al. Vulnerability index related to populations at-risk for landslides in the Brazilian Early Warning System (BEWS). International journal of disaster risk reduction, v. 49, p. 101742, 2020.

DEPARTAMENTO DE ÁGUAS E ENERGIA ELÉTRICA (DAEE). Base cartográfica digital, escala 1:50.000 - Projeto GISAT. São Paulo: DAEE, 2008.

FUNDAÇÃO DE APOIO À PESQUISA, ENSINO E EXTENSÃO (FUNEP). Plano de Redução de Riscos da Estância Balneária de Caraguatatuba (SP). 2006. Volume 1.

GIGLIOTTI, C. M. da C.; SANTOS, M. J. A expansão urbana de Caraguatatuba (1950-2010): uma análise das transformações sócio espaciais. Caminhos de Geografia, v. 14, n. 46, p. 150-159, 2013. Available from: https://seer.ufu.br/index.php/caminhosdegeografia/article/download/17794/12817/89934. Accessed: 02 July 2022.

GORELICK, N. et al. Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment. Volume 202, 2017, Pages 18-27, ISSN 0034-4257. DOI: https://doi.org/10.1016/j.rse.2017.06.031.

GORSKI, M. C. B. Rios e cidades: ruptura e reconciliação. [s.l.] : Senac, 2010.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). 2022. Cidades: Caraguatatuba. Available from: https://cidades.ibge.gov.br/brasil/sp/caraguatatuba/panorama. Accessed: 06 January 2022.

INSTITUTO NACIONAL DE METEOROLOGIA - INMET. 2022. Normais Climatológicas do Brasil (1991-2020) – Precipitação Acumulada (mm). Brasília. Available from: https://portal.inmet.gov.br/normais. Accessed: 01 May 2022.

________. 1992. Normais Climatológicas do Brasil (1691-1990) – Precipitação Acumulada (mm). Brasília. Available from: https://portal.inmet.gov.br/normais. Accessed: 01 May 2022.

INSTITUTO DE PESQUISAS TECNOLÓGICAS DO ESTADO DE SÃO PAULO (IPT). Cartas de suscetibilidade a movimentos gravitacionais de massa e inundações: 1:25.000 (livro eletrônico): nota técnica explicativa/coordenação Omar Yazbek Bitar. São Paulo: IPT – Instituto de Pesquisas Tecnológicas de Brasília, DF: CPRM – Serviço Geológico do Brasil, 2014.

______. Mapeamento e proposta de plano de gerenciamento de áreas de risco de escorregamentos do município de Caraguatatuba, SP. Parecer Técnico Nº 18578–301. 2010. Available from: www.ipt.br. Accessed: 01 August 2020.

______. Relatório Nº 39878/99. Carta de risco de escorregamentos e inundações de Caraguatatuba, SP. Secretaria da Ciência, Tecnologia e Desenvolvimento Econômico – SCTDE, Programa de Assistência Técnica aos Municípios – Patem, 1999.

INSTITUTO POLIS. Projeto Litoral Sustentável: Desenvolvimento com Inclusão. 2012. Available from: https://polis.org.br/wp-content/uploads/2020/03/Resumo-executivo-CARAGUATATUBA-Litoral-Sustentavel.pdf. Accessed: 15 September 2020.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. In Press.

______. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by C. B. field et al. Cambridge/New York, Cambridge University Press/ IPCC, 2014. Available from: https://www.ipcc.ch/report/ar5/wg2/. Accessed: 05 August 2020.

INSTITUTO DE PESQUISA ECONÔMICA APLICADA (IPEA). Ipeadata. 2022. Available from: http://www.ipeadata.gov.br/Default.aspx. Accessed: 31 August 2022.

JAPAN AEROSPACE EXPLORATION AGENCY (JAXA). ALOS-2 Project / PALSAR-2. Available from: https://www.eorc.jaxa.jp/ALOS-2/en/about/palsar2.htm. Accessed: 06 December 2020.

