CARTOGRAPHICA

Mapping urban flood-prone areas spatial structure and their tendencies of change: a network study for Brazil's Porto Alegre Metropolitan Region.

Journal:	*Cartographica*
Manuscript ID	cart-2023-0003.R1
Manuscript Type:	Special Issue
Special Issue Topics:	Natural Hazards
Keywords – enter a few keywords that pertain to the topic of your submission.:	Water-floods, risk disaster management, network resilience, metropolitan areas, iconographic data

Abstract:	Historically, the main cause of urban disasters in Brazil are flooding events, which are becoming more recurrent due to climate changes and intensive urbanization, causing extensive infrastructure, economic and life losses. Brazilian Metropolitan Areas formation goes back to the early 20th century, with urban expansion following river-basins, as regional transportation relied on inland navigation. The transition to road-based transport structured further urban sprawl from the mid-20th century onwards, as road-circulation axes expanded across flood-prone areas. Mapping those hydrogeological risks is important to understand their effect on the existent road-circulation network structure cohesiveness. From the hydrogeological risk assessment data, this paper evaluates potential changes imposed by extreme flood-events on the road-infrastructure at municipal and metropolitan scales. Space Syntax methods applied to an empirical case – the Porto Alegre Metropolitan Region (PAMR) – allow for comparative analyses between urban network of current and flooding-event simulations and depict a) the urban grids´ structural transformations under flooding; b) the road-elements at risk; c) the system's spatial integrity and circulation disruptions. The resulting cartography can subside governance and urban planning strategies to cope with floodings at different territorial scales, addressing changes on local-regional circulation patterns, system breaking points and tendencies of urban land parcelling on vulnerable areas.

Mapping urban flood-prone areas spatial structure and their tendencies of change: a network study for Brazil's Porto Alegre Metropolitan Region.

ABSTRACT

The early expansion of many *Brazilian Matropolitan Areas* is marked by the spread of port towns located alongside river basins as, in early 20th century, local transportation was reliant on inland navigation. In the 1940's, however, a gradual transition to road-based circulation has surpassed other transport modes. The following urban sprawl was still closely associated to river basins' flood-prone areas, as main metropolitan axes are often structured within them due to an unguided and irregular occupation, which increases overall risks regarding loss of life and economic damage. Considering that water-floods are a main cause of urban disaster in Brazil and are being potentiated due to regional climate change, mapping those hydrogeological risks become important to understand their effect on the existent road-circulation network structure cohesiveness. This paper objective is set on evaluating, from the hydrogeological risk assessment data, the potential changes imposed by extreme flood-events on the road-infrastructure at municipal and metropolitan scales. Urban network-based models compare the current spatial system to a flooding-event simulation, mapping a) the urban grids´ structural transformations under flooding; b) the road-elements at risk; c) the system spatial integrity. The resulting cartography can aid planners to develop actions to cope with flooding in urban areas.

KEYWORDS

Water-floods, risk disaster management, network resilience, metropolitan areas, iconographic data

1. Introduction

Throughout history, the Brazilian urban settlements' location was guided by the nearness to the seaside and to the river basins, given the dependence on maritime and river-based shipping routes. Such dependence, which lasted well into the early 20th century, marked the *Brazilian Metropolitan Areas* (BMA) patterns of expansion, as even if the early port towns have gradually grown towards inland, their development was always constrained to be bound, at least in part, to the waterfronts.
From the 1940's, road-circulation surpassed other transportation modes at local, regional, and national scales, an aspect that was reinforced by the 1950's polices and incentives towards automotive industries and motor-based transport across Brazil – culminating with the construction of Brasilia – the new capital city from 1960 – in the centre of the national territory, accessible through road transport and with a urban structure mainly focused on the automobile. The rapid urban sprawl that followed this road expansion in the cities required novel regulations, designed to cope with the often unguided and irregular occupation, as well as with the growth of the peripheral urban areas. In that vein, the Complementary Federal Law Nº 14, promulgated in June, the 8th 1973, mandates the creation of the first seven metropolitan regions in Brazil, that included the Porto Alegre Metropolitan Region (PMAR), by then, composed by 14 municipalities. At the time, the

City of Porto Alegre was considered the third largest Brazilian state capital in terms of economic importance, behind São Paulo and Rio de Janeiro, being a relevant industrial centre and south Brazil's reference in terms of services (Alonso, 2001). The contemporary urban expansion in the country resulted in 74 BMA's (2022 data), that greatly differ in extension, population size and functional composition. The BMAs are well distributed across all regions of the Brazilian territory, however, with a noticeable concentration in the south and south-eastern regions (Figure 1).

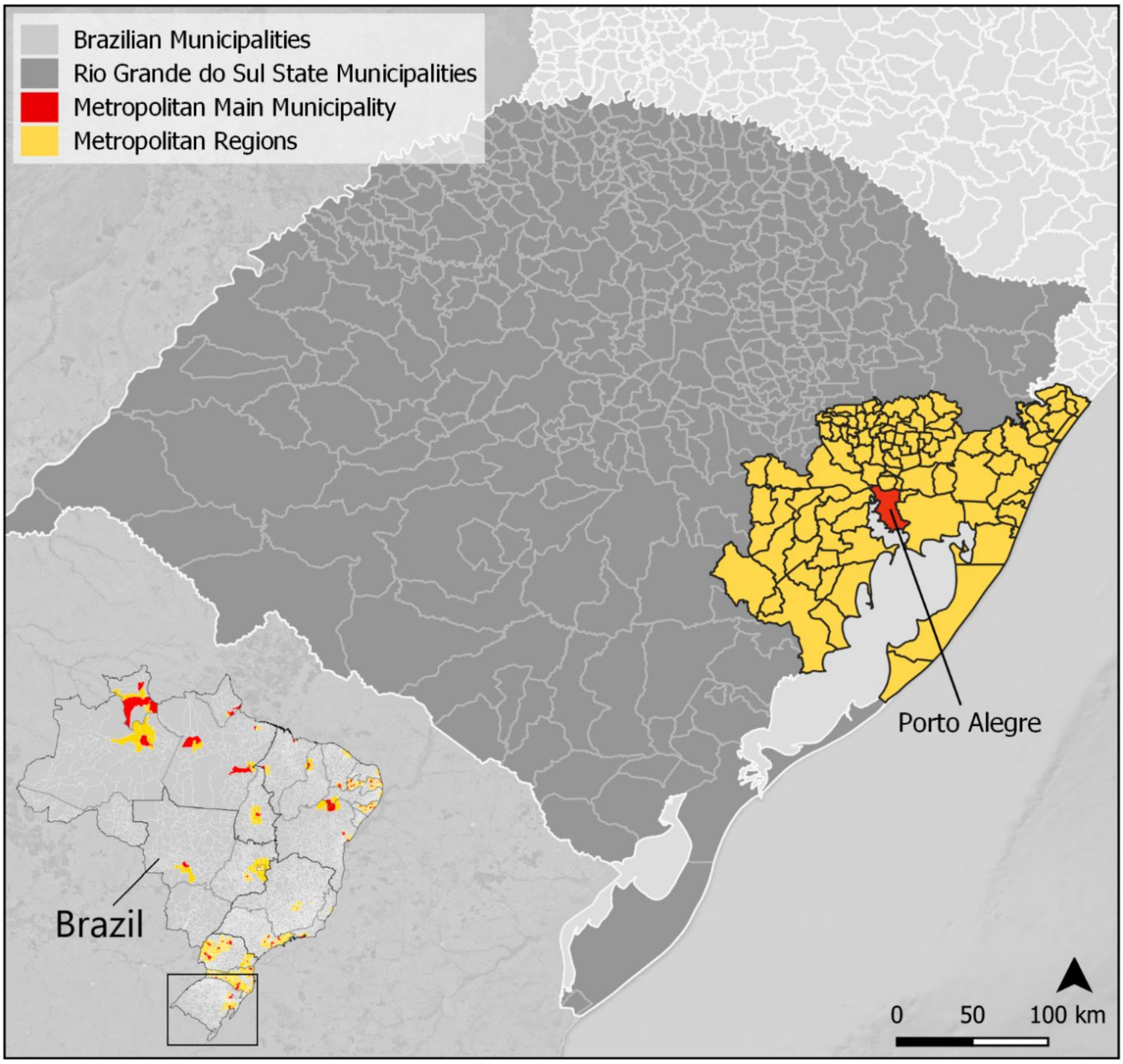

Figure 1. Brazil, Brazilian Metropolitan Regions (2015), and Porto Alegre's Metropolitan Region current development (2022)

Even after a period of important economic decline and deindustrialization during the 1980's and 1990's (Alonso 2001), the PMAR continues to figure among the most important BMA's in economic terms, while also being the fifth most populated BMA (Table 1) (IBGE 2019; 2020; 2021)

Table 1: Brazilian Metropolitan Areas ranking according to total population

Position	Metropolitan Region (BMA)	State	Population
1	São Paulo Metropolitan Region	São Paulo	21,734,682
2	Rio de Janeiro Metropolitan Region	Rio de Janeiro	12,763,459
3	Belo Horizonte Metropolitan Region	Minas Gerais	5,961,895
4	Federal District and Adjoining States Integrated Development Region	Distrito Federal Goiás Minas Gerais	4,627,771
5	Porto Alegre Metropolitan Region	Rio Grande do Sul	4,340,733

Even though under a normative, socioeconomic issues that resulted from the BMAs unregulated and irregular urbanization processes, characteristic of the early urban expansion in Brazil, persist in nowadays. This is evident when the availability of affordable housing and basic sanitation services in the most recently urbanized areas in the country is considered. As demand for housing continues to grow, informal urban developments become the norm, being characterized by a fragmented process of land acquisition and "favelaization" (Muller, 2017), that more than often rely on the use of peripheral, low-cost land (Lindsay, 2012) adjacent to the main road networks and mobility axes that span from the metropolitan centre. Beyond the socioeconomic unevenness issues that causes – and it is a result of – the irregular urban sprawl, there are also other often unaddressed envirionmental risks, that derive from the absence of proper disaster mitigation planning and sanitation services, plus due to the often-precarious territorial setting in which informal settlements are built.

Seasonal flooding is one of those risks, being rather common in Brazil given the tropical climate and the territorial conditions associated to the historical characteristics of urban expansion along the river-basins. In effect, among natural hazards, seasonal flooding is the main urban disaster cause in the country, affecting almost 40% of Brazilian municipalities and circa 30% of its urban network (IBGE, 2013). Such disasters often relate to recurrent road-circulation infrastructure collapses, homelessness due to the loss of housing in the affected areas, significant public, and private financial losses, and more than often, a high loss of life. Vulnerability to environmental hazards (Huq et al., 2020) became one of the main concerns for municipal and metropolitan regions management administration, since their impacts on citizen´s lives, public infrastructure and economic development lay at the core of several long-term planning problems. From the 2000's onwards, the *Agenda 21's Sustainable Development Objectives (SDO) and Disasters Risk Management (DRM)* actions underline metropolitan planning goals in Brazil (IPEA, 2015). Therefore, addressing urban resilience and urban sprawl control and integrating them into water-basins management, became a priority regarding novel urban developments and land-parcelling policies.

The relevance in addressing and, above all, mapping the seasonal flooding risks relies on the requirements for incorporating these data into public policies. Information regarding the radical changes in spatial configuration that result from seasonal floods is one of the most important variables that enable the assessment of the fragility and vulnerability levels of urban agglomerates, communities, and structures under disaster risk. The focus of this mapping effort should be regarding the infrastructure problems related to mobility and accessibility at local and regional scales, with emphasis on system cohesiveness. The primary goal should be in understanding how such changes can undermine accessibility and mobility patterns within metropolitan circulation networks, resulting in damage to commuting and transportation systems and, more importantly, leaving the population cut off from crucial services and urban facilities such as hospitals and food-services.

Therefore, comparing cartography resulting of current and simulated situations can provide insights into potential outcomes of a disaster event.

Considering these issues, the objective of this paper is to make an experiment in mapping and outlining the flood impacts in the road-circulation networks at local and metropolitan scales, using a cut-out of the Porto Alegre's Metropolitan Region (PAMR) as a case study. The changes in *relative accessibility* and in the *preferential routes'* structure within the urbanized area allows the identification of potential choke points within flood-prone areas. This analysis provides an immediate visualization of the changes under flooding conditions, being simple to interpretated even if exclusively accessed through its iconography. Therefore, it can be used as an accessory to other variables considered in risk analysis, as the spatial configuration or the circulation network topological structure unveils robust relations to recurrent urban impacts intertwined to social and economic dynamics within metropolitan areas. The cartographic challenge is modelling and merging two different data sets while performing a bi-variable comparative analysis which is context dependent, that is: under flooding and on regular and ordinary climate conditions.

The spatial modelling combines the configurational component, based on Space Syntax' Network Analysis (Angular Segment Analysis - ASA) with a risk assessment spatial analysis based on the hydrogeological risk area for the river basin. This water-flood patch perimeter informs the areas under flood risk within urbanized limits, as well as identify the areas with a higher propensity of minor events. Moreover, the road-circulation network comparative analysis made through ASA, enables to verify: a) the current metropolitan road-circulation network configuration relative accessibility and preferential routes system (through, respectively the metrics of Normalized Angular Integration – NAIN and Normalized Angular Choice – NACH); and b) the network configuration after suppressing the urban grids' segments that could be affected by flooding events.

Discussion and conclusions draw from the empirical case within the Porto Alegre Metropolitan Region, an area recurrently affected by water-floods, displaying several new peripheral centralities, emerging due to population densification and functional restructuring; that is, undergoing intensive and fast 'metropolisation' processes.

1.1 Porto Alegre's Metropolitan Region: a disaster risk contextualization

Porto Alegre's Metropolitan Region - PAMR encompasses a territory of circa 10,346 km² divided across 98 municipal areas (Figure 1). In terms of population, the PAMR has more than 4,340,733 inhabitants, with an average population density of circa 419 inhabitants per km² (IBGE, 2013; 2019; 2020; 2021). The metropolitan area spans from the early urban settlements that constituted the colonial ports, occupied throughout the 17th and 19th centuries. In the 17th century, Portuguese colonizers from *Açores* docked on the site where Porto Alegre, the Rio Grande do Sul state capital, is located. In 1824, German colonizers reached the *Rio dos Sinos* banks, place where the São Leopoldo municipality was founded (Martins, 2013). Other port-based and inland settlements were eventually created near to the riverbanks of the *Jacuí, Caí*, and *Gravataí* rivers, that constituted the inland shipping routes. Those gave origin to the municipalities of Alvorada, Cachoeirinha, Canoas, Gravataí and Viamão, that border Porto Alegre's urban area (Figure 2).

Porto Alegre itself is set on the conjoined delta of these four rivers (*Sinos, Jacuí, Caí*, and *Gravataí*), and eventually has grown to occupy the whole eastern shore of the *Guaiba* – an inland lake formed by these river basins. The *Guaiba Lake* extends to form a larger water body to the south when it reaches its point of connection to the *Lagoa dos Patos*, the largest inland lagoon in South America. Through it, the rivers reach the Atlantic Sea near the City of Rio Grande (Figure 2).

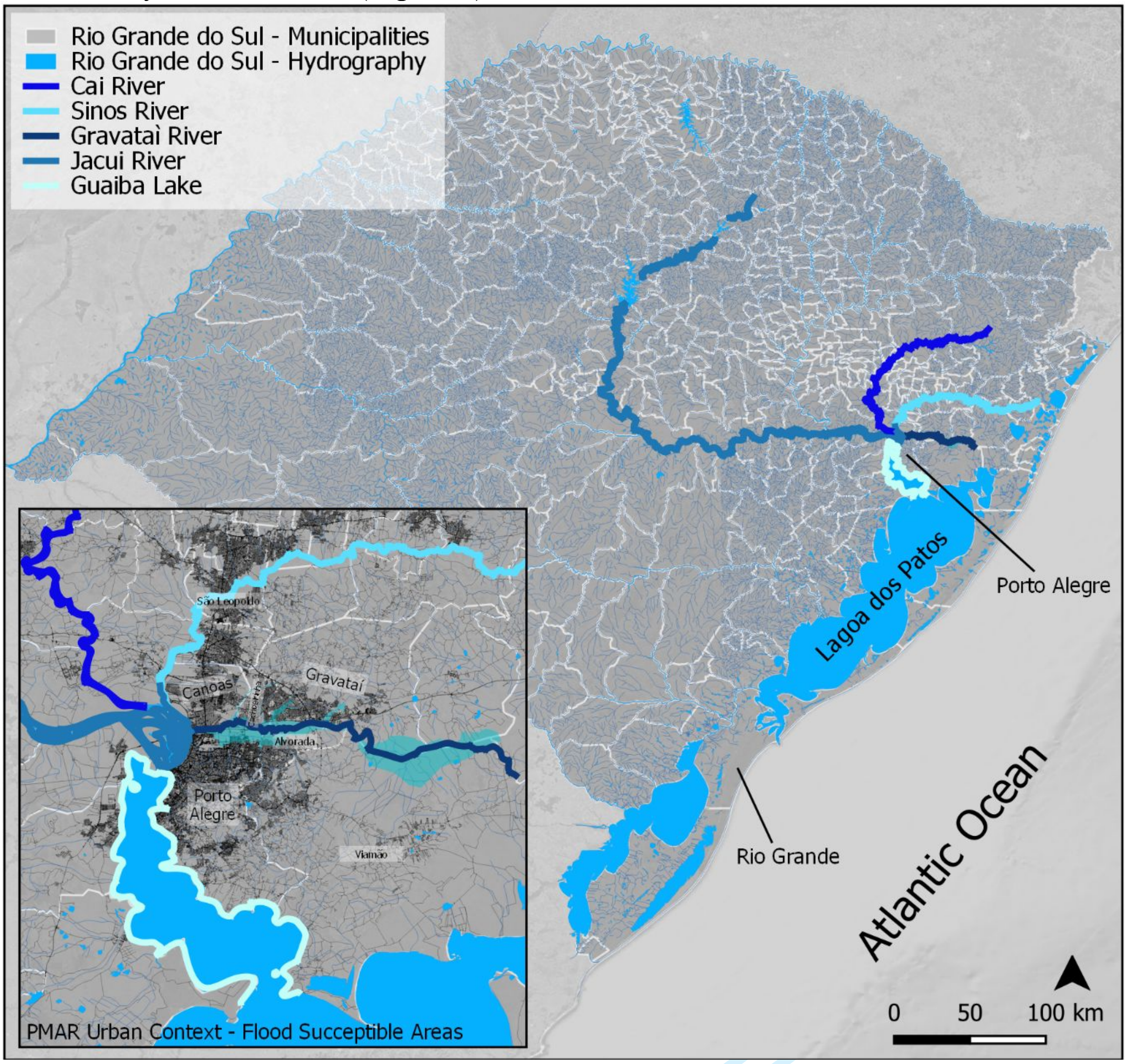

Figure 2. Porto Alegre Metropolitan Region – PAMR – urbanisation intensity; cut-out and river basins water-flood risk areas (IPEA, 2015; Melchior et al., 2018; IBGE, 2013; SEMARS, 2020).

This territorial context – which forms one of the largest and most complex water-basins in the country – constitutes itself as one of the most susceptible areas in Brazil regarding disasters related to seasonal flooding, a risk that is reinforced given its dense territorial occupation (Figure 2). *Porto Alegre,* the metropolitan capital, has an urbanization index of over 90% and hosts circa 35% of the metropolitan population (almost 1.5 million inhabitants). The bordering municipalities of *Alvorada Canoas, Cachoeirinha, Gravataí* and *Viamão* constitute together, another continuous urbanized and densely populated area, with circa 42.5% of the metropolitan population distributed across the five municipalities.

From 1960 onwards, the road-based transportation assumed a main role in Brazilian urbanization patterns as highways – both national and regional – guided the urban expansions. An example of this dynamic can be observed in the BR-116, the longest motorway in the country, extending from Brazil-Uruguay border in the *Rio Grande do Sul* State towards the northeast, to reach the State of *Ceará*. The motorway becomes a main urban avenue in several points. In *Porto Alegre*, it structures the city's central and north areas, establishing connections to the municipalities located in the PAMR's north such as *Canoas* and *São Leopoldo*, where it also is a part of these cities main road-structure. Upon construction, several motorways such the RS-030 (Porto Alegre – Atlantic Coast) and the BR-290 (Brazil – Argentina) became highly demanded axes both for intra and extra metropolitan circulation, effectively structuring Porto Alegre movements, and its connection to the neighbouring cities (Figure 3).

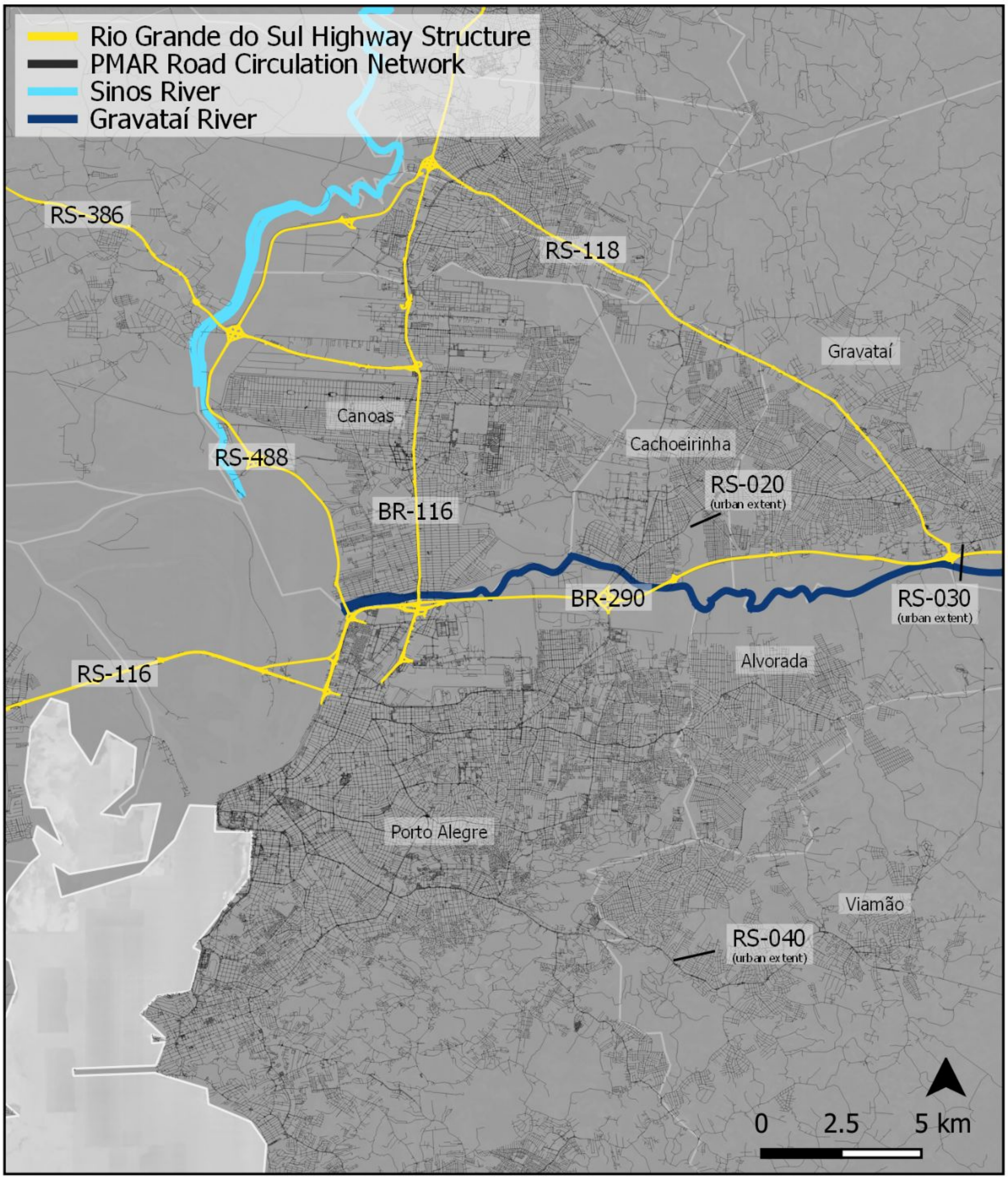

Figure 3. Porto Alegre Metropolitan Region – PAMR – urbanisation intensity, road-circulation network, and highway context

In the late 1990's, this already dense metropolitan highway system was expanded further, upon the creation of a regional ring road (RS-118) that connected the north-south axis (BR-116) to the east-west axis (BR-290; RS-040) through the municipalities of *Gravataí, Alvorada* and *Viamão*. In late 2010's, another addition to this road-system was made when the BR-448 was completed. This motorway connects *Porto Alegre* to *Canoas* and, further on, to the *Vale do Rio dos Sinos* region (*São Leopoldo*) and serves as an alternative route to the saturated BR-116 (Figure 3). Those define both the boundaries and the urban expansion axes of growth, densification, and conurbation within the PAMR.

