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Conventional emergency processes insufficient for floodable ports: the Porto Alegre, (Brazil) case

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Abstract

The port of Porto Alegre, located in the capital city of the southernmost Brazilian state of Rio Grande do Sul, has faced intense flooding recently as a consequence of climate change. Based on the water level record from these latest events (including the May 2024 floodings that yielded water levels over two meters above the wharf height - 515 cm), we propose the concept of floodable port for Porto Alegre: given its geographical setting, the port is a flood-vulnerable important regional infrastructure and logistics player that must be adapted in order to withstand increasingly frequent and intense rainfall episodes, and later return to operational capacity. Having analyzed the current risk and emergency normative documents implemented for the port of Porto Alegre and the legal requirements for the production of internal emergency plans, we concluded that such risk and emergency norms are insufficient to manage a floodable port, based on the recorded impacts of recent flooding events, as they focus solely on operational risks and emergencies. Thus, it becomes necessary to implement a Climate Emergency Plan for the Port, aiming to enforce responsive measures for predicted flooding scenarios, limiting the impacts that previously unconsidered natural hazards can cause to port infrastructure.

1 Introduction

Widespread atmospheric regime change has become a known consequence of industrialization and its impacts on the climate. In southern Brazil, increased rainfall is one of such observed changes, which has brought increasingly dire impacts to infrastructure and population. Porto Alegre, state capital of Rio Grande do Sul, Brazil's southernmost state, has recently faced an extreme climate episode, when upstream precipitation reached as much as 500 mm between April 30th and May 10th (Alcântara et al., 2024; Emater-RS, 2024). Moreover, according to Collischonn et al., (2024), some regions were met with rainfall over 900 mm between April 1 and May 5, 2024, and show that April had already had high volume of rain (monthly total of around 400 mm).

Porto Alegre is in a peculiar geomorphological position: its main water body, Guaíba, receives contributions from plateau and shield areas to north and east, respectively, with a catchment area of 84,763 square kilometers (around 33 thousand square miles) and including more than 250 municipalities (Nicolodi et al., 2010) (Fig. 1b). The local climate is subtropical humid with hot summers (Cfa Koppen classification) (Alvares et al. 2013), with annual mean precipitation of around 1,400 mm (Viana et al., 2006) and predominant wind direction towards east (Livi, 1998; Camargo, 2002; Nicolodi, 2007). The port area is situated in the Guaíba at the end of the Jacuí river delta (Fig. 1c and 1d) and has been significantly impacted by the recent climatic events. Notably, the port structures are located outside the wall that forms the city's flood protection system.