KREIBICH, H., Van Loon, A.F., Schröter, K. et al. The challenge of unprecedented floods and droughts in risk management. Nature 608, 80–86 (2022). Available from: https://doi.org/10.1038/s41586-022-04917-5. Accessed: 31 August 2022.

LONDE, L. R. et al. Desastres relacionados à água no Brasil: perspectivas e recomendações.

Ambiente & Sociedade, v. 17, p. 133-152, 2014. Available from: https://doi.org/10.1590/1809-4422ASOC1082V1742014. Accessed: 31 August 2022.

MACEDO, S. S.; QUEIROGA, E. F.; GALENDER, F. C.; DEGREAS, H. O Sistema de Espaços Livres na Constituição da Forma Urbana Contemporânea no Brasil. Paisagem Ambiente: ensaios, [S. l.], n. 30, p. 137–172, 2012. Available from: http://projedata.grupoprojetar.ct.ufrn.br/dspace/handle/123456789/1196. Accessed: 26 July 2021.

MARCHEZINI, V. et al. Sistema de alerta de risco de desastres no Brasil: desafios à redução da vulnerabilidade institucional. In: Reduction of vulnerability to disasters: from knowledge to action. São Carlos: Rima Editora, v. 1, p. 287-310, 2017. Accessed: 09 September 2020.

MATTEDI, M. A. As enchentes como tragédias anunciadas: impactos da problemática ambiental nas situações de emergência em Santa Catarina. 1999. 284f. Tese (doutorado) - Universidade Estadual de Campinas, Instituto de Filosofia e Ciências Humanas, Campinas, SP. Available from: https://hdl.handle.net/20.500.12733/1587178. Accessed: 24 February 2021.

MIGUEZ, M., Veról, A.; Di Gregorio, L. T. Gestão de riscos e desastres hidrológicos. 2017. Elsevier Brasil.

MOMO, M. R. et al. Desempenho do modelo HAND no mapeamento de áreas suscetíveis à inundação usando dados de alta resolução espacial. RBRH [online]. 2016, v. 21, n. 1. pp. 200-208. Available from: https://doi.org/10.21168/rbrh.v21n1.p200-208. Accessed: 01 May 2022.

MOURA, C. A. Avaliação de tendência a enchentes das bacias hidrográficas do município de Caraguatatuba (SP). Revista de Geografia (UFPE), v. 30, n. 2, 2013.

NETER, J. et al. Applied linear statistical models. 1996.

NEUMAN, G. et al. Análise da influência da escala na obtenção dos atributos topográficos derivados de MDE. Raega-O Espaço Geográfico em Análise, v. 43, p. 179-199, 2018. Available from: https://revistas.ufpr.br/raega/article/view/56278. Accessed: 11 June 2022.

NETO, J. G. C. Distribuições Estatísticas e Correlações Temporais de Alguns Parâmetros Hidrológicos de uma Bacia Hidrográfica Semiárida de Pernambuco. Dissertação (Mestrado em Biometria e Estatistica Aplicada) - Universidade Federal Rural de Pernambuco, Departamento de Estatistica e Informática, Recife, 2013.

NOBRE, A. D.; CUARTAS, L. A.; MOMO, M. R.; SEVERO, D. L.; PINHEIRO, A.; NOBRE, C. A. HAND contour: A new proxy predictor of inundation extent. Hydrological Processes, [S. l.], v. 30, n. 2, p. 320–333, 2015. DOI: 10.1002/hyp.10581.

NOBRE, A. D.; CUARTAS, L. A.; HODNETT, M.; RENNÓ, C. D.; RODRIGUES, G.; SILVEIRA, A.; WATERLOO, M.; SALESKA, S. Height Above the Nearest Drainage - a hydrologically relevant new terrain model. In: Journal of Hydrology, [S. l.], v. 404, n. 1–2, p. 13–29, 2011. DOI: 10.1016/j.jhydrol.2011.03.051. Available from: http://dx.doi.org/10.1016/j.jhydrol.2011.03.051. Accessed: 13 May 2020.

PEREIRA, G. C.; Silva, B. C. N. Geoprocessamento e urbanismo. 2001. Available from: https://repositorio.ufba.br/bitstream/ri/7961/1/geopro.pdf. Accessed: 26 July 2021.