An important aspect to be noted is that several of these motorways – namely the BR-116; the BR 290, the RS-118, and the RS-448 – cross or are in the immediate nearness of the *Sinos* and *Gravataí* rivers (Figure 3), which reinforces the vulnerability of these routes to seasonal flooding. In specific, the motorways that cross the *Gravataí River* (BR-116; RS-118 and the accesses to the BR-290) are subjected to a greater flooding risk due to the morphology of the area – a territory mainly composed by plains below sea-level.

The latest Brazilian Institute of Statistics Census (IBGE, 2021) identified that there are more than 3,205 dwellings and 10,706 inhabitants under permanent flood risk in *Porto Alegre.*

During its history, the city has undergone several severe flood episodes, such as in 1941, 1956, 1967, 1983, 2015 and 2017 (Lima, 2010, *G1 RS,* 2015). Since its urban core is set near to the *Guaíba's* delta, the area was object of several water management and risk mitigation projects conducted 1940 to 1990 by the Federal Government's Department for Sanitation Works, such as the construction of "containing walls". Still, between 1990 and 2015, no further studies on the river basins flooding conditions were made. The period coincided with PAMR's significative expansion in built-area (Lima, 2010; Pedroso, 2019). In 2015, a three-year contract to perform hydrogeological surveys was enacted, and comprised several technical reports that addressed the river basins conditions (MinC; METROPLAN, 2018a and MinC; METROPLAN, 2018b). These datasets, were recently made publicly available (2021), and allow to determine the territorial extent of the flood-patches. For this research, a cut-out was established depicting the most flood-prone area within the PAMR, that extends throughout its most densely populated region. It encompasses the Northern Planning Regions of its core - *Porto Alegre* - and the entirety of *Canoas, Gravataí, Cachoeirinha* and *Alvorada* municipalities (Figure 4). *Viamão* was not considered in the analysis, despite possessing a larger patch, as its affected area is not urbanized.

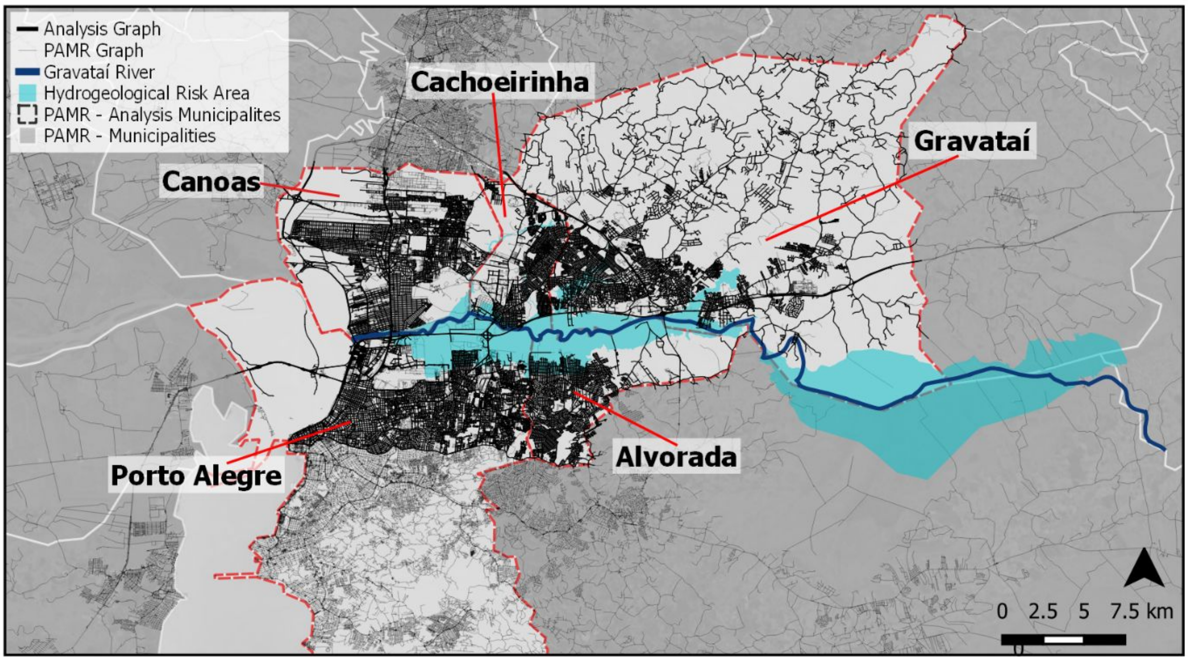

Figure 4. Porto Alegre Metropolitan Region – PAMR – Analysis area comprising the Gravataí river flooding plains.

Based on this territorial delimitation, it was possible to discuss the effects of future floods in the road-network. This provided a comparative framework to analyse, aided by Space Syntax theory and methodology, the post-disaster configuration and spatial system resilience, pinpointing potential collapsed linkages within the PAMR.

1.2 Disaster-risk management and the Space Syntax network approach.

Space Syntax, despite being originally conceived as an architecture-based theory to address the social aspects that emerged from the urban networks' configuration (Hillier & Hanson, 1989), intertwines profoundly to disaster-risk management.
In the last 10 years, its models were applied in several pre-and-post-disaster-risk analysis to outline issues related to configurational effects of road-circulation networks' collapses and emergency infrastructure positioning tendencies in urban and regional areas, themes that were explored in-depth by a plethora of authors such as: Cutini & Di Pinto, 2010; Fakhrurrazi & Van Nes, 2012; Cutini, 2013; Esposito & Di Pinto, 2014; 2015; Cutini, et al., 2019; Guiliani et al., 2021; Rusci et al. 2021; Pezzica et. al, 2019; 2021. Recent contributions, however, shifted towards addressing the spatial system structure resilience towards abrupt changes (Pezzica et. al, 2022; Altafini et. al, 2022), which strived to identify the road-elements that are more "vulnerable" on the road-circulation network or that make the whole network more "fragile". Space Syntax techniques therefore enable the evaluation of road-network structures in both intact and disrupted systems, allowing comparative analyses and alternative scenarios that can aid in the mitigation of the adverse impacts of natural disasters, such as seasonal floods.
Gil & Steinbach (2008) state that floods can have a serious impact on transport networks. The authors stress that disruptions on different road-elements in the network can propagate and affect movement potentials far from the interrupted area, an important factor to address in mobility planning. That is, a flood event can result in a different spatial configuration, which changes movement patterns in a way that the system is not prepared to handle, causing congestion or inaccessibility.
Abshirini & Koch (2017) findings on spatial system resilience weakening factors endorse Gil & Steinbach (2008), as interruptions can create archipelago-style configurations (sparsely connected or completely disconnected to rest of the system), which in turn create weaker accessibility patterns, which are already characteristics of Brazilian urbanization process, and tend to be driven to a collapse point under flood-prone areas.
In this paper, these directives are followed to analyse and discuss the results found for the Porto Alegre Metropolitan Region – PAMR - proposed cut-out. Nevertheless, this approach resumes to the currently established Angular Segment Analysis (ASA) for a preliminary evaluation of the phenomena, to instruct and risk-based analysis according to potential major changes in accessibility patterns (Cutini et. al 2019).

2. Datasets and Methods

2.1 The Space Syntax modelling approach – methods used for the network analysis.

Recent methodological developments in Space Syntax Angular Segment Analyses (ASA) proved themselves efficient in analysing urban-regional spatial configuration regarding disaster risk management (Hillier & Iida 2005; Hillier, 2019).
Current ASA methods draw from on road-circulation network graphs for which Road-Centre Lines (RCL) segments (road-elements) represent the network nodes and arches (Turner 2007). In Space Syntax, differently from the traditional graph theory approach,

arches (road-elements) are interpreted as nodes, meaning that the Space Syntax metrics' values are referent to the road-element, not to the graph junction. Therefore, the models' iconography displays an accurate depiction of the urban structure (Figure 5).

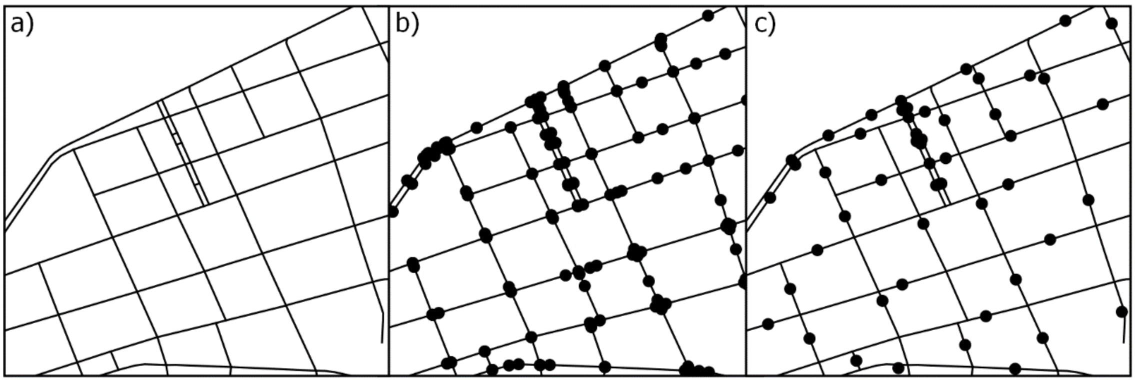

Figure 5. a) Road-Centre Line Graph; b) Traditional Graph Theory Approach (road-element as arch); c) Space Syntax Approach (road-element as node).

The application of different network centrality metrics to a same network – or Multiple Centrality Assessment (MCA) – is a methodology of quantitative spatial analysis that highlight different network properties, allowing to understand potential movement patterns on an urban structure – metric distance (a link attribute assumed as impedance), or topological distance (highlights hierarchical relations between elements). Space Syntax ASA works with two main network measures, derived from graph theory metrics: the *Angular Integration* and the *Angular Choice*, whose properties are described in Table 2. In Space Syntax, normalising ASA metrics (*Angular Integration and Angular Choice*) is a crucial step for comparing urban systems with different depths (Hillier et. al, 2012) or sizes (in number of segments). Normalized Angular Integration (NAIN) is a *closeness centrality* mathematical approximation and depicts *relative accessibility* – or the topological proximity to other segments, therefore informing which spaces people tend to converge to under disaster events. Normalized Angular Choice (NACH), instead, is a mathematical approximation of *betweenness centralities*, therefore indicates the most probable travelled shortest paths within the system, which consists of road-elements that are important for connections between urban areas, and, if interrupted, can collapse the system, and depict escape routes as well as alternative routes under abnormal conditions.

Table 2: Space Syntax ASA metrics – Angular Integration and Choice

Space Syntax	**Graph Theory**	**Formula ~~Teoria~~ Graph Theory**	**Formula Space Syntax (normalized)**	**~~Concetto~~Concept**
Integration *(int.)*	*Closeness Centrality*	$C(x) = \frac{1}{\sum_y d(x,y)}$	$NAIN = \frac{n^{1.2}}{ATD_\alpha^\ell(x)}$	Depicts *relative accessibility* – or the topological proximity of one road-element to all other road-elements
Choice (ch.)	*Betweenness centrality*	$C_B(v) = \sum_{s \neq v \neq t \in V} \frac{\sigma_{st}(}{\sigma_s}$	$NACH = \frac{Log(ACh_\alpha^\ell(x}{log(ATD_\alpha^\ell(x}$	Indicates the *preferential routes* – or the most travelled paths within the system, given a the shortest path between a road-element and all other road-elements

Normalising these centrality measures incorporates this impedance and this topological hierarchy (depth), suppressing the necessity to perform metric pondered modelling to compare changing effects on urban grids at different scales. In a scenario of occupation removal or different degrees of areas´ insulation, due to river floods in watershed areas, these models depict changes on road-network hierarchies, within different territorial frames, forecasting potential impacts on metropolitan mobility and local accessibility. Alongside, a topological approach highlights the elements which are “more important” to the network, given its overall connectivity hierarchy on the global structure.
The modelling of NAIN and NACH for the PAMR proposed cut-outs, draws from a topological approach on DepthMapX 0.8 (2018) to identify the hierarchical position of each road element on the global structure. Resulting data maps are spatialized on a GIS-based environment (QGIS, 2022), where the flooding patch is superimposed, to establish a before-and-after scenario, in which the Road-Centre Line system is processed at its current state, and without the elements encompassed within the water-flood patch, providing the tools that enable a comparative analysis of its current condition and under flooding. Statistical results iconography allows the visualization of the hierarchical changes under these two different circumstances what has been proved useful in informing large multidisciplinary responsive team works.

2.1 Methodological proceedings for constructing the graph datasets and modelling PAMR flood-risk areas.

The PAMR road network, extracted from an OSM database (OpenStreetMap, 2021), encompasses the totality of *Gravataí, Cachoerinha, Alvorada* and *Canoas* municipalities´ continuous urban grids (Figure 4). *Porto Alegre,* however, has its urban grid reduced to the North and Northwest planning regions (PR2 and PR3) at the margins of the *Gravataí river*, as those areas are the most affected by flooding risks taken in consideration. Due to radical differences in urbanization patterns between *Porto Alegre's* North and South (Figure 3), the usage of the whole network graph for this localized analysis could lead to a biasing of the North's *relative accessibility*, especially upon the proposed simulation system restrictions. Hence, the empirical study area limits for *Porto Alegre* is set on two important urban avenues: the *Castello Branco* Avenue (N), part of the BR-116 which directly links to the BR-290; and the *Protásio Alves* Avenue, which establishes a ring-road between the *Castello Branco* Avenue at *Porto Alegre's* centre, the *Alvorada* municipality (E) and the RS-118 connection (Figures 3; 4).
On a GIS platform (QGIS, 2020), the flood-patch extracted from MinC and METROPLAN (2018a; 2018b) historic dataset is overlaid to the road-circulation network cut-out; through symmetrical difference, areas susceptible to flood-risk were removed, considering terrain topography elevations: therefore, highways that are built above water-flooding levels remained unaffected by the water-flood patch. In the same manner, bridges, overpasses, and access roads built to keep the road-infrastructure above flood-prone waterlines were also maintained, whereas the bridges, overpasses, and access roads that are susceptible to interruption by flooding were removed.
The first map (Figure 6.a) comprises the current state of the road-circulation network, without flood-related interruptions, while the second (Figure 6.b) removes the flooded elements from the system. Through these maps (Figure 6), it is possible to attest the complete disconnection of Alvorada municipality from the rest of the urban agglomerate and its partition into two distinct continuous spatial elements, which were modelled independently.

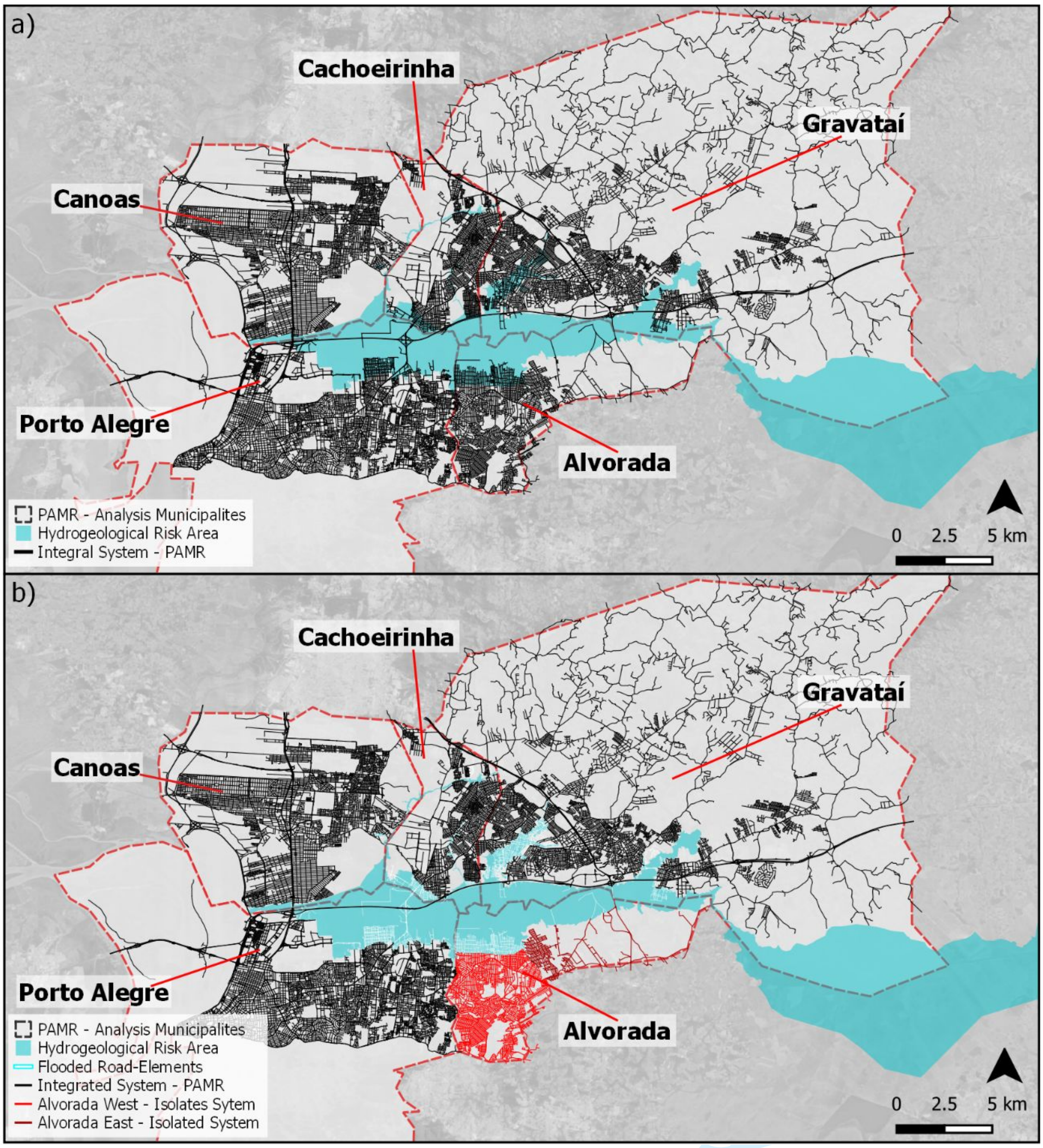

Figure 6. PAMR cut-out road-graph a) integral system b) system configuration without road-elements within the hydrogeological risk area.

The road-circulation networks graphs are constructed on QGIS (2022) shapefiles (*.shp) and exported as vector drawings (*.dxf) to DepthmapX 0.8 (2018). In this software, NAIN and NACH measures are modelled exclusively for radius *n*, the whole system, since the main objective is to address the urban-regional road-circulation network changes under flooding-events. DepthmapX 0.8 analysis results are then exported as *Mapinfo* files to QGIS and converted once again into shapefiles (.shp). On QGIS, a quartile range for NAIN and NACH was established to analyse the system´s movement pattern changes. This highlights only 10% of the total number of elements with highest NAIN and NACH measures – depicting both, the integration cores of *relative accessibility* and *preferential routes* system.

3. Results and Discussion – mapping the flood effects on the road-circulation network.

Simulation results in terms of *relative accessibility* (NAIN - rn) and *preferential routes* (NACH - rn) (Figures 7-14) demonstrate that seasonal flooding events have potential to cause important changes within the PAMR road-circulation network and in the movement potentials structure.

The comparison between the network structure in the integral and simulated models attest that the disaster affected systems tend to conserve most of its structure, as the "integral part" of the network is reduced only in circa 15% (22,421 to 18,896 road-elements) (Figure 6b.). From these, just 5% (1,301) are actual flooded elements, whereas the rest pertains to the *Alvorada's* systems, that remain disconnected from the integral network. While small in number, the flooded elements cause a significative reorganization in the internal movement potentials within *Porto Alegre's* urban core, and in the PAMR conditions of *relative accessibility* as a whole (Figures 7; 8 and Table 3).

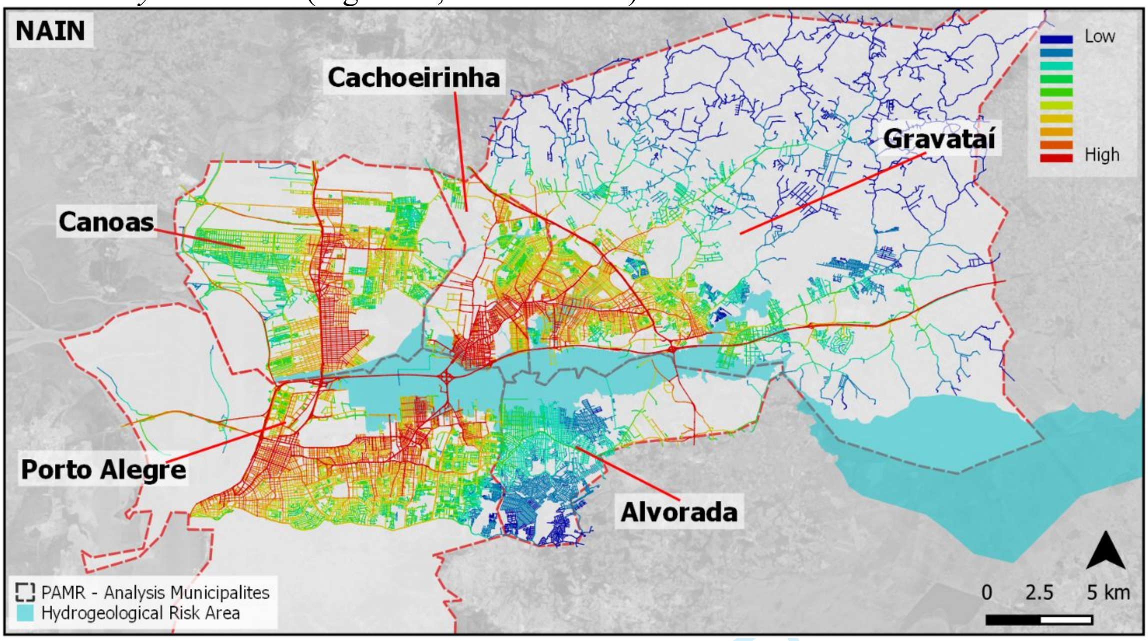

Figure 7. Results for NAIN: integral road-network configuration, outside a flood event.