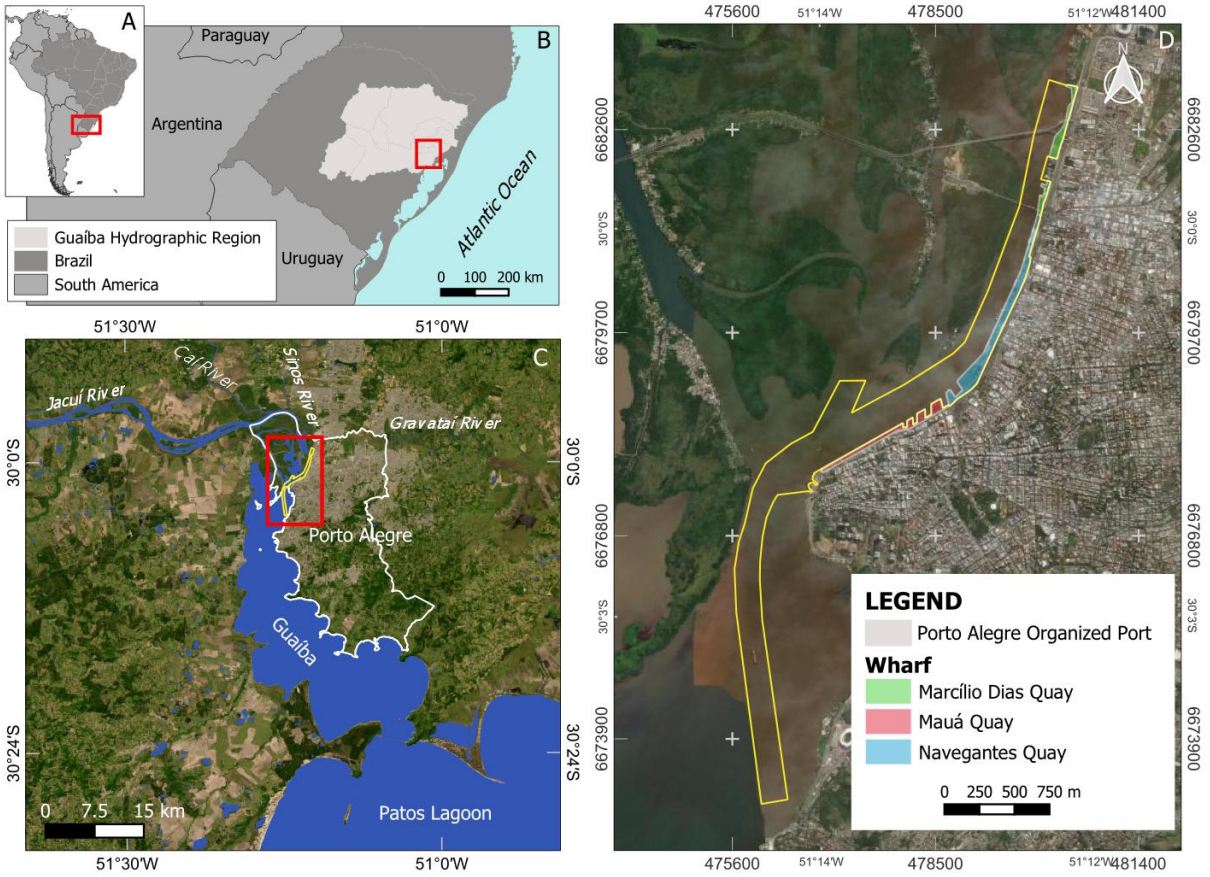

Figure 1. Geographical context of the port of Porto Alegre. (a) location in South America; (b) catchment area and location in Rio Grande do Sul, Brazil; (c) the Guaíba and its tributaries; (d) location of the Organized Port.

The Porto Alegre port is an important logistic hub for the north and central regions of the state, with cargo consisting mainly of grains, tallow, salt, and raw material for fertilizers, as well as machinery and equipment. In 2023, cargo volumes totaled over 800 thousand tons, from which the main products were fertilizers (62%), barley (14%) and beef and pork tallow and lard (10%) (ANTAQ, 2024). During the historical floods occurred in May, the terminals were taken by water (that reached a 515 cm level in the Historical City Centre (Tidesat, 2024)), and remained as such for three weeks until the level decreased to below 3 m, the wharf reference height. Port activities resumed in early August, coming to almost 100 days of operation disruption.

As southern Brazil observes heavy precipitation increase in the last decades and sees projections of further increment, as well as rise in sea level (IPCC, 2023), the port of Porto Alegre faces a need for adaptation, given the impossibility of relocation and its regional role. As such, we propose the concept of floodable port, where the port of Porto Alegre is seen as a flood-vulnerable important regional infrastructure and logistics player that must be adapted in order to withstand increasingly frequent and intense rainfall episodes, and return to operational capacity with minimal structural intervention.

Considering the current legislation and regulations in place for Brazilian ports, in conjunction with the implemented plans and programs specifically projected for the port of Porto Alegre, we analyse the relevance of the emergency procedures operative for port areas, conventionally predicted for such facilities. Thus, following the recent experience of intense rainfall and the observed impacts in the port, we pose the research question "*are conventional emergency processes applicable for floodable ports?*" In order to answer this question, we have analyzed the port's current emergency requirements and protocols, and compared the risks predicted in those documents to the impacts observed, as a means to assess whether these procedures are applicable and adequate to face flooding conditions similar to the last three main severe rainfall episodes recorded (in late 2023 and May 2024).

2 Literature Review

2.1 Ports and Climate Change-related Risk

The ISO 31000, the International Standard for Risk Management, defines risk as an effect of uncertainty on objectives, in which effect is a deviation from the expected (ISO/BS, 2018). Verschuur et al. (2023) analyzed multi-hazard risks to global port infrastructure, contemplating a number of natural hazards to which ports are exposed worldwide. The authors define port-specific risk as the sum of three types: (1) the physical damages to port infrastructure; (2) the physical damage to critical infrastructure in the port surroundings (roads, rail, power supply); and (3) the additional logistic losses to stakeholders as a result of downtime. They found that 86% of the analyzed ports are exposed to more than three hazards (which were categorized as Cyclone, Fluvial, Coastal, Pluvial, Earthquake, and Operational). Port-specific risk, as defined in the study, is expressed in terms of risk per square metre f port area, and referred to as relative risk. Relative risk is considered higher for lower income countries (according to the World Bank Income classification), as those yield financial resources to apply preventive measures, even if their port's absolute risk score is high (Verschuur et al., 2023). Further, the authors list flooding as the second highest risk among the dominant hazards, with a median risk of 1.9 billion USD/year

worldwide.