S2ID, Sistema Integrado de Informações Sobre Desastres. Relatórios. 2013. Ministério da Integração – MI. Available from: https://s2id.mi.gov.br/paginas/relatorios/. Accessed: 04 August 2022.

SAITO, S. M. Desastres Naturais: conceitos básicos. In: ESCUELA DE PRIMAVERA SOBRE SOLUCIONES ESPACIALES PARA EL MANEJO DE DESASTRES NATURALES Y RESPUESTAS DE EMERGÊNCIAS-INUNDACIONES, 1, 2008, Santa Maria - RS. Anais eletrônicos [...] Santa Maria: INPE, 2008. Available from: http://www3.inpe.br/crs/crectealc/pdf/silvia_saito.pdf. Accessed: 19 May 2020.

SÃO PAULO (SP). Decreto Nº 30.860, de 04 de dezembro de 1989. Dispõe sobre a aprovação e implantação do Plano Preventivo de Defesa Civil Específico para Escorregamentos nas Encostas do Mar. Available from: https://www.infraestruturameioambiente.sp.gov.br/institutogeologico/2017/01/plano-preventivo-de-defesa-civil/. Accessed: 31 August 2022.

SERVIÇO GEOLÓGICO DO BRASIL (CPRM). Cartas de Suscetibilidade a Movimentos Gravitacionais de Massa e Inundações - São Paulo. Produtos. Vetoriais/Raster. MUNICÍPIO DE CARAGUATATUBA-SP, 2017. Available from: http://www.cprm.gov.br/publique/Gestao-Territorial/Prevencao-de-Desastres/Cartas-de-Suscetibilidade-a-Movimentos-Gravitacionais-de-Massa-e-Inundacoes---Sao-Paulo-5088.html. Accessed: 01 August 2020.

SHADECK, R. et al. A atuação da Secretaria Nacional de Defesa Civil (SEDEC) na gestão de riscos e resposta a desastres naturais. In: VI Congresso CONSAD de Gestão Pública. 2013. Available from: http://consad.org.br/wp-content/uploads/2013/05/072-A-ATUA%C3%87%C3%83O-DA-SECRETARIA-NACIONAL-DE-DEFESA-CIVIL-SEDEC-NA-GEST%C3%83O-DE-RISCOS-E-RESPOSTA-A-DESASTRES-NATURAIS.pdf. Accessed: 09 August 2021.

SOUZA, C. R. de G. Carta de suscetibilidade morfométrica de bacias de drenagem ao desenvolvimento de inundações no litoral norte de São Paulo. De G1. VI Simpósio Nacional de Geomorfologia - Geomorfologia Tropical e Subtropical: processos, métodos e técnicas. Goiânia – GO, 2006a.

______. Mapeamento de compartimentos fisiográficos de planície costeira e baixa-encosta e da vegetação associada, no litoral norte de São Paulo. In: VI Simpósio Nacional de Geomorfologia, Goiânia - GO, 2006b.

______. Suscetibilidade morfométrica de bacias de drenagem ao desenvolvimento de inundações em áreas costeiras. Revista Brasileira de Geomorfologia, ano 6, n. 1, 2005. p. 45-62.

SOUZA, A. dos S.; FURRIER, M. TÉCNICAS DE MAPEAMENTO GEOMORFOLÓGICO APLICADAS EM ESCALA DE DETALHE. Revista Brasileira de Geomorfologia, [S. l.], v.

20, n. 1, 2019. DOI: 10.20502/rbg.v20i1.1391. Available from: https://rbgeomorfologia.org.br/rbg/article/view/1391. Accessed: 16 July 2022.

UNITED NATIONS OFFICE FOR DISASTER RISK REDUCTION (UNDRR). Global Assessment Report on Disaster Risk Reduction. 2019. Geneva, Switzerland. United Nations Office for Disaster Risk Reduction (UNDRR).

______. UNDRR Terminology on Disaster Risk Reduction. 2017. In: International Strategy for Disaster Reduction. Geneva, 2009. Available from: www.undrr.org/publications. Accessed: 10 May 2020.