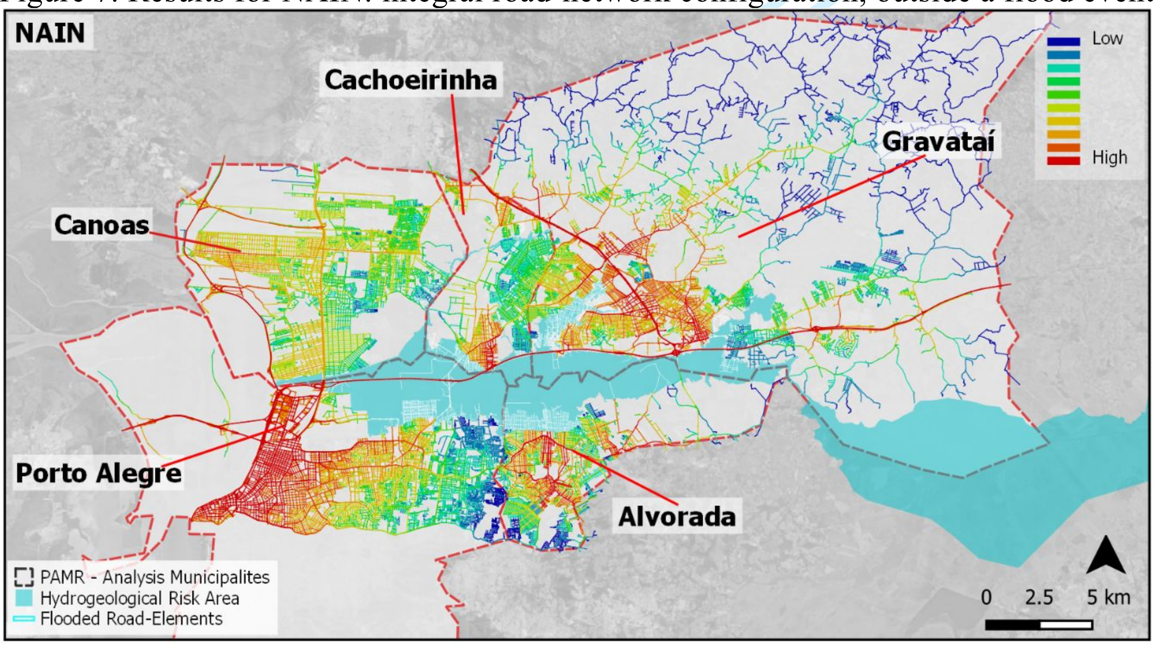

Figure 8. Results for NAIN: flood affected road-network configuration.

The simulation reveals that the most important road-circulation network elements –*Castello Branco Avenue* and the highways connecting *Porto Alegre* to *Canoas, Cachoeirinha* and *Gravataí* –remain stable, given that they are built above the flood-prone waterline. This means that manmade terrain elevations on highways and in its connections (bridges, overpasses, etc.) effectively protect the regional road-circulation network core, and from that standpoint, assure a certain degree of resilience and *accessibility robustness* to the system. Nevertheless, results reveal that certain overpasses and access-roads can be disrupted by the flooding, which cause punctual disconnections at global scale. Therefore, while general *accessibility* conditions within the PAMR, with the exception those towards *Alvorada*, tend to remain stable, the only access to the remainder of the PAMR, from *Porto Alegre*, is located at its urban core. This greatly changes the dynamics of *relative accessibility* in the region (Figures 9; 10), as upon flooding a single connection between *Porto Alegre* rest of the regional highways (BR-290, BR-448 and RS-118) is maintained, while the only remaining motorway exits above flooding level are located at *Gravataí,* and *Canoas* outskirts. In this aspect, maintaining the BR-290 access – and the *regional accessibility patterns* – intact his does not prevent a radical redistribution of NAIN hierarchies (Figures 7-10)

Table 3. NAIN Values: PAMR integral road-network system, PMAR flooded road-network system (average between the three systems) and 10% restriction (*relative accessibility cores)*.

PAMR - Current	PAMR – Flood Area (Avg.)
0.14 - 0.44 (Low)	0.30 - 0.43 (Low)
0.44 - 0.53	0.43 - 0.48
0.53 - 0.59	0.48 - 0.52
0.59 - 0.63	0.52 - 0.55
0.63 - 0.66	0.55 - 0.58
0.66 - 0.68	0.58 - 0.6
0.68 - 0.71	0.6 - 0.62
0.71 - 0.74	0.62 - 0.66
0.74 - 0.79	0.66 - 0.70
0.79 - 0.97 (High) – **10%**	0.70 - 0.78 (High) – **10%**

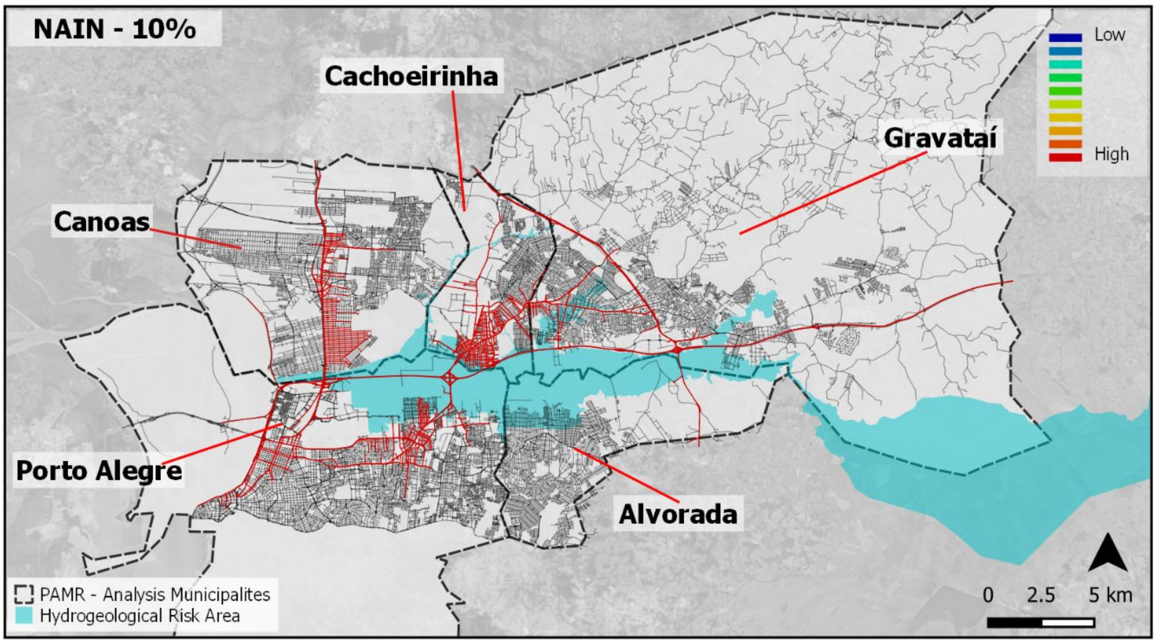

Figure 9. Results for NAIN: integral road-network configuration, outside a flood event (10% restriction).

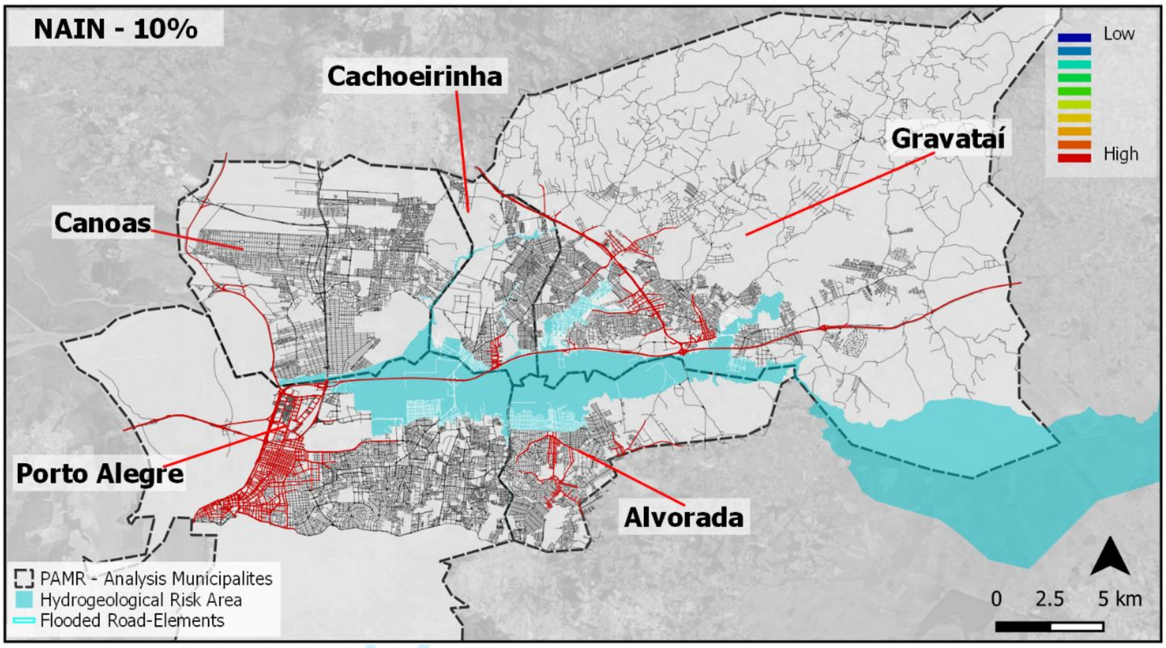

Figure 10. Results for NAIN: flood affected road-network configuration (10% restriction)

Drawing from NAIN 10% restrictions (Figure 9; 10), it is possible to identify where are the sources of radical changes on the *relative accessibility* distributiveness. Those changes occur mainly due to the flooding of a large portion of the main connection between *Porto Alegre* and *Canoas*, through the BR-116, and cuts in half the *relative accessibility core* from the centre; and due to the complete flooding of the *Porto Alegre-Cachoeirinha* connection, that crosses under the BR-290.

The *Porto Alegre-Canoas* accessibility is then dependent of – and only possible through – the BR-448, while the *Porto Alegre-Cachoeirinha* access can only be done through *Gravataí*'s urban area, accessed through the RS-118 to the east (Figure 10). From that, it can be observed that certain road-intersections with the urban grid that seem to function as *network bridges* (Altafini et. al 2022), are suppressed under flooding, therefore, changing the overall *relative accessibility* concentration system at local and especially at metropolitan scale Hence, despite the system integrity overall maintenance in terms of *accessibility*, congestion effects are certain to happen due to the *relative accessibility* concentration in *Porto Alegre*, as movement potentials are redirected towards its urban core, as well as across the BR-290, which becomes the lifeline between *Porto Alegre* and the municipalities of *Cachoeirinha* and *Gravataí*.

From the analysis (Figure 7-10) it also becomes clear that *Alvorada*, although a continuity *Porto Alegre's* Northern Region, remains an isolated periphery in the case of flooding, an aspect that is coherent with its role as satellite city for *Porto Alegre* (Melchior et al. 2018). Moreover, its overreliance on urban access to connect itself to the metropolitan system weakens its urban system as the interruptions caused by the flooded tributaries of the *Gravataí* river completely severs the connection with *Porto Alegre*, insulating its core. A feature of the simulation under a severe flooding-event is the emergence of a strong integration core within *Alvorada* municipality, which is due to the collapse and its severance from the metropolitan system. Two definite urban patches within *Alvorada* territory emerge through the disconnection by one of the *Gravataí* River tributaries: the centre area becomes an island despite the urban grid continuity to *Porto Alegre*, while the industrial district simultaneously disconnected from *Alvorada's* centre and from *Cachoeirinha,* through the RS-118, tend to function as an isolated peninsula (Gil & Sonderberg 2008).

From the NAIN measure analysis, we can conclude that water-flood greatly modifies movement patterns at metropolitan scale. The PAMR road-circulation system, while still robust and *accessible*, tends, in terms of *relative accessibility*, to collapse due to the suppression of vital connections within the metropolitan conurbation at a local scale. It is possible to infer that such changes are result from an uneven distribution of *network bridges* across the road-network which display the fragility and low resilience and redundance of the PAMR metropolitan system, in terms of maintaining the connections between its urban settlements. The scarce connections in-between the municipalities – mainly reliant on the BR-290 motorway – participate in forming a fragmented foreground network, attesting the fact that Brazilian cities are among the most deep spatial systems of the world , connected by few privileged road-elements, intertwined to a profound and intricate urban network, evident in this metropolitan context. Moreover, the mapped NAIN analyses results evidence that planned land parcelling towards the riverbank lowlands and their immediate vicinities should be avoided, or submitted to serious mitigation works beforehand. This is imperative, not only due to the innate flooding risks, but also, because of the consequential disruptions on the metropolitan spatial configuration and shifts on *relative accessibility* under a flood disaster, which may render those areas isolated from the metropolitan system.

Evaluating the metropolitan system's structure through Normalized Angular Choice (NACH) measure (Figures 11-14), informs that, from a general standpoint, flooding effects tend to be reduced regarding flows' patterns at metropolitan scales. It can be observed that the ring-roads supplementary connections outside and inside the metropolitan core largely preserves the *preferential routes* system, maintaining the integrity of the metropolitan system at a larger regional scale. In effect, this contributes to the aforementioned *accessibility robustness* of the system.

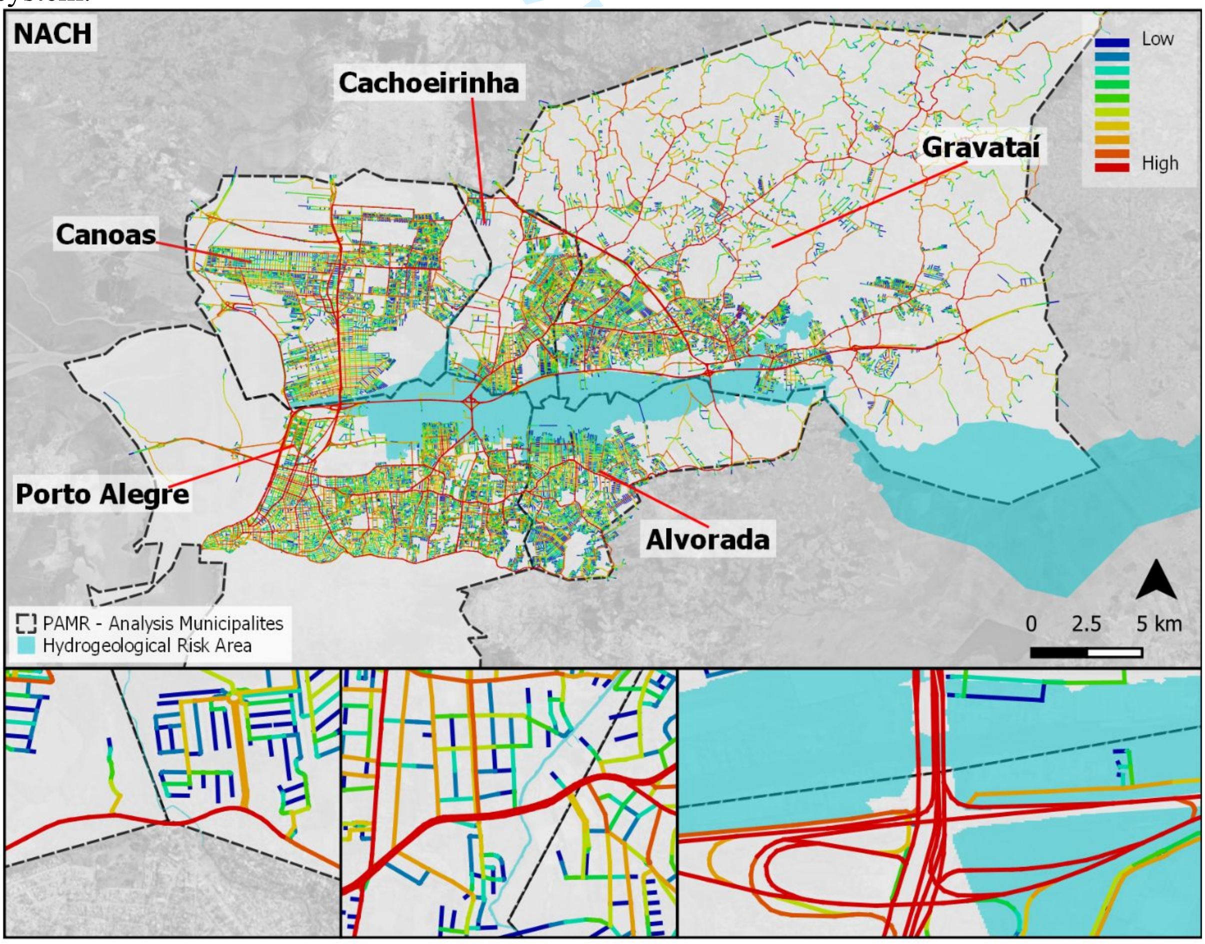

Figure 11. Results for NACH: integral road-network configuration, outside a flood event.

The role the three main highways play for the *preferential routes'* system resilience (in red - centre), relate to their highest hierarchy as urban avenues (in red and orange) ensuring regional connections a great degree of redundancy to the system at larger scales, factor informing the urban system´s resilience.

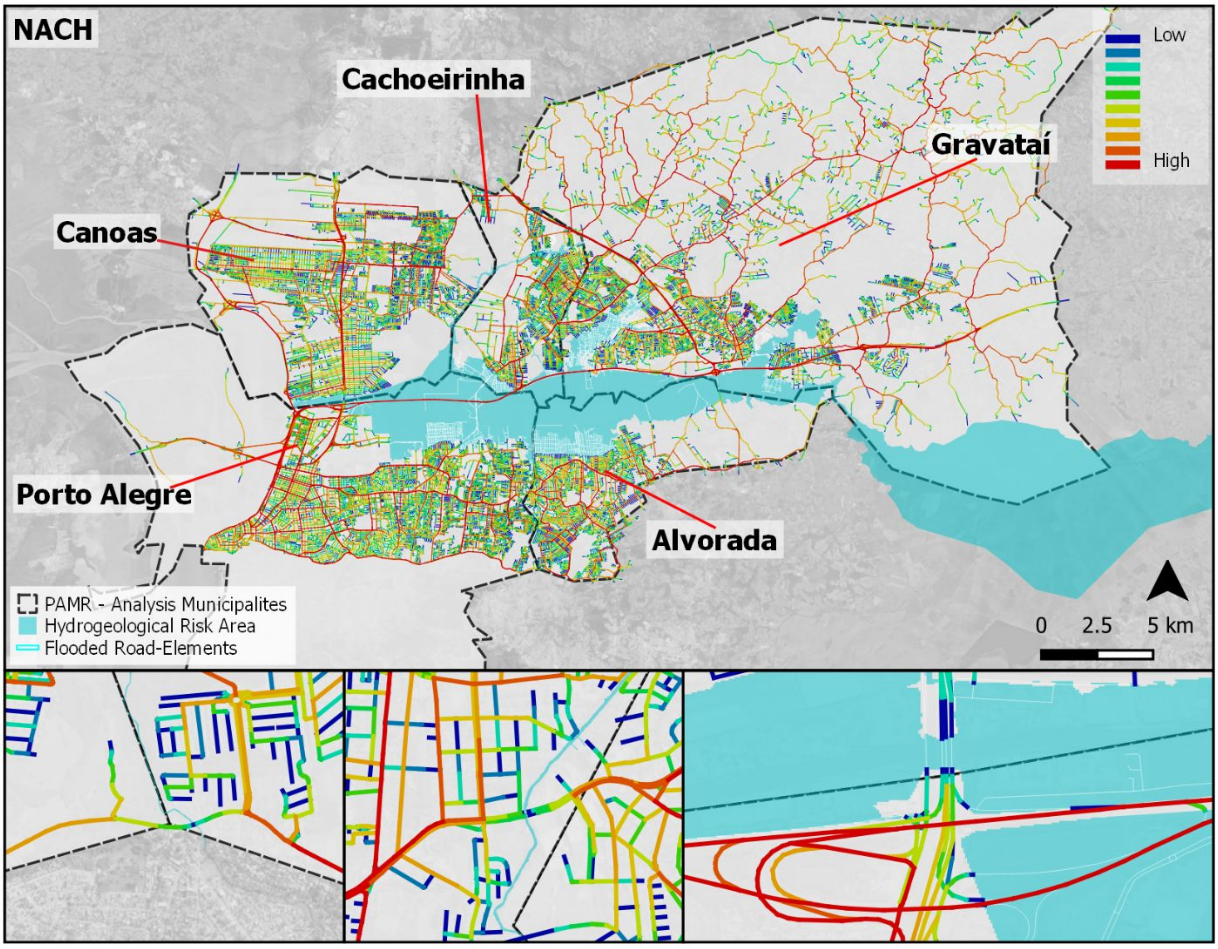

Figure 12. Results for NACH: flood affected road-network configuration.

Nevertheless, while system´s integrity regarding flows is mostly ensured at metropolitan scale, at local scale several internal road-elements that have high NACH values are interrupted by flooding, causing localised seizures to the system (Figures 12-14) – and which also answer for NAIN collapsing at metropolitan scale, despite their limited impact on local flows. This demonstrates that, while general hierarchies' are stable at metropolitan scale, where the main connections between the PAMR municipalities were planned to be resilient against flooding disruptions, at municipal scale, there is a relative neglect towards the role urban bridges between the municipalities play into maintaining connectedness between urban grids, revealing the resilience of the centre-periphery model in Brazilian planning practises. Nowadays, there is an intensive labour commuting towards industrial districts located on the northern peripheries of the metropolitan core - *Porto Alegre*; which also concentrates services and retail activities (Altafini et al, 2021) that changed radically mobility and movement patterns within the PAMR. This is especially relevant in informing the ongoing metropolisation process within the PAMR: urban dynamics and economic development policies inform a turn towards a functional polycentric expansion towards the most flood-prone sensitive area.

Table 4. NACH Values: PAMR integral road-network system, PMAR flooded road-network system (average between the three systems) and 10% restriction (*preferential routes)*.