In the Brazilian scope, the Ministry of Infrastructure (Ministério da Infraestrutura - MINFRA) issued, in 2021, the guidelines for Risk Management Program - Port Mode (RMP), required for environmental licensing processes. Such guidelines use the Preliminary Hazard Analysis (PHA) methodology to assess the risks involved in port operation activities, identifying causes for recorded events and their consequences, followed by a quantitative evaluation of occurrence frequency, severity, and associate danger (MINFRA, 2021). This document is the basis for the Risk Analysis Study (RAS) and the Individual Emergency Preparedness Plan (IEPP), both required as conditions for environmental license maintenance. The port of Porto Alegre yields both studies, issued in 2022 and 2023, respectively, focusing on operation-related hazards, as established by aforementioned normative documents. As such, these risk and emergency-protocol reports do not contemplate natural hazards, extreme climate events or climate-change-related episodes.

Wang et al. (2023) compiled the main causes of port disruption based on the literature into four main categories: (1) natural factors, including diseases, hydrological disasters, atmospheric disasters, seismic an geological hazards; (2) technological factors, including system failure, equipment failure, interface issues, network failure, scheduling problem, and cyber terrorism; (3) organizational factors, including poor organizational strategy, and poor organizational structure; and (4) socioeconomic factors, including human factors, economic factors, and policy factors. On the other hand, the National Agency for Waterway Transportation (Agência Nacional de Transportes Aquaviários – ANTAQ) defines a wider risk category - climate risk - as the interaction between the climate emergency threat, natural, human and economic system exposure and their vulnerability characteristics ANTAQ (2021). In their final report concerning the Impact and Risks of Climate Change in Brazilian Coastal Public Ports, ANTAQ, (2021) analyses 21 Brazilian seaports based on economic relevance (measured by yearly cargo movement above 500 thousand tons). Although Porto Alegre is not included in the analysis, the recommended list of adaptive measures includes climate change-related risks complementary to the operational risks estimated by the current official procedures. It is worth noting that the administration for the port of Porto Alegre had planned for 2024 to carry a climatic risk assessment according to ANTAQ (2021) guidelines. However, the May events occurred during the very early stages of the study, presenting unforeseen scenarios.

2.2 Floodable vs Resilient

With the increase of frequency and intensity of rainfall and storm episodes, and consequently floods, stakeholders worldwide have become aware of the repetitive water-related hazard impact on existing infrastructure. “Water sensitive” frameworks were first formulated aiming to minimize impact of water runoff in urban environments by temporarily reducing the effects of climatic events in those areas (Palazzo, 2019, and references therein). The idea of “floodable” locations, nevertheless, has been used with a wider meaning: either to describe a given naturally flood-prone area that sees periodical or seasonal episodes of water input and temporary residency, even if populated (e.g. Barbaro et al., 2022; Lam et al., 2023; Niculescu et al., 2017); or as an urban area adapted to receive flash flood water meaning to reduce material and environmental impact, as well as reusing its recycled water (e.g. Jodar-Abellan et al., 2018; Palazzo, 2019; Sánchez-Almodóvar et al., 2023). In this study, we propose the use of floodable [port] to characterize a

naturally flood-prone area that faces episodic water surge and temporary residency, with no means to redirect, block, retain, or absorb said water input. A floodable port is, hereby, an operational port installation located in an area with a flooding record and relatively high flood probability that is adapted to withstand water surge episodes and be managed to regain operational capability with no or minimal structural intervention.

Port resilience, however, is its ability to operate under extreme conditions, to cope with hazard impacts, and to implement measures for quick recovery after an episode, shortening recovery duration. This classification requires the implementation of a wide combination of contributing factors to guarantee operational and infrastructural resilience with preparedness and responsiveness, including strong governance and society communication (León-Mateos et al, 2021; Punt et al., 2023; Wang et al., 2022; Wang et al. 2023). Given the current limited capacity of the port of Porto Alegre to deal with the increasingly frequent flooding episodes and the severity of the impacts, extensive adaptation is required in order to achieve flood resilience, if intended - given the requirements for size and timing of investment (Randrianarisoa & Zhang, 2019; Yang et al., 2018). Thus, we maintain the characterization of floodable port for the port of Porto Alegre.

3 Methodology

The analysis was carried by means of comparison between the existing legal and normative requirements for risk assessment and emergency procedures in the port of Porto Alegre, and the main impacts observed in the recent flooding events of May 2024, with the aim of contrasting current procedures and flood impacts and determine whether the implemented protocols suffice as means to prevent, mitigate, resolve port emergencies, and regain operability.