______. Sendai Framework for Disaster Risk Reduction. Japan, 2015. 32 p. Available from: https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030. Accessed: 28 December 2019.

UNITED STATES GEOLOGICAL SURVEY (USGS). Earth Resources Observation and Science (EROS) Center. USGS EROS Archive - Digital Elevation - Shuttle Radar Topography Mission (SRTM) Non-Void Filled. Available from: https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-shuttle-radar-topography-mission-srtm-non?qt-science_center_objects=0#qt-science_center_objects. Accessed: 06 December 2020.

VALERIANO, M. M.; Rossetti, D. F. Topodata: Brazilian full coverage refinement of SRTM data. Applied Geography (Sevenoaks), v. 32, p. 300-309, 2011. Available from: http://www.dsr.inpe.br/topodata/documentos.php. Accessed: 15 December 2020.

WHERRY, R. J. Contributions to correlational analysis. Orlando: Academic Press, 1984. 463p.

3 CONSIDERAÇÕES FINAIS

Segundo Mascaró e Yoshinaga (2005) “um dos maiores desafios do crescimento equilibrado e duradouro das populações é provê-las de serviços urbanos em quantidade e qualidade suficientes”, onde o crescimento desordenado, combinado às ações antrópicas na alteração do espaço (sobretudo em busca do desenvolvimento), acabam por contribuir com a ampliação da vulnerabilidade de um sistema social, que muitas vezes é incapaz de se adaptar à constante mudança, culminando para o acontecimento de desastres.

É importante ressaltar que todas as considerações feitas em nosso trabalho reiteram sobre o fato de desastres não serem naturais (MARCHEZINI et al., 2017; MATTEDI e BUTZKE, 2001; MASKREY, 1993), mas sim construídos e, portanto, reforçam a interdependência entre produção de dados e informações de qualidade acerca desses riscos que os compõem, assim como o planejamento urbano nas municipalidades (CORDOVEZ, 2002), quando tratamos de subsidiar o desenvolvimento de mecanismos de resposta (NUNES, 2015; O’KEEFE et al., 1976).

O objetivo do artigo apresentado no Capítulo 2 consistiu em validar o potencial de uso da metodologia HAND para mapeamento de áreas em risco hidrogeológico, a partir da disponibilidade de dados topográficos de diferentes resoluções como entrada, para (1) observar as variabilidades de representação do relevo nos mapas normalizados; (2) elencar a resolução que oferece melhores condições de representação do relevo; e (3) a factibilidade de produção desses mapeamentos somente partir da utilização dados de livre acesso (em geral, com resoluções menores), para casos onde municípios não podem adquirir dados topográficos de alta resolução.

A metodologia consistiu na utilização do modelo normalizado de terrenos HAND (do inglês, *Height Above the Nearest Drainage*) para a geração de mapas de áreas de risco hidrogeológicos; os produtos gerados foram correlacionados com informações geográficas, de infraestrutura e sociais, subsidiando análises descritiva e temporal de dados. Foram utilizados como entrada dados *open source* e dados cedidos pela Secretaria de Planejamento e Desenvolvimento da Prefeitura Municipal de Caraguatatuba, sendo: Modelo Digital de Superfície (MDS) proveniente de imagens aerofotogramétricas obtidas por VANT (através de empresa contratada pelo município de Caraguatatuba) com resolução espacial de 1,12 metros; Modelo Digital de Elevação (MDE) com resolução espacial 5 metros, proveniente do Serviço

Geológico do Brasil (CPRM); MDE com resolução espacial 30 metros, proveniente de imagens da missão SRTM (*Shuttle Radar Topography Mission*); e MDE com resolução espacial de 12,5 metros, proveniente de imagens obtidas através do sensor ALOS-PALSAR-2 (*Advanced Land Observing - Phased Array type L-band Synthetic Aperture Radar*).