PAMR - Current	PAMR – Flood Area (Avg.)
0.00 - 0.70 (Low)	0.00 - 0.66 (Low)
0.70 - 0.84	0.66 - 0.82
0.84 - 0.89	0.82 - 0.87
0.89 - 0.93	0.87 - 0.92
0.93 - 0.97	0.92 - 0.95
0.97 - 1.01	0.95 - 0.99
1.01 - 1.06	0.99 - 1.04
1.06 - 1.12	1.04 - 1.11
1.12 - 1.22	1.11 - 1.20
1.22 - 1.52 (High) – 10%	1.20 - 1.51 (High) – 10%

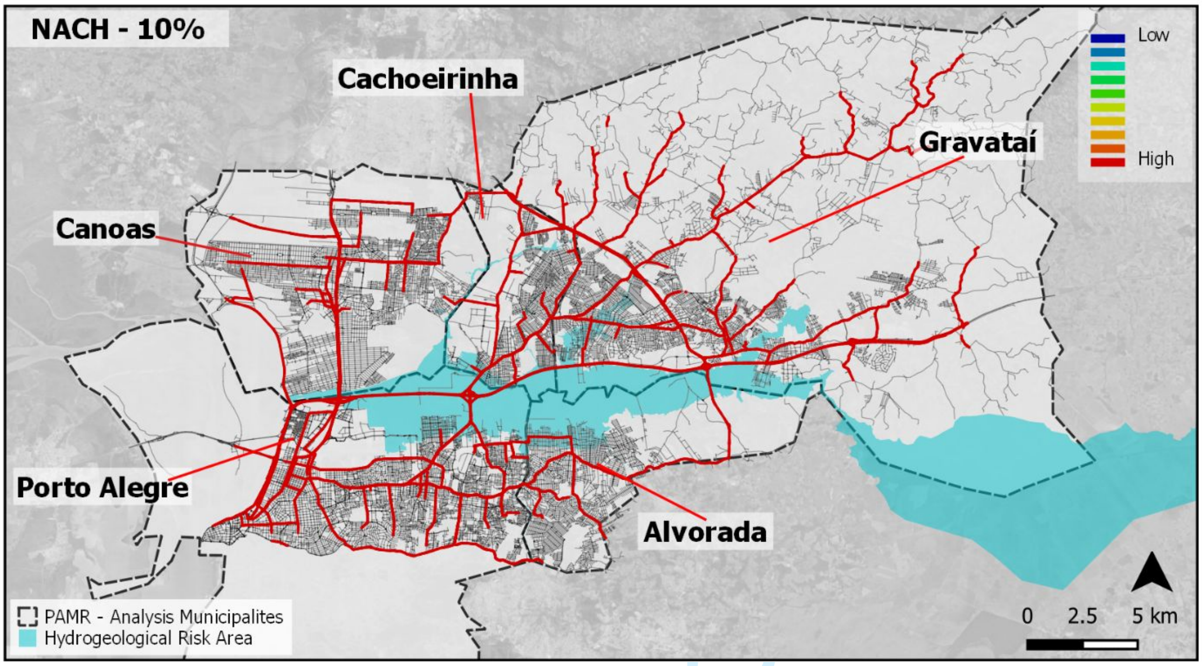

Figure 13. Results for NAIN: integral road-network configuration, outside a flood event (10% restriction).

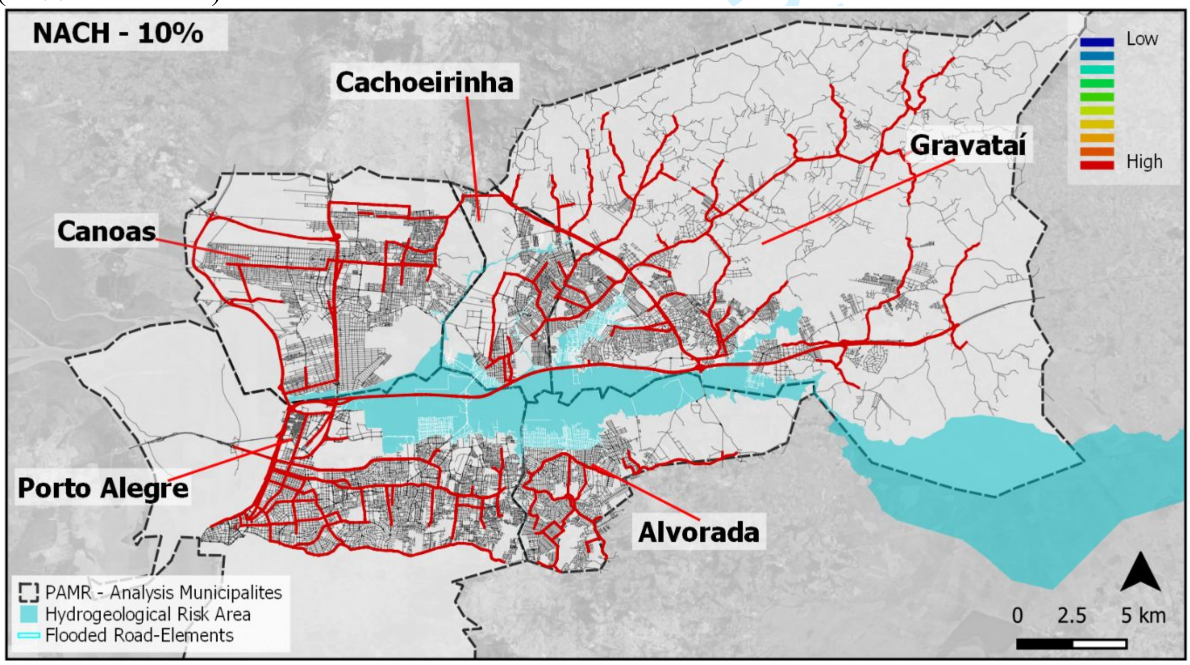

Figure 14. Results for NAIN: flood affected road-network configuration (10% restriction)

Even though Porto Alegre centre is losing importance in fomenting economic development, it still plays part as a movement attractor and in structuring the urban-regional road-circulation system, since it houses the most important commuting node within the metropolitan region – as attested by the evidence displayed here that it tends to preserve metropolitan connections disrupted by floods. Nevertheless, the measures taken to improve the metropolitan circulation system resilience disregard recent metropolisation process ongoing on its immediate peripheries. The BR-290, another important axis on the national road network, crossing the Brazilian territory up to its Northeast and along the coast, connects to RS-030, crossing *Cachoeirinha*, and defines the northern border of the preserved NACH core, as well as the urban extensions to *Porto Alegre* city core, and its connection to BR-448, keeping freight circulation consistent. The highlight of NACH is also *Alvorada* municipality: NAIN demonstrates that it becomes an isolated system. Albeit the robust interpenetration between the Porto Alegre urban grid and that of its central area, under flooding, this municipality becomes isolated to the point of becoming an actual island. This is dramatic in the sense that *Alvorada* is a dormitory-city and commuting with Porto Alegre is intensive (Melchiors et al., 2017).

Alvorada and *Canoas* municipalities are the ones submitted to the most the adverse effects of planning policies inconsistences regarding the management of water basins and metropolitan restrictions for land development based on incomplete technical analyses. On *Gravataí* territory, watershed occurs along its main river and the *Barnabé* Stream*,* a tributary of the *Gravataí* River along its core, a high-density area. *Porto Alegre* Northern Planning Regions undergo major real-estate development, especially on the lowland areas closer to BR-290, one of the metropolitan routes with higher flow probability and an emergent new centrality at metropolitan scale. Along this road, gated communities and shopping centres characterize suburban sprawl patterns, despite the area´s high hydrogeological risk.

Those findings relate directly to the tendencies of change under flood-risk depicted by the modelling iconography. Flood-prone patch modify *Porto Alegre* neighbouring Northern areas and its bordering municipalities urban expansion patterns, informed by regional circulation and metropolitan mobility.

4. Conclusions

Urban expansions in Brazil tend to follow a sparse, spatially discontinuous and fragmentary processes, which depends on the acquisition and occupation of peripheral low-cost land that borders the main road-circulation networks. This tendency that summarizes the accelerated urbanization process that most of Brazilian *Metropolitan Areas* undergo since the 1970s. These peripheral areas, subject of an unguided and irregular occupation are, more than often, prone to important natural hazards, such as seasonal floodings that increase the risks of economic and life loss. This was proven the very case of Porto Alegre Metropolitan Region – PAMR.

This empirical study reveals that the configuration that results from the urban network morphology structure can be very sensitive to interruptions caused by seasonal floodings and that mapping the possible effects of those can give planners an important picture of how the mobility systems react and what are the bottlenecks in urban movement. It also reveals the disparities regarding the levels of resilience in regional mobility systems, and that while linear systems can maintain the *accessibility robustness* of a region – privileging connections between the metropolitan cores – its peripheries tend to be greatly affected at regional scale. Moreover, this analysis demonstrates the importance that ringness between primary and secondary centres laying in different municipalities plays in providing alternative routes under flooding circumstances, especially for metropolitan mobility planning issues.

Abshirini & Koch, (2017) findings on resilience defined as the degree to which a city retains the same segments forming the foreground network before and after a disturbance support the findings that PAMR is not a resilient system at municipality scale; since changes in NAIN are noticeable and directly affect the patterns of accessibility and movement potentials within the case studied. At regional scale, we can conclude that the PAMR system is resilient if only regional flows are considered, as for *relative accessibility* greatly changes upon a relativelly small system configurational changed. This both confirms and challenges Cutini's (2013) work. Studying effects on centrality patterns before and after change is informative, but the particular use of bridges as key actors in the system is refined when it comes to understanding the global properties of the network. That is why modelling NAIN-*n* solely was enough to evaluate the proposed study case.

The regularity found in this study, however, does not mean by itself a higher generic resilience for river cities. Therefore, it lacks a multivariable measurement of resilience taking into account additional urban areas properties, for instance, grid compactness and built density. This preliminary research did not supply enough evidence to confirm these findings. Differences in urban expansion patterns between Brazilian and European cities encompass the first one effective urbanisation boom after the diffusion of road transportation (1950). Therefore, highways and main roads play an important role in informing patterns of suburbanisation and sprawl as the emergence of new kinds of functional centralities associated to private transport mobility, what has been associated to lower sustainability levels.

In this article, the multi-scale mobility approach relays on the combined analysis of the circulation network structure with flood-prone patches and the limits they should impose to land parcelling intensification and land use changes. Results run against the achievement of full land parcelling and implemented infrastructure economic potential exploitation that underlies historically Brazilian planning policies. Nevertheless, this planning culture is changing in order to ponder environmental risks costs (financial, human and environmental) and to promote less uneven and more sustainable development for metropolitan regions and cities. To achieve these goals, effective actions for metropolitan regions are required on behalf of managing urban expansions, regional structuring and territorial planning while targeting resilience and sustainability across scales, the most effective tactics to face real estate sector intensive pressure for new land developments within flood risk areas. In this sense, analytic tools and methods that allow spatial configurations and circulation networks comparative studies such as Space Syntax simulations support decision-making process, since they provide evidence for changes and transformations tendencies in such extreme situations as flooding. Nevertheless, there is always municipalities´ autonomy limiting inter-federative approaches for managing water resources and river basins, an essentially regional problem, addressed by metropolitan authorities since the *Estatuto da Metrópole* Federal Law (2015) enactment, designed to overcome metropolitan regions integrated planning hindrances.

References:

Abshirini, E. and Koch, 'Resilience, space syntax and spatial interfaces: The case of river cities', *ITU A|Z,* (2017) Vol 14, No 1 • March 2017, 25 41doi.org/10.1016/j.progress.2013.08.001

Alonso J. A. F. Caracterização econômica da região metropolitana de Porto Alegre nos anos 90. *Indicadores Econômicos FEE.* (2001) V. 29, N. 1 p 253-292.

Altafini, D; Poloni, F, Meini, B, Bini, D, Cutini, V. Markov-Chain-based centralities and Space Syntax' Angular Analysis: an initial overview and application. In: *Proceedings of the 13th Space Syntax Symposium,* Western Norway University of Applied Sciences (HVL), Bergen, Norway (2022). pp. 522.1-522.21

Altafini, D, Braga, A, Cutini V, Planning sustainable urban-industrial configurations: relations among industrial complexes and the centralities of a regional continuum. In: *International Planning Studies*, (2021) DOI:10.1080/13563475.2021.1875810, pp. 1-21.

Cutini, V. The city when it trembles. Earthquake destructions, post-earthquake reconstruction and grid configuration. In: Kim, Y. O., Park, H. T., Seo, K. W. (eds), *Proceedings of the 9th International Space Syntax*, Seoul: Sejong University. (2013)

Cutini, V., Di Pinto V. On the slopes of Vesuvius: Configuration as a thread between hazard and opportunity, Proceedings of the 10th International Space Syntax Symposium, London, University College of London. (2015).

Cutini, V.; Falco, A.; Giuliani, F. Urban grid and Seismic Prevention: a configurational approach to the emergency managemenof italian historic centres. *12th International Space Syntax Symposum,* Beijing Jiaotong University (2019), http://www.12sssbeijing.com/upload/file/1562668710.pdf

Cutini, V.; Pezzica, C. Street network resilience put to test: the dramtic crash of Genoa and Bologna bridges, *Sustainability* (2020) 12, 4706 doi: 103390/su12114706

depthmapX development team. (2018). depthmapX (Version 0.8.0) [Computer software]. Retrieved from https://github.com/SpaceGroupUCL/depthmapX/

Esposito, A. and Di Pinto, V. (2014) "Urban Resilience and Risk Assessment: How Urban Layout Affects Flood Risk in the City" In *2014 14th International Conference on Computational Science and Its Applications (ICCSA)* (pp. 204-207). IEEE Computer Society.

Esposito A. and De Pinto V. (2015). Calm after the storm: The configurational approach to manage flood risk in river cities. Proceedings of the 10th International Space Syntax Symposium, London.

Fakhrurrazi, F., & Van Nes, A. (2012). Space and panic: the application of space syntax to understand the relationship between mortality rates and spatial configuration in Banda Aceh during the tsunami 2004. In *Proceedings of the 8th International Space Syntax Symposium, January 3-6, 2012, Santiago de Chile, Chile. Editors: Greene, M., Reyes, J., Castro, A.*. PUC.

_______, Guaíba registra a segunda maior cheia da história no RS, *G1 RS,* October 17, 2015. https://g1.globo.com/rs/rio-grande-do-sul/noticia/2015/10/nivel-do-guaiba-atinge-recorde-e-mantem-estado-de-alerta-no-rs.html (Accessed January 10, 2023)

Gil, J. and Steinbach, P. (2008) From flood risk to indirect flood impact: evaluation of street network performance for effective management, response and repair. *WIT Transactions on Ecology and the Environment*, volume *118*, pp.335-344. DOI 10.2495/FRIAR080321

SEMARS - Governo do RS *Bacias hidrográficas do Rio Grande do Sul*, Secretaria de Meio-Ambiente e Infraestrutura do Estado Rio Grande do Sul, (2020) https://sema.rs.gov.br (accessed in January 18, 2023)

Hillier, B., Iida, S. Network and psychological effects in urban movement. In: *Spatial Information Iheory* (2005) (pp. 475-490). Springer Berlin Heidelberg.

Hillier, B., Yang, T., and Turner, A. Normalising least angle choice in Depthmap-and how it opens up new perspectives on the global and local analysis of city space. *Journal of Space Syntax* (2012), 3(2), 155-193.

Hillier, B. Spatial sustainability in cities: Organic patterns and sustainable forms. In: Koch, D., Marcus, L. and Steen, J. (eds.), P*roceedings of the 7th International Space Syntax* (2009), Stockholm: Royal Institute of Technology, p.K01.1-K01.20

Hillier, B, Hanson, J. The social logic of space. Cambridge University Press, (1989).

Giuliani, F., De Falco, A., Cutini, V. and Di Sivo, M., A simplified methodology for risk analysis of historic centers: the world heritage site of San Gimignano, Italy*, International Journal of Disaster Resilience in the Built Environment*, (2021) Vol. 12 No. 3, pp. 336-354. https://doi.org/10.1108/IJDRBE-04-2020-0029

Huq, M.E. *et al.* (2020). Measuring vulnerability to environmental hazards: qualitative to quantitative, Environment, Springer, https://doi.org/10.1007/978-3-030-49732-3_17

IBGE (2002). «Área territorial oficial». Resolução da Presidência do IBGE de nº 5 (R.PR-5/02).

IBGE (2013) Bacias e divisões hidrográficas do Brasil. https://biblioteca.ibge.gov.br/visualizacao/livros/liv101854.pdf

IBGE, *Pesquisa Nacional por Amostra de Domicílios Contínua* (2019) https://www.ibge.gov.br/estatisticas/sociais/trabalho/9171-pesquisa-nacional-por-amostra-de-domicilios-continua-mensal.html?=&t=microdados (Accessed in 18 January, 2023)

IBGE, *Pesquisa Nacional por Amostra de Domicílios Contínua* (2020) https://www.ibge.gov.br/estatisticas/sociais/trabalho/9171-pesquisa-nacional-por-amostra-de-domicilios-continua-mensal.html?=&t=microdados (Accessed in 18 January, 2023)

IBGE, *Pesquisa Nacional por Amostra de Domicílios Contínua* (2021) https://www.ibge.gov.br/estatisticas/sociais/trabalho/9171-pesquisa-nacional-por-amostra-de-domicilios-continua-mensal.html?=&t=microdados (Accessed in 18 January, 2023)

IPEA (2015) "Governança Metropolitana no Brasil – Região Metropolitana de Porto Alegre" © *Instituto de Pesquisa Econômica Aplicada, Rio de Janeiro*

Lima, L. *Mapeamento da sucetibilidade à inundação na bacia hidrográfica do Arroio do Salso, Porto Alegre-RS.* (2010). Dissertação (Mestrado) Universidade Federal do Rio Grande do Sul, Instituto de Geociências, Programa de Pós-graduação em Geografia, Porto Alegre, RS.

Lindsey, D. "The embedded periphery: slums, favelas, shantytowns and a new regime of spatial inequality in the modern world-system." In *Routledge Handbook of World-Systems Analysis*, Routledge, 2012 pp. 345-352.

Martins. C. M. R. Texto para discussão 112 - *Caracterização da Região Metropolitana de Porto Alegre*, FEE, 2013 ISSN 1984 5588

Melchiors, L. C., Braga, A.C, Zampieri, F. Campos, H. Reestruturação metropolitana e emergência de centralidades: novos fluxos pendulares e a configuração espacial da

Região Metropolitana de Porto Alegre, *Arquitetura Revista*, (2018) 14(2), p. 187–203. doi: 10.4013/arq.2018.142.08.

MinC; METROPLAN. Estudo de Alternativas e Projetos para minimização do efeito de cheias e estiagens na Bacia do Rio dos Sinos. Plano Nacional de Gestão de Riscos e Respostas a Desastres Urbnaos / *Plano Metropolitano de Proteção contra cheias*, Technical Report (2018a).

MinC; METROPLAN. Estudo de Alternativas e Projetos para minimização do efeito de cheias e estiagens na Bacia do Rio Gravataí. Plano Nacional de Gestão de Riscos e Respostas a Desastres Urbnaos / *Plano Metropolitano de Proteção contra cheias*, Technical Report (2018b).

Müller, Frank I. "Urban informality as a signifier: Performing urban reordering in suburban Rio de Janeiro." *International Sociology* 32, no. 4 (2017): 493-511.

Pezzica, C, Cutini, V, de Souza, (2022) Urban-regional dynamics of street network resilience: the spatial outcomes of Genoa's and Bologna's bridge crashes. *Proceedings of the 13th International Space Syntax*, Western Norway University of Applied Sciences (HVL), Bergen, Norway. pp. 438.1-438.17

Pezzica, C, Cutini, V, de Souza, C. (2021) Mind the gap: state of the art on decision-making related to post-disaster housing assistance. *International Journal of Disaster Risk Reduction* 53, 101975

Pezzica, C.; Cutini, V.; de Souza, C. B (2019) "Rapid Configurational Analysis Using Osm Data: Towards the use of Space Syntax to orient post-disaster decision making" *12th International Space Syntax Symposium Proceedings#147 – Safety emergency,* Beijing Jiaotong University, http://www.12sssbeijing.com/upload/file/1562668571.pdf

QGIS, Białowieża, version 3.22 (2022) Available in: http://www.qgis.org/en/site/index.html

Rusci, S, Altafini, D, Di Pinto, V. Urban Demolition: Application of Blight Elimination Programs and Flood Buyout Programs to the Italian Case. In: *Sustainability* (2021) 13, no. 16: 9412. https://doi.org/10.3390/su13169412

Turner, A. Stitching Together the Fabric of Space and Society: An Investigation into the Linkage of the Local to Regional Continuum, in: Koch, D; Marcus, L; Steen, J. (Ed.), *Proceedings of the 7th International Space Syntax Symposium*. (2009) KTH, Stockholm, pp. 1–12.

Turner, A. From axial to road-centre lines: A new representation for space syntax and a new model of route choice for transport network analysis. *Environment and Planning B* (2007). 34, 539–555. https://doi.org/10.1068/b32067

Mapping urban flood-prone areas spatial structure and their tendencies of change: a network study for Brazil's Porto Alegre Metropolitan Region.

ABSTRACT

Historically, the main cause of urban disasters in Brazil are flooding events, which are becoming more recurrent due to climate changes and intensive urbanization, causing extensive infrastructure, economic and life losses. Brazilian Metropolitan Areas formation goes back to the early 20th century, with urban expansion following river-basins, as regional transportation relied on inland navigation. The transition to road-based transport structured further urban sprawl from the mid-20th century onwards, as road-circulation axes expanded across flood-prone areas. Mapping those hydrogeological risks is important to understand their effect on the existent road-circulation network structure cohesiveness. From the hydrogeological risk assessment data, this paper evaluates potential changes imposed by extreme flood-events on the road-infrastructure at municipal and metropolitan scales. Space Syntax methods applied to an empirical case – the Porto Alegre Metropolitan Region (PAMR) – allow for comparative analyses between urban network of current and flooding-event simulations and depict a) the urban grids´ structural transformations under flooding; b) the road-elements at risk; c) the system's spatial integrity and circulation disruptions. The resulting cartography can subside governance and urban planning strategies to cope with floodings at different territorial scales, addressing changes on local-regional circulation patterns, system breaking points and tendencies of urban land parcelling on vulnerable areas.

KEYWORDS

Water-floods, risk disaster management, network resilience, metropolitan areas, iconographic data

1. Introduction

Throughout history, Brazilian urban settlements' formation favoured the proximity to the seacoast and river-basins, given the dependence on maritime and inland fluvial transport routes. Such interdependence lasted well into the early 20th century, defining the ground zero and the expansion pathways for several *Brazilian Metropolitan Areas* (BMA). Even if the early port towns have gradually expanded inland during the 20th century, their urban development was still bound to the waterfronts. From 1940s on-rail and, above all, road-bound transport surpassed other transportation modes at local, regional, and national scales. This aspect becomes evident after 1950s development policies that incentivised the automotive industry and motor-based transport across Brazil. The process culminates in the 1960s, following the construction of Brasilia, the new capital city in the centre of the national territory, only accessible through road transportation, with a design focused mainly on car traffic. The fast and often unguided urban sprawl that followed the road system expansions required novel regulations, given the cities' changing patterns of territorial occupation, where regional road systems acted as growth vectors for urban peripheries. In that vein, the Complementary Federal Law nº 14, (June, the 8th 1973) mandates the creation of the first seven *Brazilian Metropolitan Areas or Regions*, including *the Porto Alegre Metropolitan Region* (PAMR) composed by 14 municipalities. Back then, Porto Alegre was the third largest Brazilian Capital city, a major industrial centre, its economic importance only surpassed by São Paulo and Rio de Janeiro, and a reference in terms of services for the South Region (Alonso, 2001). Due to the exponential urbanization of the country, nowadays there are 74 BMAs (2022 data), that strongly differ in territorial area, population size and functional composition. Although more evenly distributed within the national territory, the main BMAs stand noticeably on the South and Southeast regions (Figure 1).