Na metodologia de aplicação do modelo ressaltamos que o principal dado de entrada é a topografia, porém o bom delineamento da drenagem neste dado é também muito importante para geração dos mapas HAND. A maleabilidade do programa permitiu realizar ajustes para incorporar uma drenagem digital (com grau de confiança médio-alto) como ponto de partida para nosso estudo, dispensando a drenagem que o próprio programa gera de maneira automática. Apesar dessa funcionalidade do programa em permitir agregar atributo vetorial de drenagem, encorajamos o desenvolvimento de estudos futuros a partir deste trabalho, reforçando a importância da geração/atualização de dados topográficos, para subsidiar que processamentos futuros com uso do programa HAND sejam realizados inteiramente a partir de um único dado topográfico acurado.

Dentre as quatro resoluções utilizadas, o dado de alta resolução (com pixel de 1,12 metros) foi considerado como dado de referência no estudo, pois garantiu a melhor representação do relevo no mapa normalizado dentre os dados selecionados, onde subsidiou melhor segmentação de HAND-classes, que por consequência permite melhor analisar áreas de potencial risco hidrogeológico no município de Caraguatatuba. A partir dessa constatação, os cálculos de correlação desse dado com os demais foram realizados, onde foi possível identificar que o MDE com resolução de 30 metros apresenta melhor correlação sendo, então, capaz de reproduzir processamentos de forma similar àqueles gerados a partir do MDE com resolução de 1,12 metros.

Ressalta-se que as discussões abordadas por esta pesquisa não visam dirimir a busca de gestores municipais (ou gestores em outras esferas de poder) em munir seus bancos de dados com dados refinados e precisos[1], apenas considerou-se pertinente discutir sobre a possibilidade de produzir análises a partir de banco de dados próprios, dando espaço à realocação de recursos e investimentos destinados à obtenção de dados para a aplicação física de medidas de mitigação de riscos, em casos onde municipalidades não dispõem de recursos financeiros para tal fim.

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[1] Em 2021, a Prefeitura de Caraguatatuba divulgou sobre a contratação de empresa privada para a criação de um mapa digital urbano abrangendo todo o município, em continuidade a cobertura aerofotogramétrica parcial (utilizado em nosso estudo) previamente realizado no município. Informações sobre o processo podem ser consultadas em https://www.caraguatatuba.sp.gov.br/licitacoes/licitacao/2174.

Portanto, nosso trabalho conclui de forma satisfatória com demonstração da existente possibilidade de produção de mapeamento de áreas de risco hidrogeológicos utilizando um dado topográfico de entrada de livre acesso, onde sobretudo mostra que um dado geoespacial com resolução mais grosseira é capaz de gerar informações similares às produzidas por um dado de alta resolução, com certo grau de precisão; o que viabiliza o uso de dados já existentes para que municipalidades com recursos financeiros escassos utilizem dados e softwares disponíveis gratuitamente na elaboração de seus mapeamentos, assim colaborando com gestores em processos de tomada de decisão para construção de cidades resilientes.

REFERÊNCIAS

BRASIL. **Lei Federal nº 12.608, de 10 de abril de 2012**. Institui a Política Nacional de Proteção e Defesa Civil – PNPDEC e dá outras providências. Disponível em: http://www.planalto.gov.br/ccivil_03/_Ato2011-2014/2012/Lei/L12608.htm. Acesso em: 15 out. 2020.

CAMPOS, J. F. **Santo Antônio de Caraguatatuba**: memória e tradições de um povo. [s.l.]: Fundacc, 2000.

CASTRO, L. M. F. B. et al. Mudança climática, riscos e vulnerabilidade: um estudo dos eventos ocorridos em 1967 e 1996 na planície litorânea de Caraguatatuba – SP. **CLIMEP - Climatologia e Estudos da Paisagem**, [S. l.], v. 6, n. 1–2, p. 22–43, 2011.

CORDOVEZ, J. C. G. **Geoprocessamento como ferramenta de gestão urbana**. Simpósio Regional de Geoprocessamento e Sensoriamento Remoto, v. 1, p. 1-19, 2002.

FUNDAÇÃO DE APOIO À PESQUISA, ENSINO E EXTENSÃO (FUNEP). **Plano de redução de riscos da estância balneária de Caraguatatuba (SP)**. São Paulo: Ministério do Desenvolvimento Regional, 2006. v. 1. Assunto: Proteção e Defesa Civil.

INSTITUTO DE PESQUISAS TECNOLÓGICAS DO ESTADO DE SÃO PAULO (IPT). **Cartas de suscetibilidade a movimentos gravitacionais de massa e inundações**: 1:25.000: nota técnica explicativa/coordenação Omar Yazbek Bitar. São Paulo: IPT – Instituto de Pesquisas Tecnológicas de Brasília, DF: CPRM – Serviço Geológico do Brasil, 2014.

INSTITUTO DE PESQUISAS TECNOLÓGICAS DO ESTADO DE SÃO PAULO (IPT). **Mapeamento e proposta de plano de gerenciamento de áreas de risco de escorregamentos do município de Caraguatatuba, SP.** Parecer Técnico Nº 18578–301. 2010. Disponível em: www.ipt.br. Acesso em: 01 ago. 2020.

INSTITUTO DE PESQUISAS TECNOLÓGICAS DO ESTADO DE SÃO PAULO (IPT). Relatório Nº 39878/99. **Carta de risco de escorregamentos e inundações de Caraguatatuba, SP**. Secretaria da Ciência, Tecnologia e Desenvolvimento Econômico – SCTDE, Programa de Assistência Técnica aos Municípios – Patem, 1999.

KREIBICH, H., VAN LOON, A. F., SCHRÖTER, K. et al. The challenge of unprecedented floods and droughts in risk management. **Nature**, v. 608, p. 80–86, 2022. Disponível em: https://doi.org/10.1038/s41586-022-04917-5. Acesso em: 31 ago. 2022.

MARCELINO, E. V.; NUNES, L. H.; KOBIYAMA, M. Mapeamento de risco de desastres naturais do estado de Santa Catarina. **Caminhos de Geografia**, v. 7, n. 17, 2006. Disponível em: http://www.seer.ufu.br/index.php/caminhosdegeografia/article/view/15273. Acesso em: 09 ago. 2021.

MARCHEZINI, V. et al. Sistema de alerta de risco de desastres no Brasil: desafios à redução da vulnerabilidade institucional. In: (Orgs.) Victor Marchezini, Ben Wisner, Luciana R. Londe e Silvia M. Saito. **Reduction of vulnerability to disasters: from knowledge to action**. São Carlos: Rima, 2017, v. 1.

MASCARÓ, J. L.; YOSHINAGA, M**. Infra-estrutura urbana**. Porto Alegre: Masquatro, 2005.

MASKREY, A. **Los desastres no son naturales**. Cidade do Panamá: Andrew Maskrey (Org.). LA RED: Red de Estudios Sociales en Prevención de Desastres en América Latina, 1993. Disponível em: http://www.desenredando.org/public/libros/1993/ldnsn/LosDesastresNoSonNaturales-1.0.0.pdf. Acesso em: 09 set. 2020.

MATA-LIMA, H. et al. Impactos dos desastres naturais nos sistemas ambiental e socioeconômico: o que faz a diferença?. **Ambiente e Sociedade**, São Paulo, v. 16, n. 3, p. 45-64, set. 2013. Disponível em: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1414-753X2013000300004&lng=pt&nrm=iso. Acesso em: 22 mai. 2020.

MATTEDI, M. A. Subsídios para análise dos desastres. **ComCiência**, Campinas, n. 117, 2010. Disponível em: http://comciencia.scielo.br/scielo.php?script=sci_arttext&pid=S1519-76542010000300011&lng=en&nrm=iso. Acesso em: 24 fev. 2021.

MATTEDI, M. A. As enchentes como tragédias anunciadas: impactos da problemática ambiental nas situações de emergência em Santa Catarina. 1999. 284f. Tese (doutorado) - Universidade Estadual de Campinas, Instituto de Filosofia e Ciências Humanas, Campinas, 1999. Disponível em: https://hdl.handle.net/20.500.12733/1587178. Acesso em: 24 fev. 2021.