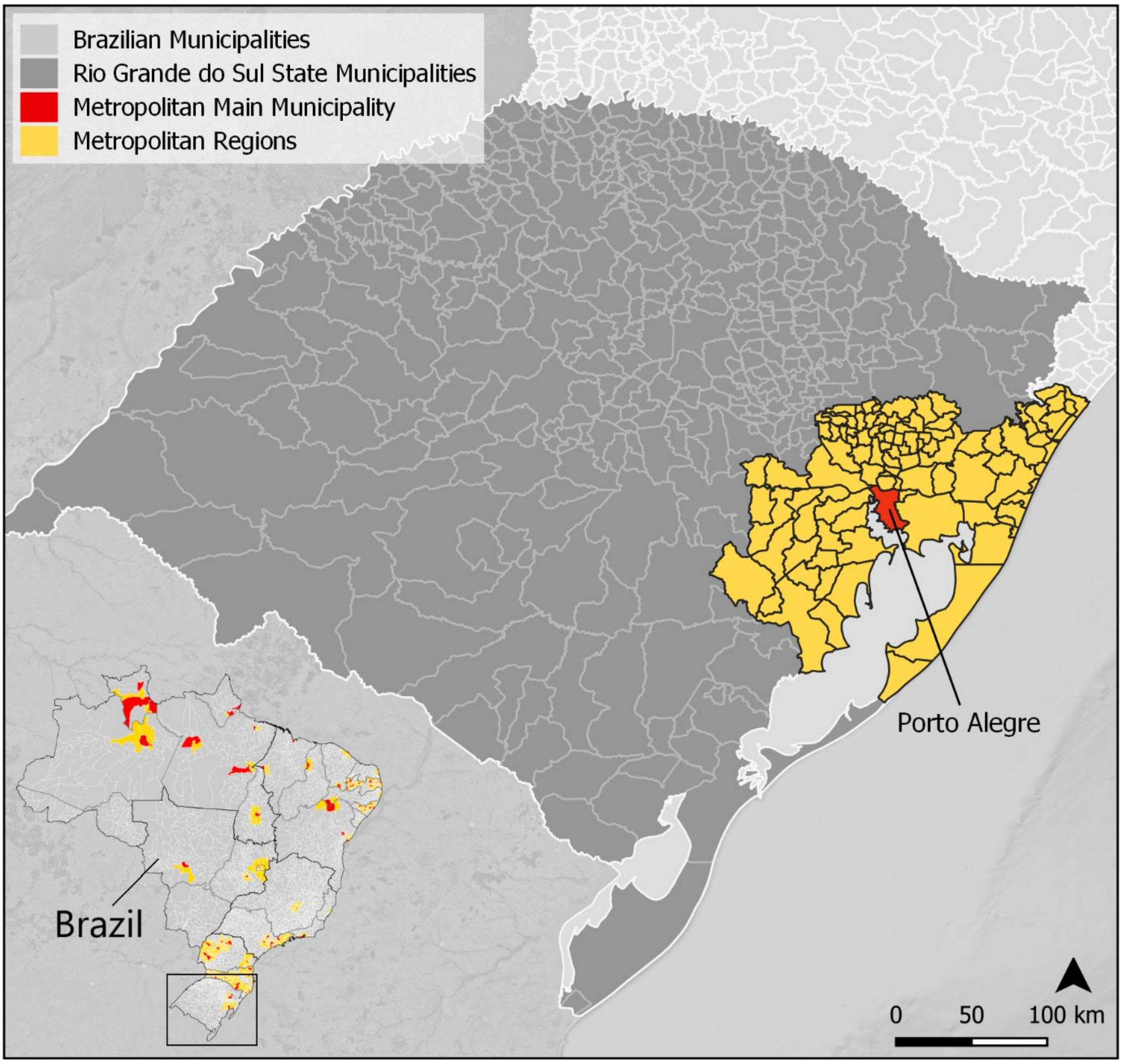

Figure 1. Brazil, Brazilian Metropolitan Regions (2015), and Porto Alegre's Metropolitan Region current development (2022)

Even after a period of severe economic decline and deindustrialization during the 1980-1990's (Alonso 2001), the PMAR still figures among the most economically relevant, being the fifth most populated BMA (Table 1) (IBGE 2019; 2020; 2021)

Table 1: Brazilian Metropolitan Areas ranking according to total population

Position	Metropolitan Area (BMA)	State	Population
1	São Paulo Metropolitan Region	São Paulo	21,734,682
2	Rio de Janeiro Metropolitan Region	Rio de Janeiro	12,763,459
3	Belo Horizonte Metropolitan Region	Minas Gerais	5,961,895
4	Federal District and Adjoining States Integrated Development Region	Distrito Federal Goiás Minas Gerais	4,627,771
5	Porto Alegre Metropolitan Region	Rio Grande do Sul	4,340,733

Despite the normative governance (Brasil, 2001), the BMAs still undergo through informal and unregulated urbanization processes, characteristic of the ongoing Brazilian urban expansion. Marked by fragmentation, discontinuity, and an uneven infrastructure distribution, these expansions relate to irregular land parcelling that, more than often, rely on peripheral, low-cost land use (Lindsay, 2012) as much as on "slumming" or "favelization" (Muller, 2017), adjacent to the main mobility axes spanning from the metropolitan core. Informal land developments remain a main source of BMAs issues, being nowadays close to the norm among low-income populations, considering the scarce availability of affordable housing. Beyond the social inequalities and the socioeconomic unevenness that results from – and causes – informal occupation within the cities' land leftovers, those areas, due to the absence of planning and building regulation, also remain rather prone to natural disasters.

Seasonal flooding is one of those recurrent disasters, being a common risk in Brazil given the tropical climate and the territorial conditions associated to historical characteristics of urban expansion along river-basins and valleys. In effect, among natural hazards, seasonal flooding is the main urban disaster cause in the country, affecting almost 40% of Brazilian municipalities and 30% of its urban network (IBGE, 2013). Such disasters relate to recurrent road-circulation infrastructure collapses, homelessness due to the loss of housing in the affected areas, significant public, and private financial losses, and a high loss of life. Vulnerability to environmental hazards (Huq et al., 2020) became one of the main concerns for municipal and metropolitan regions management administration, since their impacts on citizen´s lives, public infrastructure and economic development lay at the core of several long-term planning problems. From the 2000's onwards, the *Agenda 21's Sustainable Development Objectives (SDO) and Disasters Risk Management (DRM)* actions underline metropolitan planning goals in Brazil (IPEA, 2015). Hence, integrating the urban sprawl into water-basins management became a governmental priority, that must be enforced, above all, in novel urban development guidelines for projects' approval and land-parcelling policies.

In that aspect, addressing seasonal flooding risks requires the incorporation of mapped data into public planning tools and policies. Information regarding the radical changes in spatial configuration related to water-floods is one of the most important variables that enable the assessment of the fragility and vulnerability levels of urban agglomerates, communities, and infrastructures under disaster risk. This cartographical effort targets the infrastructure problems related to mobility and accessibility at local and regional scales, with emphasis on system cohesiveness. The primary goal should be understanding how such changes can undermine accessibility and mobility patterns within metropolitan circulation networks, resulting in damage to commuting and transportation systems and, more importantly, leaving the population cut off from crucial services and urban facilities such as hospitals and supply-services. Therefore, cartographic comparisons of current and

simulated situations provide insights into a disaster event potential outcome and their impact degrees on city life.
Considering these issues, the paper conducts and experiment in mapping and outlining flooding impacts on the road-circulation networks at local and metropolitan scales, drawing from a cutout of the Porto Alegre's Metropolitan Region (PAMR) as a case study. The changes in *relative accessibility* and on the *preferential routes'* structure within the urbanized area allows to identify potential choke points within flood-prone areas. This analysis provides a direct overview of the spatial system´s changes under flooding conditions, being easily interpretable even when exclusively accessed through its iconography. Therefore, it can be a support instrument associated to variables used in risk analysis, since the spatial configuration or the circulation network topological structure unveils robust relations to recurrent urban impacts intertwined to social and economic dynamics within metropolitan areas. The cartographic challenge is modelling and merging two different data sets while performing a bi-variable comparative analysis which is context dependent, that is: under stable weather conditions and under a flooding event.
The spatial modelling combines the configurational component, based on Space Syntax' Network Analysis (Angular Segment Analysis - ASA) with a risk assessment spatial analysis based on river basin hydrogeological risk area. The water-flood patch perimeter informs the areas under flood risk within urbanized limits, as well as identify the areas with a higher propensity of minor events. Moreover, the road-circulation network comparative analysis made through ASA, enables to verify: a) the current metropolitan road-circulation network configuration relative accessibility and preferential routes system (through, respectively the metrics of Normalized Angular Integration – NAIN and Normalized Angular Choice – NACH); and b) the emergent network configuration after suppressing the urban grids' segments that could be affected by flooding events.
The discussion and conclusion drawn from Porto Alegre's Metropolitan Region empirical case, an area recurrently affected by water-floods, demonstrate how the system structure can undergo through a collapse, as the affected mobility routes isolate some areas. Moreover, it shows that the intensive urban sprawl due to the intensification of land parcelling tend to disregard environmental risks; and ponders the public sector planning policies under real estate intensive pressure for housing developments approval within flood risk areas. Conclusions target municipal governments withstanding posture against an inter-federative approach in managing water resources and river basins, despite conforming an essentially regional problem.

1.1 Porto Alegre's Metropolitan Region: a disaster risk contextualization

Porto Alegre's Metropolitan Region - PAMR encompasses a territory of circa 10,346 km² divided across 98 municipalities (Figure 1). In terms of population, the PAMR has more than 4,340,733 inhabitants, with an average population density of circa 419 inhabitants per km² (IBGE, 2013; 2019; 2020; 2021). The metropolitan area spans from the early urban settlements that constituted the colonial ports, occupied throughout the 17th and 19th centuries. In the 17th century, Portuguese colonizers from *Açores* docked on the site where Porto Alegre, the Rio Grande do Sul state capital, is located. In 1824, German colonizers reached the *Rio dos Sinos* banks, place where the São Leopoldo municipality was founded (Martins, 2013). Other port-based and inland settlements were eventually created near to the riverbanks of the *Jacuí, Caí*, and *Gravataí* rivers, that constituted the inland shipping routes and originated the municipalities *of Alvorada, Cachoeirinha, Canoas, Gravataí and Viamão*, bordering Porto Alegre's urban area (Figure 2).

Porto Alegre itself is set on the conjoined delta of these four rivers (*Sinos, Jacuí, Caí*, and *Gravataí*), and eventually has grown to occupy the whole eastern shore of the *Guaiba* – an inland lake formed by these river basins. The *Guaiba Lake* forms a larger water body southwards, connecting to the *Lagoa dos Patos* - the largest South America lagoon. Through it, the rivers reach the Atlantic Sea near the City of Rio Grande (Figure 2). This territorial context – which forms one of the largest and most complex water-basins in the country – constitutes itself as one of the most susceptible areas in Brazil regarding disasters related to seasonal flooding, a risk that is reinforced given its dense territorial occupation (Figure 2).

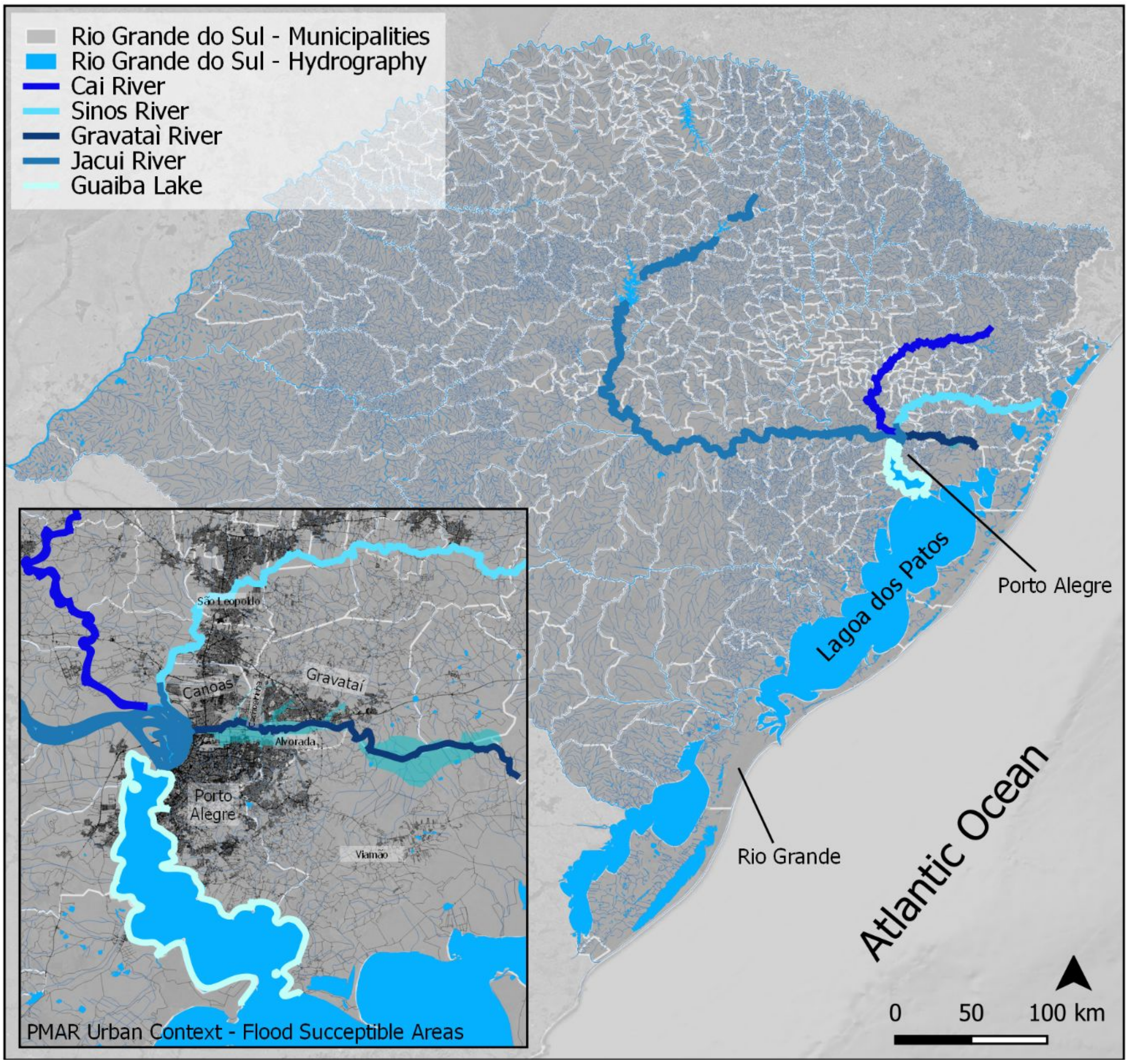

Figure 2. Porto Alegre Metropolitan Region – PAMR – urbanisation intensity; cut-out and river basins water-flood risk areas (IPEA, 2015; Melchior et al., 2018; IBGE, 2013; SEMARS, 2020).

Porto Alegre, the metropolitan core, has an urbanization index of over 82% and hosts circa 35% of the metropolitan population (almost 1.5 million inhabitants). The bordering municipalities of *Alvorada Canoas, Cachoeirinha, Gravataí* and *Viamão* constitute together, another continuous urbanized and densely populated area, with circa 42.5% of the metropolitan population distributed across five municipalities (Table 2).

Table 2: Municipalities cutout data on population, area and river basin attribution*

Municipality	Founding/ PAMR	Pop. (total)	Area (km^2)	Density (pop/km^2)	Urbanization and Urban Land-Use Increase (2000-15)	River Basin Attribution
Alvorada	1965/1973	211.352	71,6	2.949,09	100 % + 16%	Gravataí
Cachoeirinha	1965/1973	131.240	43,8	2.997,03	100 % +19.3%	Gravataí, Sinos
Canoas	1939/1973	348.208	130,8	2.662,04	99,86% +24.8%	Gravataí, Sinos, Guaíba
Gravataí	1880/1973	283.620	462,07	613,00	93,87% +18.41%	Gravataí, Sinos
Porto Alegre	1809/1973	1.48.252	495,04	3.004,2	82,15% +14.3%	Gravataí, Jacuí, Guaiba

*data from Martins (2013); IBGE (2003, 2021); SEMARS (2015); Mengue, et. Al. (2017).

From 1960 onwards, the road-based transportation assumed a main role in Brazilian urbanization patterns as highways – both national and regional – guided the urban expansions (Figure 3). An example of this dynamic can be observed in the BR-116, the longest motorway in the country (4.542 km), extending from Brazil-Uruguay border in the *Rio Grande do Sul* State towards the northeast, to reach the State of *Ceará*.
The motorway becomes a main urban avenue in several points. In *Porto Alegre*, it structures the city's central and north areas, establishing connections to the municipalities located in the PAMR's north such as *Canoas* and *São Leopoldo*, being also part of these cities main urban road-circulation systems. Upon construction, several motorways such the RS-030 (Porto Alegre – Atlantic Coast) and the BR-290 (Brazil – Argentina) became highly demanded axes both for intra and extra metropolitan circulation, effectively structuring Porto Alegre mobility system, and its connection to the neighbouring cities (Figure 3).
In the late 1990s, this already dense metropolitan highway system was expanded further, upon the creation of a regional ring road (RS-118) connecting the north-south axis (BR-116) to the east-west axis (BR-290; RS-040) through the municipalities of *Gravataí, Alvorada* and *Viamão*. By the end of 2010's, the BR-448 was another addition to this road-system. This motorway connects *Porto Alegre* to *Canoas* and, further, crossing the *Vale do Rio dos Sinos* region (*São Leopoldo*), being alternative route to the saturated BR-116 (Figure 3). Those roads and motorways define both the boundaries and the urban expansion axes of growth, densification, and intensive conurbation within the PAMR. Several of these motorways – namely the BR-116; the BR 290, the RS-118, and the RS-448 – cross or lay in the immediate vicinity of the *Sinos* and *Gravataí* rivers (Figure 3), which enhances the vulnerability of these routes to seasonal flooding. In specific, the motorways crossing the *Gravataí* River (BR-116; RS-118 and the accesses to the BR-290) at greater flooding risk due to the area topography – lowlands and plains below sea level.

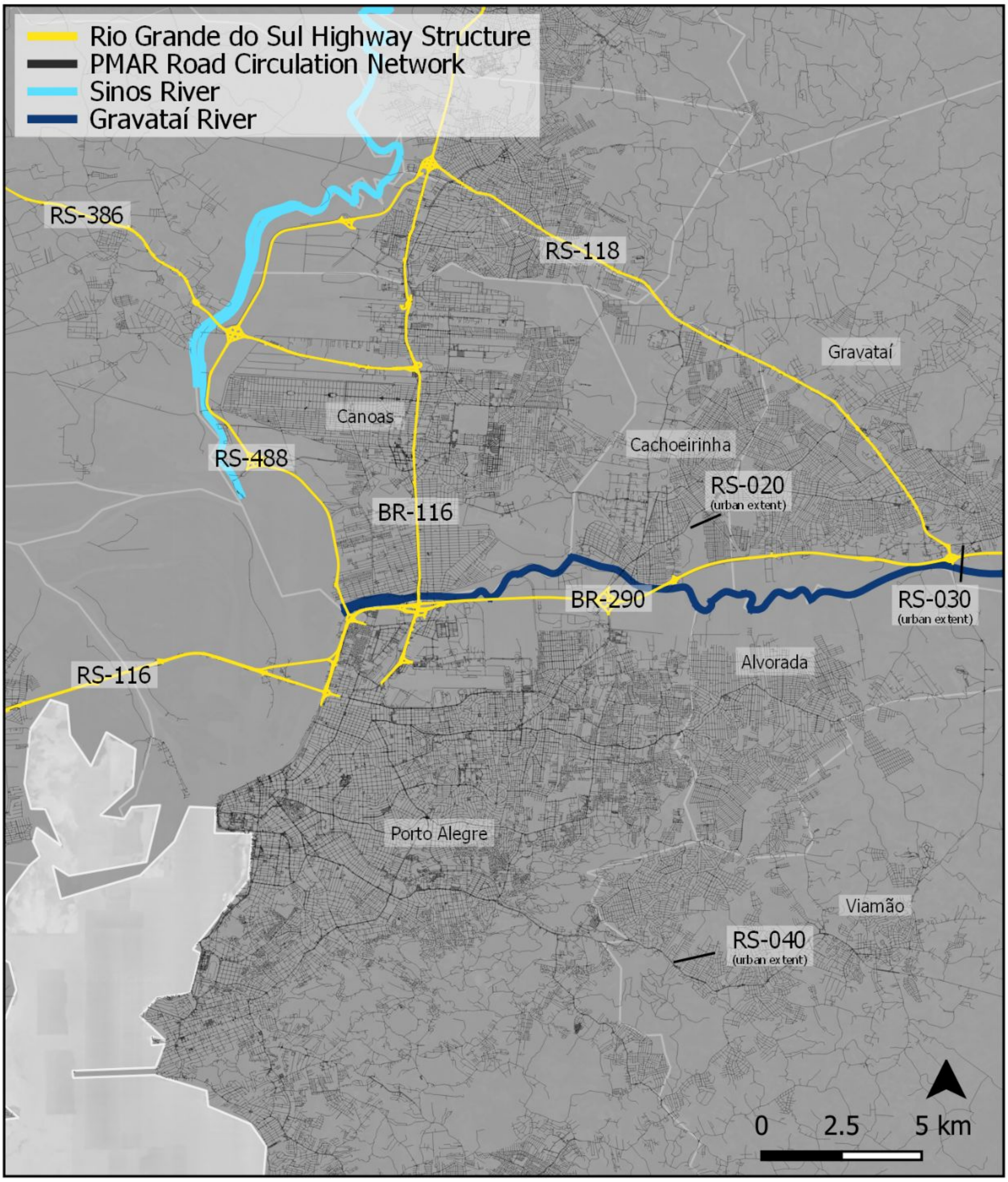

Figure 3. Porto Alegre Metropolitan Region – PAMR – urbanisation intensity, road-circulation network, and highway context

The latest National Census (IBGE, 2021) identified that *Porto Alegre* has more than 3,205 dwellings and average 10,706 inhabitants under permanent water-flood risk. Historically, the city has undergone severe flooding events, registered in 1941, 1956, 1967, 1983, 2015 and 2017 (Lima, 2010, G1 RS, 2015). Since its urban core is close to the Guaíba's delta, this area was object of several water management and risk mitigation projects (Federal Government's Department for Sanitation Works) from 1940 to 1990, such as the construction of "retaining walls" between the centre and the port.

Even so, there were no further studies on these river basins flooding probabilities between 1990 and 2015. This period coincides with PAMR's intensive built-stock and urbanised areas expansion (Lima, 2010; Pedroso, 2019; see also Figure 5, p.9).
In 2015, the Metropolitan Governance institution – METROPLAN – signed a three-year contract to perform hydrogeological surveys, comprising several technical reports on the river basins conditions (MinC; METROPLAN, 2018a and MinC; METROPLAN, 2018b). The datasets were publicly available in 2021, determining the flood-prone patches extent. For this analysis, the cutout depicts the main flood-prone area within the PAMR, extending throughout its most densely populated area. It encompasses the Northern Planning Regions of *Porto Alegre* and the entirety of *Canoas, Gravataí, Cachoeirinha* and *Alvorada* municipalities (Figure 4). *Viamão* was not included despite its large flood-prone patch since it affects non-urban areas.

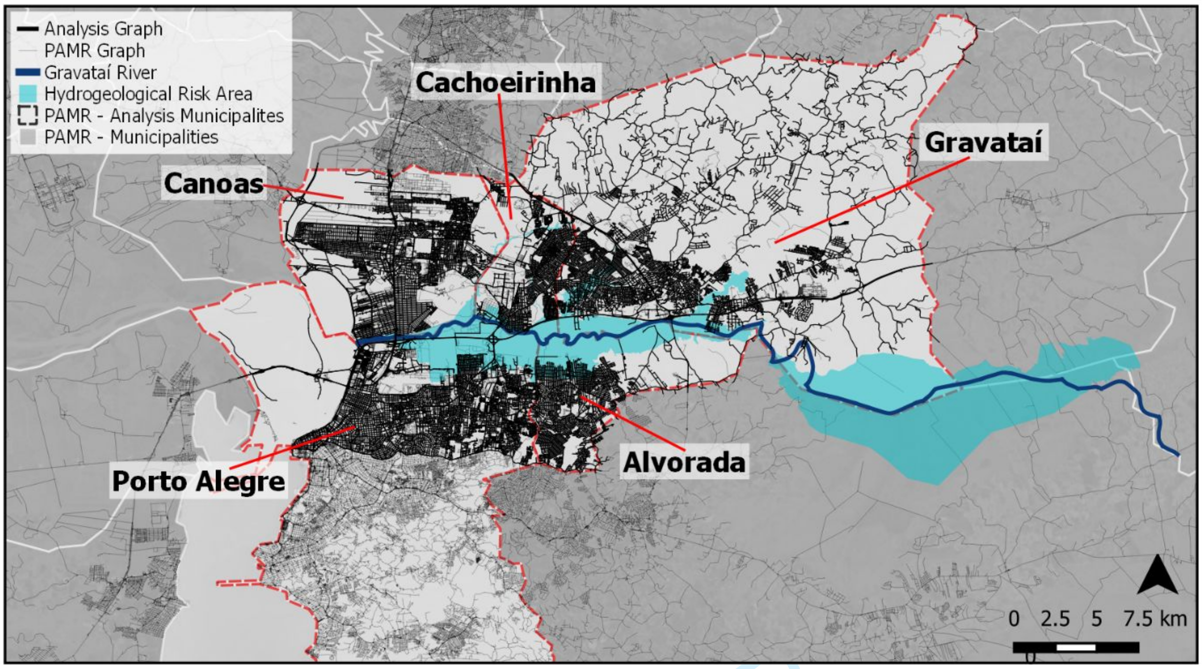

Figure 4. Porto Alegre Metropolitan Region – PAMR – Analysis area comprising the *Gravataí* river flooding plains.

In partnership with METROPLAN's Urban and Regional Planning Division, Mengue et.al (2017) developed a geospatial database on land-parcelling that provides a historical series describing the location and size of urban development plots approved by municipal governments from 1977 to 2022 (Figure 5).
This database indicates that a total of 1146 developments were approved in the period for the analysed municipalities. From this total, 977 are set within the analysis area (Figure 4), corresponding to a coverage of 276,4 km^2. 163 developments (16,6%) are set within the hydrogeological risk area boundaries, however, those cover 125,1 km^2 or 45,2% of the total land parcellings area, demonstrating that, while not numerous, these developments tend to be large (Figure 5a). Considering the 163 developments year of approval (Figure 5b), it can be observed that many land parcellings within the risk areas were approved in the last two decades (68), with most in the period from 2010-2022 (43). This demonstrates that, while studies were conducted in the period, proving that the designated areas would be under severe hydrogeological risk, the intense market forces behind the widespread real-estate urban expansion in Brazil continue to surpass territorial governance, especially those set at metropolitan scale.

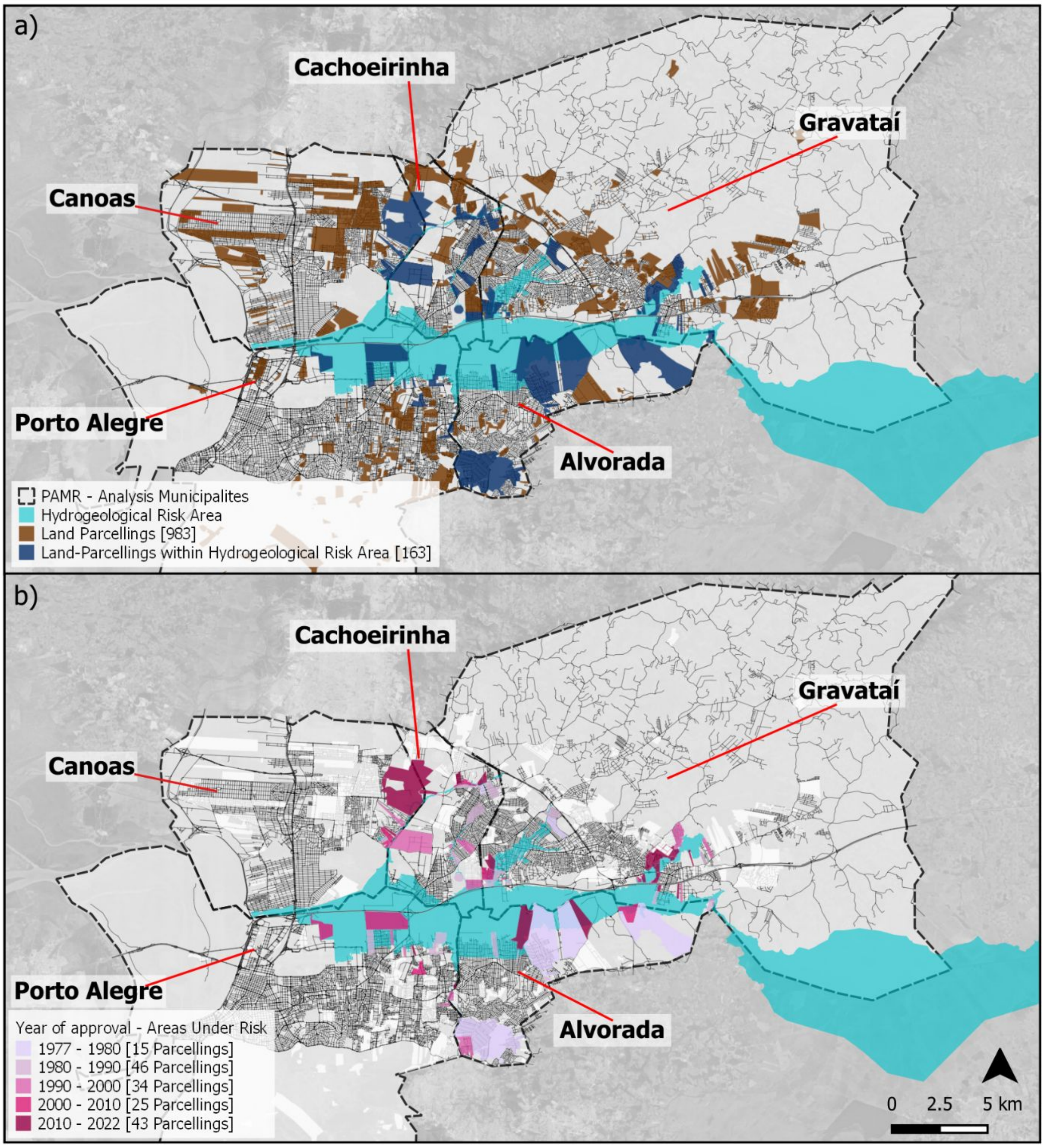

Figure 5. PMAR analysis area land parcellings' distribution with a) land parcellings within the hydrogeological risk area; b) year of approval for the land parcellings under risk.

Based on these conditions and territorial delimitation, it was possible to discuss the effects of future floods in the road-network. This provided a comparative framework to analyse, aided by Space Syntax theory and methodology, the post-disaster configuration and spatial system resilience, pinpointing potential collapsed linkages within the PAMR.

1.2 Disaster-risk management and the Space Syntax network approach.

Space Syntax, despite being originally conceived as an architecture-based theory to address the social aspects that emerged from the urban networks' configuration (Hillier & Hanson, 1989), intertwines profoundly to disaster-risk management.
In the last 10 years, its models were applied in several pre-and-post-disaster-risk analysis to outline issues related to configurational effects of road-circulation networks' collapses and emergency infrastructure positioning tendencies in urban and regional areas, themes that were explored in-depth by a plethora of authors such as: Cutini & Di Pinto, 2010; Fakhrurrazi & Van Nes, 2012; Cutini, 2013; Esposito & Di Pinto, 2014; 2015; Cutini, et al., 2019; Guiliani et al., 2021; Rusci et al. 2021; Pezzica et. al, 2019; 2021. Recent contributions, however, shifted towards addressing the spatial system structure resilience towards abrupt changes (Pezzica et. al, 2022; Altafini et. al, 2022), striving to identify the most vulnerable road-elements on the road-circulation network or the ones that undermine its overall structure. Space Syntax techniques therefore enable the evaluation of road-network structures in both intact and disrupted systems, allowing comparative analyses and alternative scenarios that can aid in the mitigation of the adverse impacts of natural disasters, such as seasonal floods. Gil & Steinbach (2008) stated that floods can have a serious impact on transport networks, stressing that disruptions on different road-elements in the network can propagate and affect movement potentials far away from the critical points, what is utmost to address in mobility planning. That is, a flood event can give emergence to a different spatial configuration, what changes mobility and accessibility patterns and even destabilises the system through traffic congestion or closures. Abshirini & Koch (2017) findings on spatial system resilience – here defined as the degree to which a city retains the same segments forming the foreground network before and after a disturbance – endorse Gil & Steinbach (2008), as interruptions can create archipelago-style configurations (sparsely connected or completely disconnected to the rest of the system), which in turn weakens accessibility, characteristic of Brazilian urbanization, tending to collapse under flooding. In this paper, these directives are followed to analyse and discuss the results for the Porto Alegre Metropolitan Region – PAMR - proposed cutout. Nevertheless, this approach resumes into a preliminary evaluation of the phenomena through Angular Segment Analysis (ASA) to instruct the risk-based analysis according to major changes tendencies in accessibility patterns (Cutini et. al 2019).

2. Datasets and Methods

2.1 The Space Syntax modelling approach – methods used for the network analysis.

Recent methodological developments in Space Syntax Angular Segment Analyses (ASA) proved themselves efficient in analysing urban-regional spatial configuration regarding disaster risk management (Hillier & Iida 2005; Hillier, 2019).
Current ASA methods draw from on road-circulation network graphs for which Road-Centre Lines (RCL) segments (road-elements) represent the network nodes and arches (Turner 2007). In Space Syntax, differently from the traditional graph theory approach, arches (road-elements) are interpreted as nodes, meaning that the Space Syntax metrics' values are referent to the road-element, not to the graph junction or connections. Thus, the models' iconography displays an accurate depiction of the urban structure (Figure 6).

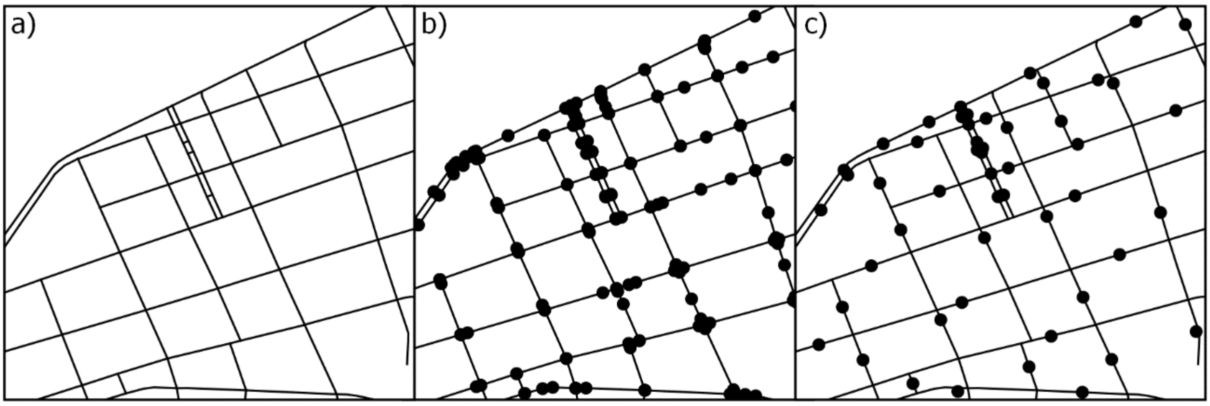

Figure 6. a) Road-Centre Line Graph; b) Traditional Graph Theory Approach (road-element as arches); c) Space Syntax Approach (road-element as nodes).

The application of different network centrality metrics to the same network – or Multiple Centrality Assessment (MCA) – is a methodology of quantitative spatial analysis that highlight different network properties, allowing to understand potential movement patterns on an urban structure – metric distance (a link attribute assumed as impedance), or topological distance (highlights hierarchical relations between elements). Space Syntax ASA works with two main network measures, derived from graph theory metrics: the *Angular Integration* and the *Angular Choice*, whose properties are described in Table 3. In Space Syntax, normalising ASA metrics (*Angular Integration and Angular Choice*) is a crucial step for comparing urban systems with different depths (Hillier et. al, 2012) or sizes (in number of segments). Normalized Angular Integration (NAIN) is a *closeness centrality* mathematical approximation and depicts *relative accessibility* – or the topological proximity to other segments, therefore informing which spaces people tend to converge to under disaster events. Normalized Angular Choice (NACH), instead, is a mathematical approximation of *betweenness centralities*, therefore shortest paths with higher probability of travelling within the system, which consists of road-elements that are important for connections between urban areas, and, if interrupted, can collapse the system; it depict escape routes as well as the alternative ones under exceptional conditions. .

Table 3: Space Syntax ASA metrics – Angular Integration and Choice

Space Syntax	**Graph Theory**	**Formula Graph Theory**	**Formula Space Syntax (normalized)**	**Concept**
Integration (*int.*)	*Closeness Centrality*	$C(x) = \frac{1}{\sum_y d(x,y)}$	$NAIN = \frac{n^{1.2}}{ATD_\alpha^\ell(x)}$	Depicts *relative accessibility* – or the topological proximity of one road-element to all other road-elements
Choice (ch.)	*Betweenness centrality*	$C_B(v) = \sum_{s \neq v \neq t \in V} \frac{\sigma_{st}(}{\sigma_s}$	$NACH = \frac{Log(ACh_\alpha^\ell(x}{log(ATD_\alpha^\ell(x}$	Indicates the *preferential routes* – or the most travelled paths probability within the system, given the shortest path between a road-element and all other road-elements

Normalising these centrality measures incorporates this impedance and this topological hierarchy (depth), suppressing the necessity to perform metric pondered modelling to compare changing effects on urban grids at different scales. In a scenario of occupation removal or different degrees of areas´ insulation, due to floods in watershed areas, these models depict changes on road-network hierarchies, within different territorial frames, forecasting potential impacts on metropolitan mobility and local accessibility. Alongside, a topological approach highlights the elements which are "most important" elements to preserve/maintain the network integrity, given its global structure overall connectivity hierarchy on the global structure.
The modelling of NAIN and NACH for the PAMR proposed cutouts, draw from a topological approach on DepthMapX 0.8 (2018) to identify the hierarchical position of each road element on the global structure. Resulting data maps are spatialized on a GIS-based environment (QGIS, 2022), where the flooding patch is superimposed, to establish a before-and-after scenario, in which the Road-Centre Line system is processed at its current state, and without the elements encompassed within the water-flood patch, providing the tools that enable a comparative analysis of its current condition and under flooding. Statistical results iconography allows the visualization of the hierarchical changes under these two different circumstances, useful in informing large multidisciplinary responsive team works and support decision making regarding potential impacts of new land development projects on the circulation network.

2.1 Methodological proceedings for constructing the graph datasets and modelling PAMR flood-risk areas.

The PAMR road network, extracted from an OSM database (OpenStreetMap, 2021), encompasses the totality of *Gravataí, Cachoerinha, Alvorada* and *Canoas* municipalities´ continuous urban grids (Figure 4). *Porto Alegre,* however, has its urban grid reduced to the *northern planning regions* at the margins of the *Gravataí* river basin, as those areas are the most affected by flooding risks. Due to radical differences in urbanization patterns between *Porto Alegre's* North and South (Figure 3), the usage of the whole network graph for this localized analysis could lead to a biasing of the North's *relative accessibility measure*, especially upon the proposed simulation system restrictions. Hence, the empirical study area limits for *Porto Alegre* is set on two important urban avenues: the *Castello Branco* Avenue (N), part of the BR-116 which directly links to the BR-290; and the *Protásio Alves* Avenue, which establishes a ring-road between the *Castello Branco* Avenue at *Porto Alegre's* centre, the *Alvorada* municipality (E) and the RS-118 connection (Figures 3; 4).
On a GIS platform (QGIS, 2020), the flood-patch is extracted from MinC and METROPLAN (2018a; 2018b) historic and overlaid to the road-circulation network cutout. Furthermore, the road-network under flood-risk was removed through symmetrical difference, according to terrain topography. Therefore, highways that are built above flood-prone levels remained unaffected by the water-flood patch. In the same manner, bridges, overpasses, and access roads built to keep the road-infrastructure above flood-prone waterlines were also maintained, whereas removing the bridges, overpasses, and access roads that are susceptible to interruption by flooding.
The first map (Figure 7.a) comprises the current state of the road-circulation network, without flood-related interruptions, while the second (Figure 7.b) removes the flooded elements from the system. Through these maps (Figure 7), it is possible to attest the complete disconnection of *Alvorada* municipality from the rest of the urban agglomerate

and its partition into two distinct continuous spatial elements, which were modelled independently.
Road-circulation networks graphs are constructed on QGIS (2022) shapefiles (*.shp) and exported as vector drawings (*.dxf) to *DepthmapX 0.8* (2018). In this software, NAIN and NACH measures are modelled exclusively for radius *n*, the whole system, since the main objective is to address the urban-regional road-circulation network changes under flooding-events. *DepthmapX* 0.8 analysis results are then exported as *Mapinfo* files to QGIS and converted once again into shapefiles (.shp). On QGIS, a quartile range for NAIN and NACH was established to analyse the system´s movement pattern changes. This highlights only 10% of the total number of elements with highest NAIN and NACH measures – depicting both, the integration cores of *relative accessibility* and the *preferential routes* system.

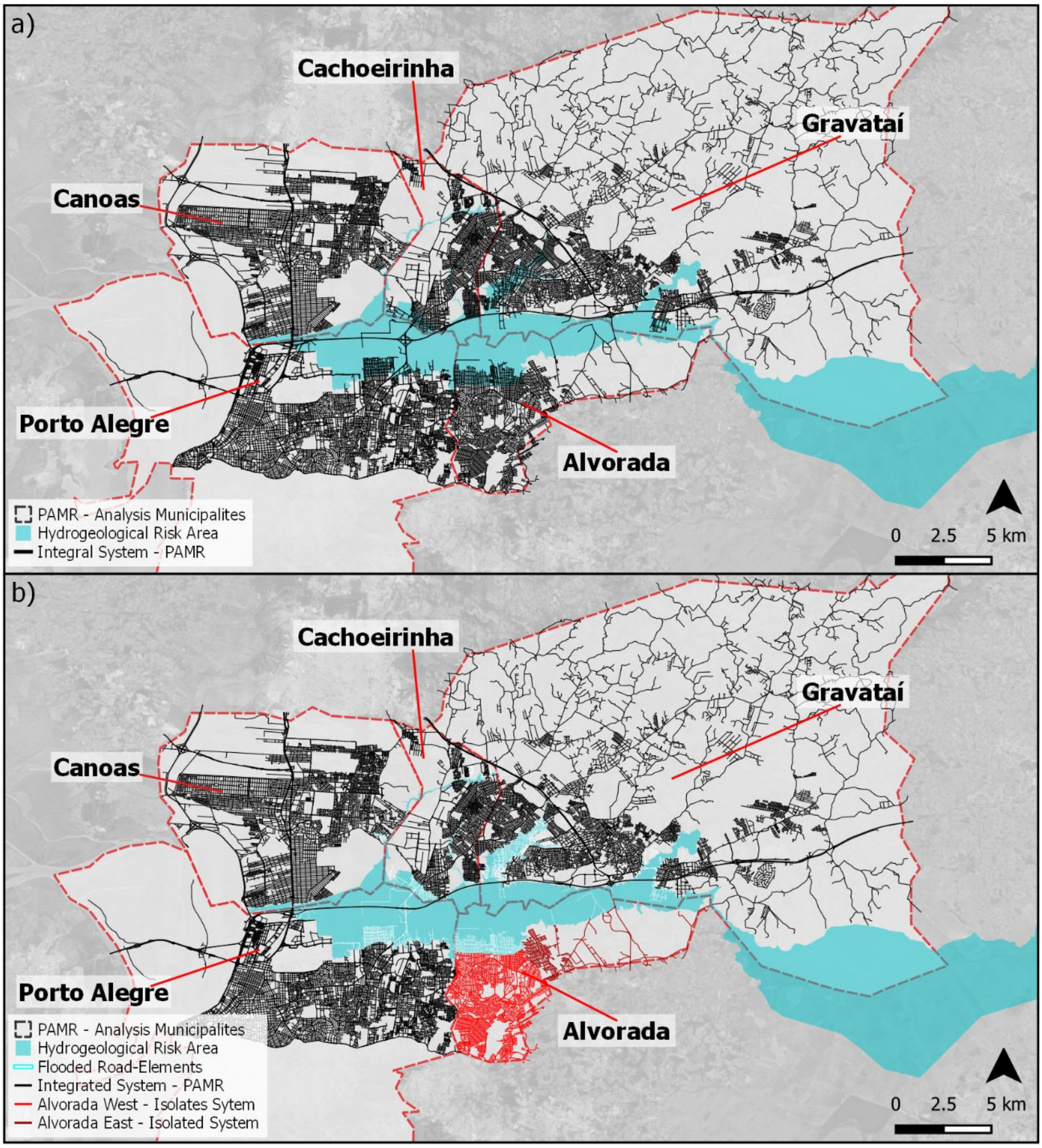

Figure 7. PAMR cut-out road-graph a) integral system b) system configuration without road-elements within the hydrogeological risk area.