MATTEDI, M. A.; BUTZKE, I. C. A relação entre o social e o natural nas abordagens de hazards e de desastres. **Ambiente e Sociedade**, v. 4, n. 9, p. 93-114, 2001. Disponível em: https://doi.org/10.1590/S1414-753X2001000900006. Acesso em: 09 set. 2020.

NUNES, L. H. **Urbanização e desastres naturais**. São Paulo: Oficina de Textos, 2015. 112 p.

O’KEEFE, P.; WESTGATE, K. and WISNER, B. “Taking the ‘naturalness’ out of ‘natural’ disasters”. **Nature**, v. 260, n. 5552, p.566-567, 1976. Disponível em: https://www.nature.com/articles/260566a0. Acesso em: 09 set. 2020.

SAITO, S. M. et al. População urbana exposta aos riscos de deslizamentos, inundações e enxurradas no Brasil. **Sociedade & Natureza**, v. 31, n. 1, p. 1-25, 2019. Disponível em: https://seer.ufu.br/index.php/sociedadenatureza/article/view/46320. Acesso em: 31 ago. 2022.

SAITO, S. M. Desastres Naturais: conceitos básicos. *In*: ESCUELA DE PRIMAVERA SOBRE SOLUCIONES ESPACIALES PARA EL MANEJO DE DESASTRES NATURALES Y RESPUESTAS DE EMERGÊNCIAS-INUNDACIONES, 1., 2008, Santa Maria. **Anais** [...] Santa Maria: INPE, 2008. Disponível em: http://www3.inpe.br/crs/crectealc/pdf/silvia_saito.pdf. Acesso em: 19 mai. 2020.

SÃO PAULO (Estado). **Decreto Nº 30.860, de 04 de dezembro de 1989**. Dispõe sobre a aprovação e implantação do plano preventivo de Defesa Civil específico para escorregamentos nas encostas do mar. Disponível em: https://www.infraestruturameioambiente.sp.gov.br/institutogeologico/2017/01/plano-preventivo-de-defesa-civil/. Acesso em: 31 ago. 2022.

SEIXAS, S. R. C. et al. Mudanças ambientais globais, vulnerabilidade e risco: impactos na subjetividade em Caraguatatuba, litoral norte paulista. **Revista VITAS** – Visões

Transdisciplinares sobre Ambiente e Sociedade, v. 1, p. 1-28, 2011.

SERVIÇO GEOLÓGICO DO BRASIL (CPRM). **Cartas de Suscetibilidade a Movimentos Gravitacionais de Massa e Inundações – São Paulo**: Produtos Vetoriais/Raster: município de Caraguatatuba-SP. 2017. Disponível em: http://www.cprm.gov.br/publique/Gestao-Territorial/Prevencao-de-Desastres/Cartas-de-Suscetibilidade-a-Movimentos-Gravitacionais-de-Massa-e-Inundacoes---Sao-Paulo-5088.html. Acesso em: 01 ago. 2020.

SHADECK, R. et al. **A atuação da Secretaria Nacional de Defesa Civil (SEDEC) na gestão de riscos e resposta a desastres naturais**. In: VI Congresso CONSAD de Gestão Pública. 2013. Disponível em http://consad.org.br/wp-content/uploads/2013/05/072-A-ATUA%C3%87%C3%83O-DA-SECRETARIA-NACIONAL-DE-DEFESA-CIVIL-SEDEC-NA-GEST%C3%83O-DE-RISCOS-E-RESPOSTA-A-DESASTRES-NATURAIS.pdf. Acesso em: 09 ago. 2021.

UNITED NATIONS OFFICE FOR DISASTER RISK REDUCTION (UNDRR). **UNDRR Terminology on Disaster Risk Reduction**. 2017. Genebra: UN General Assembly, 2009. Disponível em: www.undrr.org/publications. Acesso em: 10 mai. 2020.

UNITED NATIONS OFFICE FOR DISASTER RISK REDUCTION (UNDRR). **Sendai Framework for Disaster Risk Reduction**. Japan: UN General Assembly, 2015. 32 p. Disponível em: https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030. Acesso em: 28 dez. 2019.