3. Results and Discussion – mapping the flooding effects on the road-circulation network.

Simulation results in terms of *relative accessibility* (NAIN - Rn) and *preferential routes* (NACH - Rn) (Figures 8-15) demonstrate that seasonal flooding events have potential to cause important changes within the PAMR road-circulation network and in the movement potentials structure.

The comparison between the network structure in the integral and simulated models attest that the disaster affected systems tend to conserve most of its structure, as the "integral part" of the network is reduced only in circa 15% (22,421 to 18,896 road-elements) (Figure 7b.). From these, just 5% (1,301) are actual flooded elements, whereas the rest pertains to the *Alvorada's* systems, that remain disconnected from the integral network. While small in number, the flooded elements cause a significant reorganization of the internal movement potentials within *Porto Alegre's* urban core, and in the PAMR conditions of *relative accessibility* as a whole (Figures 8; 9 and Table 4). The simulation reveals that the most important road-circulation network elements – *Castello Branco Avenue* and the highways connecting *Porto Alegre* to *Canoas, Cachoeirinha* and *Gravataí* – remain stable, given that they are built above the flood-prone waterline. This means that manmade terrain elevations on highways and in its connections (bridges, overpasses, etc.) effectively protect the regional road-circulation network core, and from that standpoint, assure a certain degree of resilience and *accessibility robustness* to the system.

Nevertheless, results reveal that certain overpasses and access-roads can be disrupted by flooding, causing punctual disconnections at global scale. This greatly changes the regional dynamics of *relative accessibility* in the region (Figures 10; 11), as upon flooding a single connection between *Porto Alegre* rest of the cities is maintained, through the regional highways (BR-290, BR-448 and RS-118), while several important primary and secondary-road connections among *Porto Alegre, Cachoeirinha, Canoas* and *Alvorada* collapse.

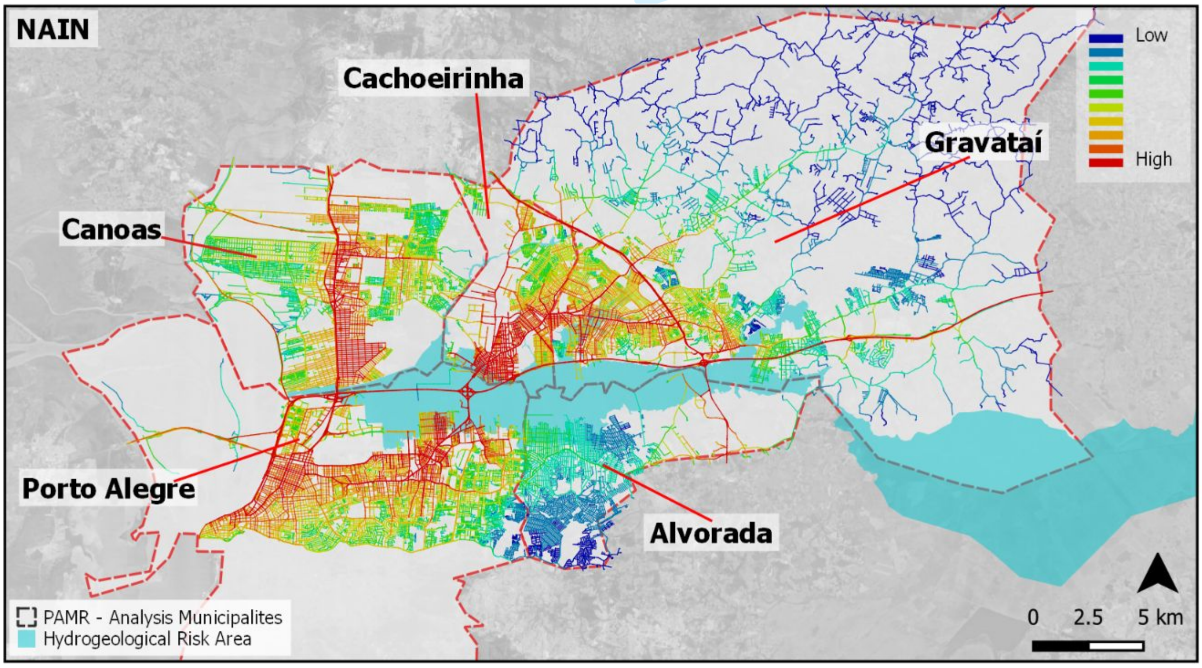

Figure 8. Results for NAIN: integral road-network configuration, outside a flood event.

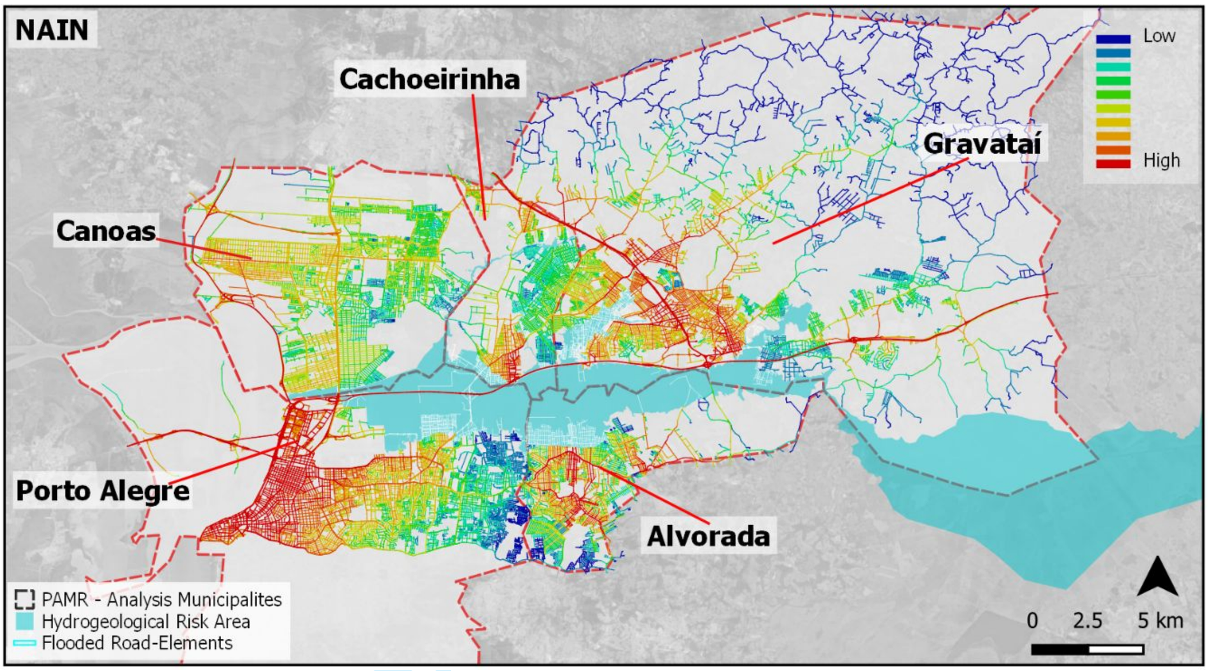

Figure 9. Results for NAIN: flood affected road-network configuration.

In this aspect, maintaining the BR-290 access – and the *regional accessibility patterns* – intact does not prevent a radical redistribution of NAIN hierarchies due to the primary and secondary-roads collapse, corroborating with the findings in Cutini, 2013 and Abshirini & Koch, 2017 (Figures 8-11).

Table 4. NAIN Values: PAMR integral road-network system, PMAR flooded road-network system (average between the three systems) and 10% restriction (*relative accessibility cores)*.

PAMR - Current	PAMR – Flood Area (Avg.)
0.14 - 0.44 (Low)	0.30 - 0.43 (Low)
0.44 - 0.53	0.43 - 0.48
0.53 - 0.59	0.48 - 0.52
0.59 - 0.63	0.52 - 0.55
0.63 - 0.66	0.55 - 0.58
0.66 - 0.68	0.58 - 0.6
0.68 - 0.71	0.6 - 0.62
0.71 - 0.74	0.62 - 0.66
0.74 - 0.79	0.66 - 0.70
0.79 - 0.97 (High) **– 10%**	0.70 - 0.78 (High) **– 10%**

Drawing from NAIN 10% restrictions (Figure 10; 11), the sources of radical changes on the *relative accessibility* distributiveness can be identified. Those changes occur mainly due to the flooding of a large portion of the main connection between *Porto Alegre* and *Canoas*, through the BR-116, and cuts in half the *relative accessibility core* from the centre; and due to the complete flooding of the *Porto Alegre-Cachoeirinha* connection, that crosses under the BR-290.The *Porto Alegre-Canoas* accessibility is dependent – and only possible – through the BR-448, while the *Porto Alegre-Cachoeirinha* access is restricted to the RS-118 to the east, crossing through *Gravataí*'s urban area (Figure 10).

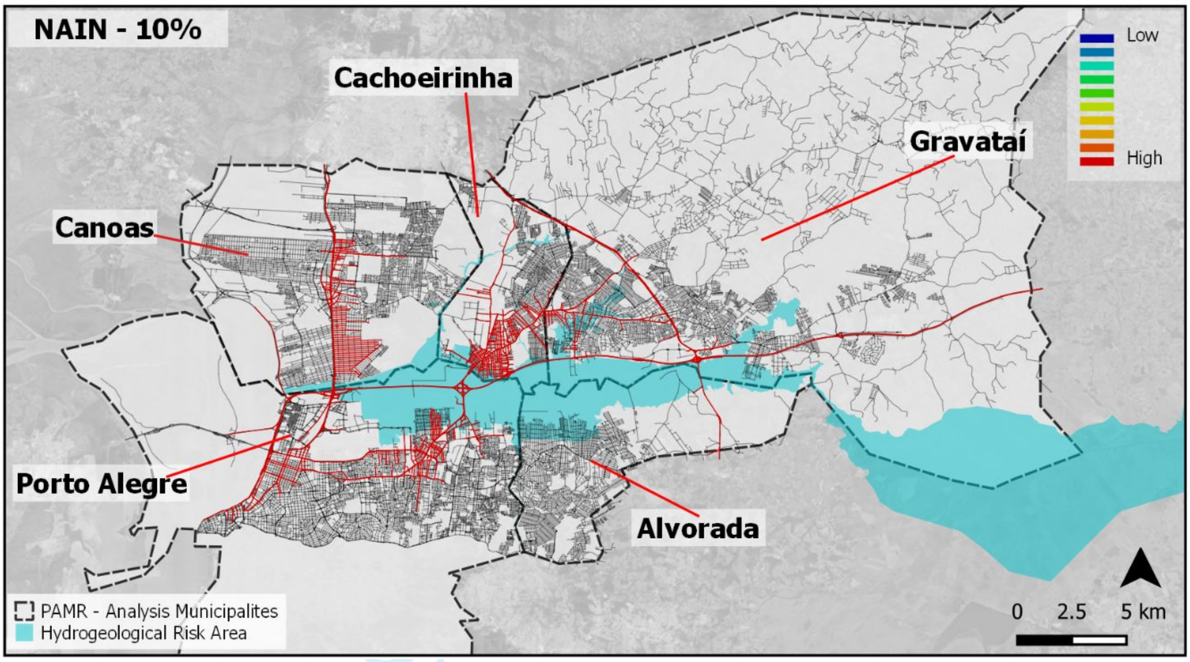

Figure 10. Results for NAIN: integral road-network configuration, outside a flood event (10% restriction).

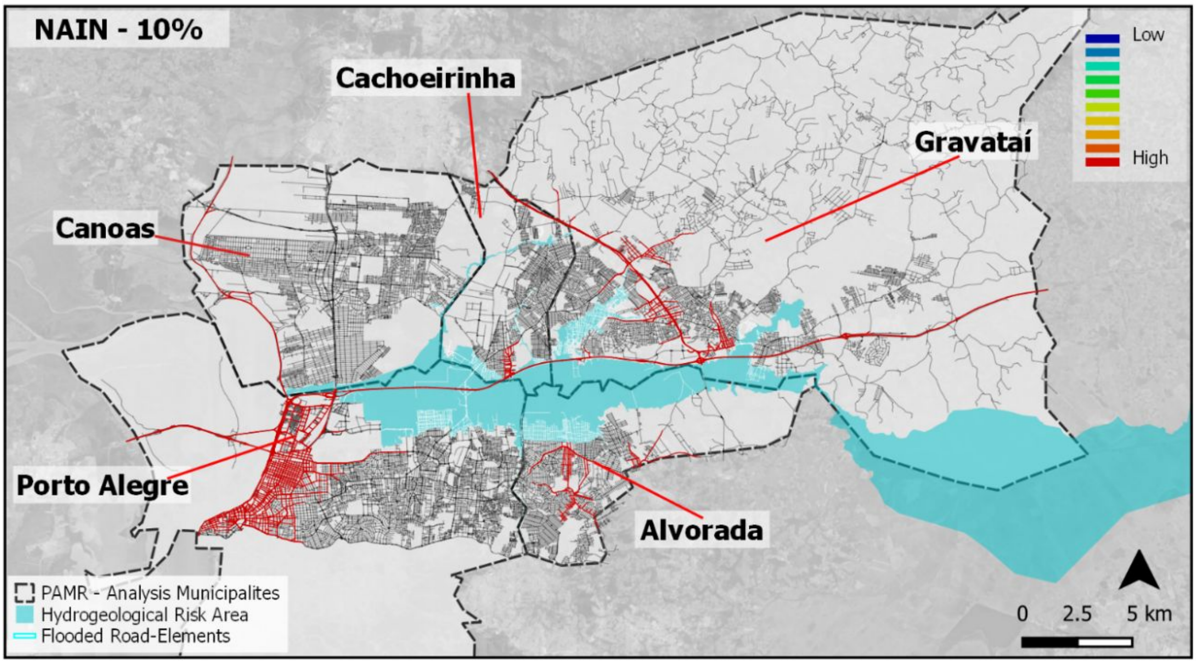

Figure 11. Results for NAIN: flood affected road-network configuration (10% restriction)

Certain road-intersections with the urban grid that seem to function as *network bridges* (Altafini et. al 2022), are suppressed under flooding, therefore changing the overall *relative accessibility* concentration system at local and especially at metropolitan scale Hence, despite the system integrity overall maintenance in terms of *accessibility*, congestion effects are certain to happen due to the *relative accessibility* concentration in *Porto Alegre's* urban core. The redirection of movement potentials towards the BR-290, turns it into the lifeline between *Porto Alegre* and the municipalities of *Cachoeirinha* and *Gravataí*.
The analysis (Figure 8-11) also reveals that *Alvorada*, although being the spatial continuity *Porto Alegre's* Northern Region, is severed from the network upon a flooding event, due to

interruptions caused by the tributaries of the *Gravataí* river and its overreliance on those urban access to connect itself to the metropolitan system. A feature of the simulation under a severe flooding-event is the emergence of a strong integration core within *Alvorada* municipality, reproducing the local movements within the city. Moreover, two definite urban patches within *Alvorada* territory emerge through the disconnection by one of the *Gravataí* River tributaries: the centre area becomes an independent network, while the industrial district simultaneously disconnected from *Alvorada's* centre and from *Gravataí,* through the RS-118, tend to function as an isolated system.

From the NAIN measure analysis, we can conclude that water-flood greatly modifies *relative accessibility* and movement patterns at metropolitan scale. The PAMR road-circulation system, while still mostly robust and *accessible*, collapses at an inter-urban local scale due to the suppression of vital connections within the metropolitan conurbation at a local scale . It is possible to infer that such changes are result from an uneven distribution of *network bridges* across the road-network displaying the fragility, low resilience and redundance of the PAMR metropolitan system, in terms of maintaining the connections between its urban settlements. The scarce connections in-between the cities – mainly reliant on the BR-290 motorway – demonstrate a fragmented foreground network, connected by few privileged road-elements, intertwined to a profound and intricate patchwork style urban network. Mapped NAIN analyses results evidence indicate to avoid land parcelling towards the riverbanks lowlands and their immediate vicinities in this metropolitan context. Moreover, when submitted to approval by urban planning instances it should be required undergo serious mitigation works beforehand. This is imperative, not only due to the innate flooding risks, but also, because of the consequential disruptions on the metropolitan spatial configuration and shifts on *relative accessibility* under a flood disaster, which may render those areas isolated from the metropolitan system, enhancing risks for evacuation of civilians.

Evaluating the metropolitan system's structure through Normalized Angular Choice (NACH) measure (Figures 12-15), informs that, from a general standpoint, flooding effects tend to be reduced regarding flows' patterns at metropolitan scales.

It can be observed that the ring-roads supplementary connections outside and inside the metropolitan core largely preserves the *preferential routes* system, maintaining the integrity of the metropolitan system at a larger regional scale. In effect, this contributes to the aforementioned *accessibility robustness* of the system. The role the three main highways play for the *preferential routes'* system resilience (in red - centre), relate to their highest hierarchy as urban avenues (in red and orange) ensuring regional connections a great degree of redundancy to the system at larger scales, factor informing the urban system´s resilience. Nevertheless, while system´s integrity regarding flows is mostly ensured at metropolitan scale, at local scale several internal road-elements that have high NACH values are interrupted by flooding, causing localised seizures to the system (Figures 13 & 15) – and which also answer for NAIN collapsing at metropolitan scale, despite their limited impact on local flows. This demonstrates that, while general hierarchies' are stable at metropolitan scale, where the main connections between the PAMR municipalities were planned to be resilient against flooding disruptions. At municipal scale, there is a relative neglect towards the role urban bridges between the municipalities play into maintaining connectedness between urban grids, revealing the resilience of the centre-periphery model in Brazilian planning practises. This is especially relevant in informing the ongoing metropolisation process within the PAMR: urban dynamics and economic development policies inform a turn towards a functional polycentric expansion towards the most flood-prone sensitive area.

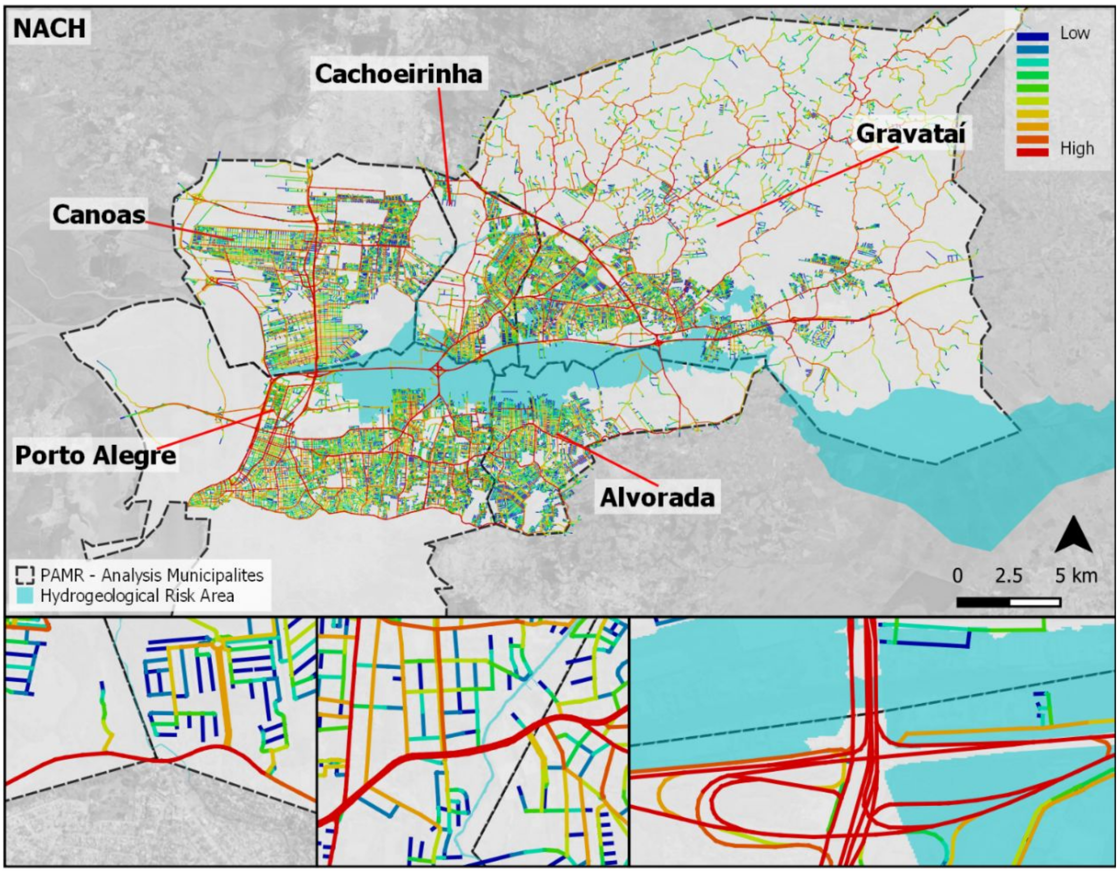

Figure 12. Results for NACH: integral road-network configuration, outside a flood event.

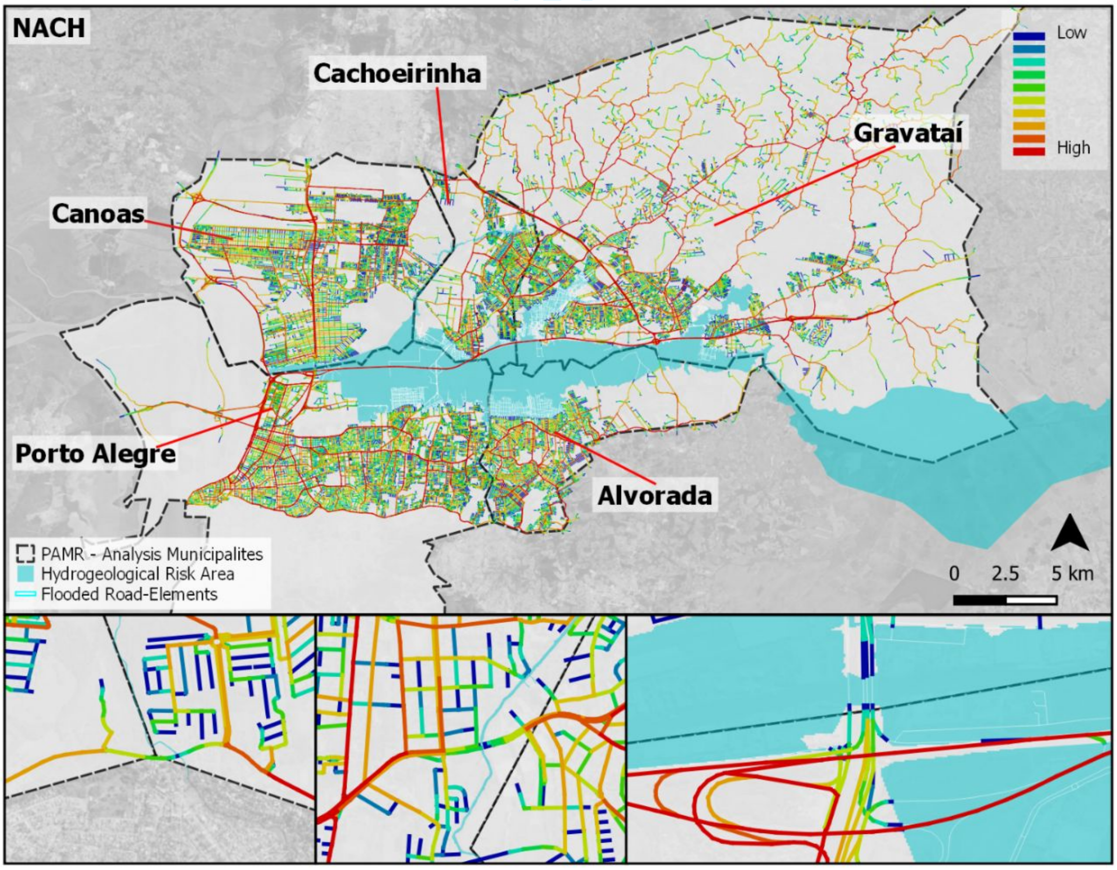

Figure 13. Results for NACH: flood affected road-network configuration.

Table 5. NACH Values: PAMR integral road-network system, PMAR flooded road-network system (average between the three systems) and 10% restriction (*preferential routes)*.

PAMR - Current	PAMR – Flood Area (Avg.)
0.00 - 0.70 (Low)	0.00 - 0.66 (Low)
0.70 - 0.84	0.66 - 0.82
0.84 - 0.89	0.82 - 0.87
0.89 - 0.93	0.87 - 0.92
0.93 - 0.97	0.92 - 0.95
0.97 - 1.01	0.95 - 0.99
1.01 - 1.06	0.99 - 1.04
1.06 - 1.12	1.04 - 1.11
1.12 - 1.22	1.11 - 1.20
1.22 - 1.52 (High) **– 10%**	1.20 - 1.51 (High) **– 10%**

Nowadays, there is an intensive labour commuting towards industrial districts located on the northern peripheries of the metropolitan core – *Porto Alegre*; which also concentrates services and retail activities (Altafini et al, 2021) that changed radically mobility and movement patterns within the PAMR.

Even though Porto Alegre centre is losing importance in fomenting economic development, it still plays part as a movement attractor and in structuring the urban-regional road-circulation system, since it houses the most important commuting node within the metropolitan region – as attested by the evidence displayed here that it tends to preserve metropolitan connections disrupted by floods. Nevertheless, the measures taken to improve the metropolitan circulation system resilience disregard recent metropolisation process ongoing on its immediate peripheries.

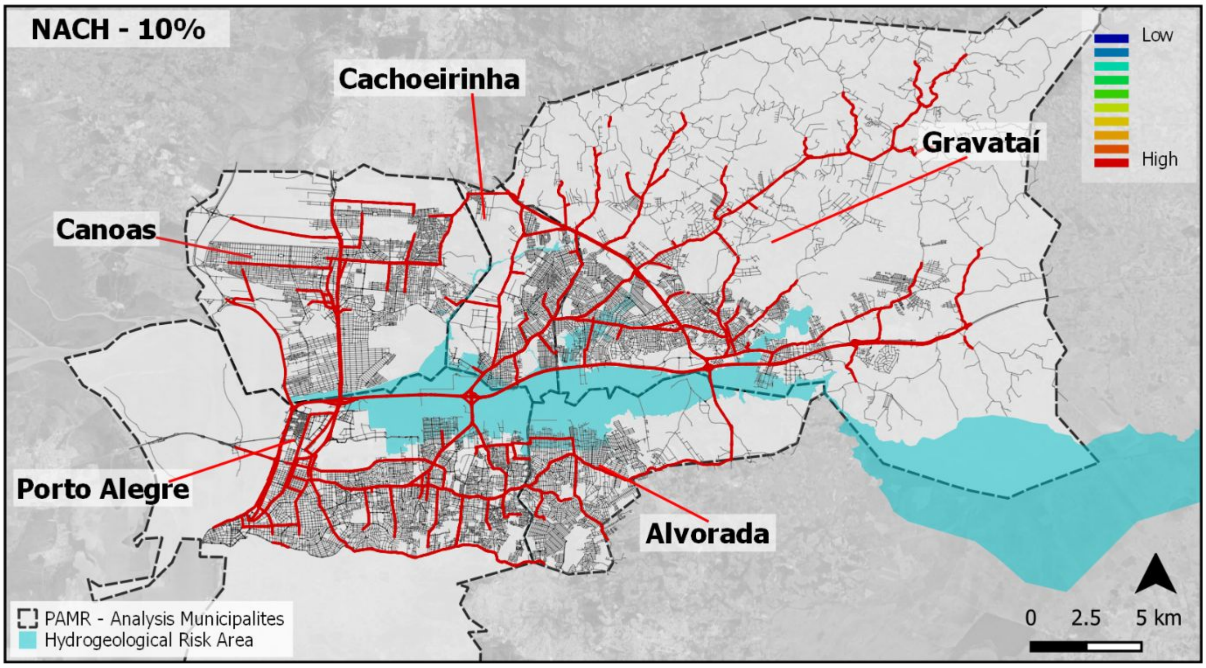

Figure 14. Results for NAIN: integral road-network configuration, outside a flood event (10% restriction).

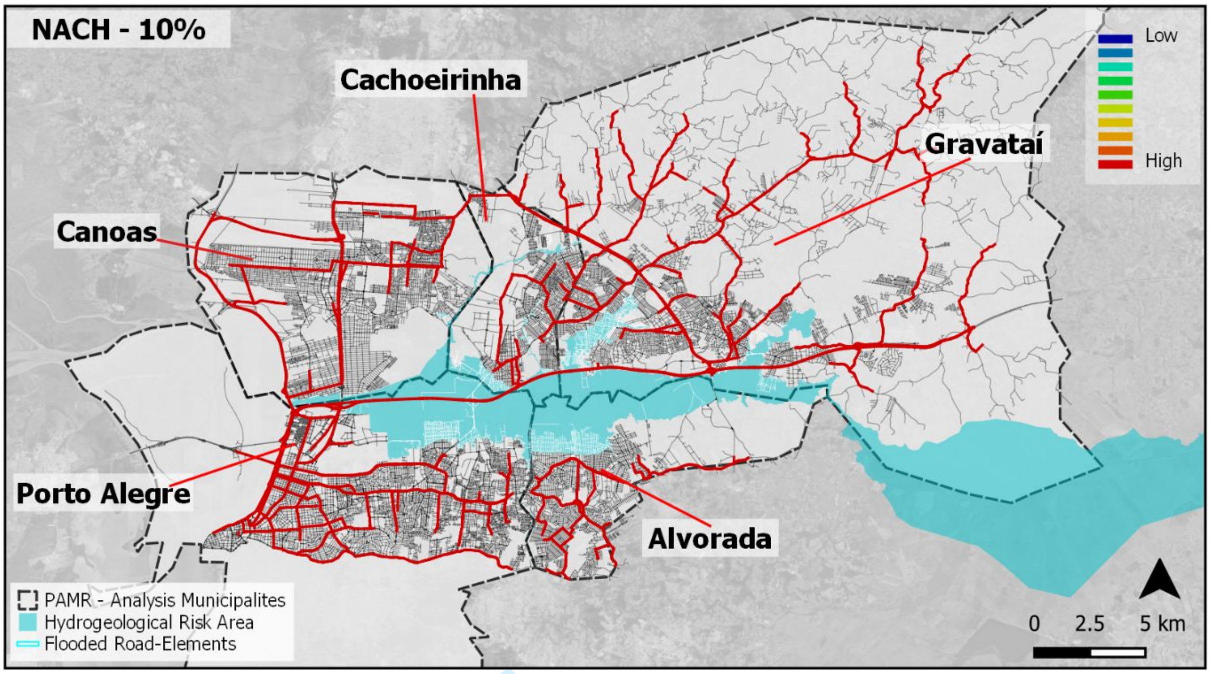

Figure 15. Results for NAIN: flood affected road-network configuration (10% restriction)

The BR-290, another important axis on the national road network, crossing the Brazilian territory up to its Northeast and along the coast, connects to RS-030, crossing *Cachoeirinha*, and defines the northern border of the preserved NACH core, as well as the urban extensions to *Porto Alegre* city core, and its connection to BR-448, keeping freight circulation consistent. The highlight of NACH is also *Alvorada* municipality: NAIN demonstrates that it becomes an isolated system. Albeit the robust interpenetration between the Porto Alegre urban grid and that of its central area, under flooding, this municipality becomes isolated to the point of becoming an actual island. This is dramatic in the sense that *Alvorada* is a dormitory-city and commuting with Porto Alegre is intensive (Melchiors et al., 2017). *Alvorada* and *Canoas* municipalities are the ones submitted to the most the adverse effects of planning policies inconsistences regarding the management of water basins and metropolitan restrictions for land development based on incomplete technical analyses. On *Gravataí* territory, watershed occurs along its main river and the *Barnabé* Stream, a tributary of the *Gravataí* River along its core, a high-density area. *Porto Alegre* Northern Planning Regions undergo major real-estate development, especially on the lowland areas closer to BR-290, one of the metropolitan routes with higher flow probability and an emergent new centrality at metropolitan scale. Along this road, gated communities and shopping centres characterize suburban sprawl patterns, despite the area´s high hydrogeological risk.
Those findings relate directly to the tendencies of change under flood-risk depicted by the modelling iconography. Flood-prone patch modify *Porto Alegre* neighbouring Northern areas and its bordering municipalities urban expansion patterns, informed by regional circulation and metropolitan mobility.

4. Conclusions

When compared with the Europe, the Brazilian urbanization process is recent, as it occurs and intensify after the diffusion of road-based transportation in the 1950's. In that regard, highways and primary-roads have an important role in informing patterns of urban sprawl, suburbanisation, as well as in guiding the emergence of new urban centres.

Urban expansions in Brazil tend to follow sparse, spatially discontinuous, and fragmentary processes, based on the acquisition and occupation of peripheral low-cost land bordering the main road-circulation axes. This tendency summarizes the accelerated urbanization process that most of Brazilian Metropolitan Areas undergo since the 1970's. These peripheral areas, often subject to an unguided and irregular occupation, outside the governance reach, are also the most prone to severe natural hazards, such as seasonal flooding, thus being under a constant risk of infrastructure, economic and life loss.

The analysis for Porto Alegre's Metropolitan Region – PAMR, corroborates just that. It reveals that the configuration emerging from the urban network morphology structure is rather sensitive to the interruptions in infrastructure caused by seasonal flooding, conditions that are aggravated by the recent expansion towards areas under hydrogeological risk in the peripheries. Moreover, it revealed the unevenness in urban-regional resilience attesting the importance that ringness and redundancy between different municipalities primary and secondary-roads plays in providing alternative routes to their centres and maintaining metropolitan mobility under flooding circumstances. Resilience, defined as the degree to which a city retains the same segments forming the foreground network before and after a disturbance does not apply to the PAMR metropolitan system at municipality scale. Changes in *relative accessibility* (NAIN) at that scale demonstrate that some municipalities (*Cachoeirinha and Canoas*) lose their main accesses to the metropolitan network, while others (*Alvorada*) are completely severed from it. At metropolitan scale, however, the PMAR system retains resilience in terms of *regional flows* (NACH), avoiding a complete collapse in terms of *relative accessibility*. This both confirms and challenges effects on centrality patterns and *accessibility* before and after change, as identifying redundancies at local scale could provide a better understanding of the global properties of a network under distress. Nevertheless, the changes identified in NAIN suffice to evaluate this case.

Additionally, results indicate the issues of land parcelling and implemented infrastructure that underlie historically the Brazilian Planning Policies. Evidence for land parcelling permissions along the 2010-2020 decade inform the increase of large-scale urban development instalments on flooding prone areas. For PAMR case, although their total incidence within flooding prone patch is contained (16,6%), the total occupied area is considerable as 45,2% of the total land parcelling's area is under hydrogeological risks. This points the limits of public intervention on private land infrastructure system, what can enhance flooding impacts on citizen´s lives and contribute to enhance flooding effects due to the size of such areas.

To achieve these goals, effective actions for metropolitan regions are required in managing urban expansions, regional structuring and territorial planning, while targeting resilience and sustainability across scales, the most effective tactics to face real estate sector intensive pressure for new land developments within flood risk areas. In this sense, analytic tools and mapping methods that allow spatial configurations and circulation networks comparative studies such as Space Syntax simulations support decision-making process, since provide evidence for changes and transformations tendencies in extreme situations as flooding. Nevertheless, there is always municipalities´ autonomy limiting inter-federative approaches for managing water resources and river basins, an essentially regional problem, addressed by metropolitan authorities since the Federal Governance (Brasil, 2001) enactment, designed to overcome metropolitan regions integrated planning hindrances. The iconography is most effective in a more participatory governance approach, when community representatives take part in decision processes.

References:

Abshirini, E. and Koch, 'Resilience, space syntax and spatial interfaces: The case of river cities', *ITU A|Z,* (2017) Vol 14, No 1 • March 2017, 25 41doi.org/10.1016/j.progress.2013.08.001

Alonso J. A. F. Caracterização econômica da região metropolitana de Porto Alegre nos anos 90. *Indicadores Econômicos FEE.* (2001) V. 29, N. 1 p 253-292.

Altafini, D; Poloni, F, Meini, B, Bini, D, Cutini, V. Markov-Chain-based centralities and Space Syntax' Angular Analysis: an initial overview and application. In: *Proceedings of the 13th Space Syntax Symposium,* Western Norway University of Applied Sciences (HVL), Bergen, Norway (2022). pp. 522.1-522.21

Altafini, D, Braga, A, Cutini V, Planning sustainable urban-industrial configurations: relations among industrial complexes and the centralities of a regional continuum. In: *International Planning Studies*, (2021) DOI:10.1080/13563475.2021.1875810, pp. 1-21.

Brasil. Lei nº 10.257, de 10 de julho de 2001: regulamenta os arts. 182 e 183 da Constituição Federal, estabelece diretrizes gerais da política urbana e dá outras providências (2001). Available at: https://www.planalto.gov.br/ccivil_03/leis/leis_2001/l10257.htm

Cutini, V. The city when it trembles. Earthquake destructions, post-earthquake reconstruction and grid configuration. In: Kim, Y. O., Park, H. T., Seo, K. W. (eds), *Proceedings of the 9th International Space Syntax*, Seoul: Sejong University. (2013)

Cutini, V., Di Pinto V. On the slopes of Vesuvius: Configuration as a thread between hazard and opportunity, Proceedings of the 10th International Space Syntax Symposium, London, University College of London. (2015).

Cutini, V.; Falco, A.; Giuliani, F. Urban grid and Seismic Prevention: a configurational approach to the emergency managemenof italian historic centres. *12th International Space Syntax Symposum,* Beijing Jiaotong University (2019), http://www.12sssbeijing.com/upload/file/1562668710.pdf

Cutini, V.; Pezzica, C. Street network resilience put to test: the dramtic crash of Genoa and Bologna bridges, *Sustainability* (2020) 12, 4706 doi: 103390/su12114706

depthmapX development team. (2018). depthmapX (Version 0.8.0) [Computer software]. Retrieved from https://github.com/SpaceGroupUCL/depthmapX/

Esposito, A. and Di Pinto, V. (2014) "Urban Resilience and Risk Assessment: How Urban Layout Affects Flood Risk in the City" In *2014 14th International Conference on Computational Science and Its Applications (ICCSA)* (pp. 204-207). IEEE Computer Society.

Esposito A. and De Pinto V. (2015). Calm after the storm: The configurational approach to manage flood risk in river cities. Proceedings of the 10th International Space Syntax Symposium, London.

Fakhrurrazi, F., & Van Nes, A. (2012). Space and panic: the application of space syntax to understand the relationship between mortality rates and spatial configuration in Banda Aceh during the tsunami 2004. In *Proceedings of the 8th International Space Syntax*

Symposium, January 3-6, 2012, Santiago de Chile, Chile. Editors: Greene, M., Reyes, J., Castro, A.. PUC.

_______, Guaíba registra a segunda maior cheia da história no RS, *G1 RS,* October 17, 2015. https://g1.globo.com/rs/rio-grande-do-sul/noticia/2015/10/nivel-do-guaiba-atinge-recorde-e-mantem-estado-de-alerta-no-rs.html (Accessed January 10, 2023)

Gil, J.; Steinbach, P. (2008) From flood risk to indirect flood impact: evaluation of street network performance for effective management, response and repair. *WIT Transactions on Ecology and the Environment*, volume *118*, pp.335-344. DOI 10.2495/FRIAR080321

SEMARS - Governo do RS *Bacias hidrográficas do Rio Grande do Sul*, Secretaria de Meio-Ambiente e Infraestrutura do Estado Rio Grande do Sul, (2020) https://sema.rs.gov.br (accessed in January 18, 2023)

Hillier, B., Iida, S. Network and psychological effects in urban movement. In: *Spatial Information Iheory* (2005) (pp. 475-490). Springer Berlin Heidelberg.

Hillier, B., Yang, T., and Turner, A. Normalising least angle choice in Depthmap-and how it opens up new perspectives on the global and local analysis of city space. *Journal of Space Syntax* (2012), 3(2), 155-193.

Hillier, B. Spatial sustainability in cities: Organic patterns and sustainable forms. In: Koch, D., Marcus, L. and Steen, J. (eds.), P*roceedings of the 7th International Space Syntax* (2009), Stockholm: Royal Institute of Technology, p.K01.1-K01.20

Hillier, B, Hanson, J. The social logic of space. Cambridge University Press, (1989).

Giuliani, F., De Falco, A., Cutini, V. and Di Sivo, M., A simplified methodology for risk analysis of historic centers: the world heritage site of San Gimignano, Italy*, International Journal of Disaster Resilience in the Built Environment*, (2021) Vol. 12 No. 3, pp. 336-354. https://doi.org/10.1108/IJDRBE-04-2020-0029

Huq, M.E. *et al.* (2020). Measuring vulnerability to environmental hazards: qualitative to quantitative, Environment, Springer, https://doi.org/10.1007/978-3-030-49732-3_17

IBGE (2002). «Área territorial oficial». Resolução da Presidência do IBGE de nº 5 (R.PR-5/02).

IBGE (2013) Bacias e divisões hidrográficas do Brasil. https://biblioteca.ibge.gov.br/visualizacao/livros/liv101854.pdf

IBGE, *Pesquisa Nacional por Amostra de Domicílios Contínua* (2019) https://www.ibge.gov.br/estatisticas/sociais/trabalho/9171-pesquisa-nacional-por-amostra-de-domicilios-continua-mensal.html?=&t=microdados (Accessed in 18 January, 2023)

IBGE, *Pesquisa Nacional por Amostra de Domicílios Contínua* (2020) https://www.ibge.gov.br/estatisticas/sociais/trabalho/9171-pesquisa-nacional-por-amostra-de-domicilios-continua-mensal.html?=&t=microdados (Accessed in 18 January, 2023)

IBGE, *Pesquisa Nacional por Amostra de Domicílios Contínua* (2021) https://www.ibge.gov.br/estatisticas/sociais/trabalho/9171-pesquisa-nacional-por-amostra-de-domicilios-continua-mensal.html?=&t=microdados (Accessed in 18 January, 2023)

IPEA (2015) “Governança Metropolitana no Brasil – Região Metropolitana de Porto Alegre” © *Instituto de Pesquisa Econômica Aplicada, Rio de Janeiro*

Lima, L. *Mapeamento da sucetibilidade à inundação na bacia hidrográfica do Arroio do Salso, Porto Alegre-RS.* (2010). Dissertação (Mestrado) Universidade Federal do Rio Grande do Sul, Instituto de Geociências, Programa de Pós-graduação em Geografia, Porto Alegre, RS.

Lindsey, D. "The embedded periphery: slums, favelas, shantytowns and a new regime of spatial inequality in the modern world-system." In *Routledge Handbook of World-Systems Analysis*, Routledge, 2012 pp. 345-352.

Martins. C. M. R. Texto para discussão 112 - *Caracterização da Região Metropolitana de Porto Alegre*, FEE, 2013 ISSN 1984 5588

Melchiors, L. C., Braga, A.C, Zampieri, F. Campos, H. Reestruturação metropolitana e emergência de centralidades: novos fluxos pendulares e a configuração espacial da Região Metropolitana de Porto Alegre, *Arquitetura Revista*, (2018) 14(2), p. 187–203. doi: 10.4013/arq.2018.142.08.

Mengue, V; Guerra, R; Monteiro, D; Moraes, M; Vogt, H. Análise da expansão urbana em áreas suscetíveis à inundação utilizando o modelo HAND: o caso da Região Metropolitana de Porto Alegre, Brasil. *Revista de Geografia e Ordenamento do Território* (GOT), n.º 12 (dezembro). Centro de Estudos de Geografia e Ordenamento doTerritório, p. 231-253, (2017) dx.doi.org/10.17127/got/2017.12.010 ISSN: 2182-1267

MinC; METROPLAN. Estudo de Alternativas e Projetos para minimização do efeito de cheias e estiagens na Bacia do Rio dos Sinos. Plano Nacional de Gestão de Riscos e Respostas a Desastres Urbnaos / *Plano Metropolitano de Proteção contra cheias*, Technical Report (2018a).

MinC; METROPLAN. Estudo de Alternativas e Projetos para minimização do efeito de cheias e estiagens na Bacia do Rio Gravataí. Plano Nacional de Gestão de Riscos e Respostas a Desastres Urbnaos / *Plano Metropolitano de Proteção contra cheias*, Technical Report (2018b).

Müller, F. "Urban informality as a signifier: Performing urban reordering in suburban Rio de Janeiro." *International Sociology* 32, no. 4 (2017): 493-511.

Pezzica, C, Cutini, V, de Souza, (2022) Urban-regional dynamics of street network resilience: the spatial outcomes of Genoa's and Bologna's bridge crashes. *Proceedings of the 13th International Space Syntax*, Western Norway University of Applied Sciences (HVL), Bergen, Norway. pp. 438.1-438.17

Pezzica, C, Cutini, V, de Souza, C. (2021) Mind the gap: state of the art on decision-making related to post-disaster housing assistance. *International Journal of Disaster Risk Reduction* 53, 101975

Pezzica, C.; Cutini, V.; de Souza, C. B (2019) “Rapid Configurational Analysis Using Osm Data: Towards the use of Space Syntax to orient post-disaster decision making” *12th International Space Syntax Symposium Proceedings#147 – Safety emergency,* Beijing Jiaotong University, http://www.12sssbeijing.com/upload/file/1562668571.pdf

QGIS, Białowieża, version 3.22 (2022) Available in: http://www.qgis.org/en/site/index.html

Rusci, S, Altafini, D, Di Pinto, V. Urban Demolition: Application of Blight Elimination Programs and Flood Buyout Programs to the Italian Case. In: *Sustainability* (2021) 13, no. 16: 9412. https://doi.org/10.3390/su13169412

Turner, A. Stitching Together the Fabric of Space and Society: An Investigation into the Linkage of the Local to Regional Continuum, in: Koch, D; Marcus, L; Steen, J. (Ed.), *Proceedings of the 7th International Space Syntax Symposium*. (2009) KTH, Stockholm, pp. 1–12.

Turner, A. From axial to road-centre lines: A new representation for space syntax and a new model of route choice for transport network analysis. *Environment and Planning B* (2007). 34, 539–555. https://doi.org/10.1068/b32067