Table 1 lists the analyzed official requirements for port risk analysis and emergency procedures (including operational and natural-hazard oriented), along with the implemented protocols for the port of Porto Alegre as enforcement of said normative requirements. Analysis did not address normative concerning exclusively legal, administrative, or economic risks, which are also classified under current regulatory requirements. A wider view of multiscale Brazilian port-relevant policy framework can be seen in Lima & Souza (2022).

Table 1. Normative documents analyzed by the study seeking to assess effectiveness toward climate change and flood-related hazard. FEPAM - Henrique Luis Roessler Rio Grande do Sul State Environment Protection Foundation (Fundação Estadual de Proteção Ambiental Henrique Luis Roessler do Estado o Rio Grande do Sul).

Normative Document	Description	Year of Issue	Sphere
Risk Management Program - Port Mode	Defines activities and procedures to be executed during port services and operations concerning accident prevention and environmental preservation	2021	Federal
Industrial Risk Analysis Manual	Risk assessment manual of the Rio Grande do Sul environmental licensing foundation (FEPAM) which describes risk analysis processes and licensing condition demands for risk studies	2016	State

Normative Document	Description	Year of Issue	Sphere
Risk Analysis Study (RAS)	Port of Porto Alegre risk assessment study implemented as a condition of the environmental operation license	2022	Local (Port of Porto Alegre)
Individual Emergency Preparedness Plan (IEPP)	Port of Porto Alegre emergency preparedness plan, issued as part of the port's Risk Management Program, a condition of the environmental operation license	2023	Local (Port of Porto Alegre)

As floodings are among the most significant port-specific risks, the most damaging natural hazard around the world, and projected to continuously increase destructive impact as a consequence of the climate emergency (Alfieri et al., 2017; Noonan & Sadiq, 2019; Verschuur et al., 2023), as well as the most pressing natural hazard in the context of the port of Porto Alegre, our analysis here will focus specifically on floodings, as opposed to assessing risk related to different types of natural hazards.

4 Analysis and Results

The comparison between the compiled emergencies and risks present in the analyzed normative documents and on the observed impacts of recorded hazards can be seen in Table 2. Severity and frequency assessment of emergencies not listed in the existing documentation was carried using the same metrics used in those documents (Kundnani et al., 2022; MINFRA, 2021).

Table 2. Compilation of port-related emergencies as predicted and observed for the port of Porto Alegre.

Identified Emergency	Type	Severity	Frequency	Estimated/Observed Impacts	In Normative Document
Machinery, vehicle, or vessel fuel leakage	Operational	Marginal, Critical if tanker vehicle	Remote	Fire, explosion, contamination	Y
Stored fuel or lubricant (150 L barrel) leakage	Operational	Major	Remote	Fire, soil contamination	Y
Fall of fuel or lubricant (150 L barrel) into water	Operational	Critical	Occasional	Leakage, fire, contamination	Y
Fall of vehicle or machinery into water	Operational	Critical	Remote	Oil/fuel leakage, contamination	Y
Electric transformer accident	Operational	Critical	Remote	Fire, insulating oil leakage, contamination	Y
Fall of cargo into water	Operational	Minor	Probable	Water and soil contamination	Y
Class I* residue leakage	Operational	Major	Remote	Soil contamination, fire	Y

Identified Emergency	Type	Severity	Frequency	Estimated/Observed Impacts	In Normative Document
Sludge transfer	Operational	Major	Unlikely	Leakage, contamination	Y
Ballast water replacement	Operational	Critical	Occasional	Contamination, introduction of invasive species	Y
Fire/Explosion in vehicle, machinery or vessel	Operational	Critical	Remote	Fire, explosion, contamination	Y
Flood water in wharf building	Natural Hazard	Major	Probable	Loss of property, damage to equipment, contamination	N
Flood water in wharf cellar	Natural Hazard	Major	Probable	Loss of property, damage to stored cargo, contamination	N
Loss of vehicle or vessel	Natural Hazard	Major	Remote	Loss of property, leakage, contamination	N
Damage to critical infrastructure	Natural Hazard	Major	Remote	Interruption of operation, damage to equipment	N
Damage to port infrastructure	Natural Hazard	Major	Remote	Loss or damage to property	N
Interruption of operation	Natural Hazard	Critical	Probable	Financial loss, harm to connectivity and logistics	N
Contact with displaced wild animals	Natural Hazard	Minor	Remote	Physical harm, animal harm, contamination	N

*Dangerous residue classification as established in ABNT NBR 10004:2004

The comparison seen in Table 2 shows that the normative documents analyzed only relate risks and emergencies operational in character, while not considering natural hazard or climate-related emergencies and impacts. Furthermore, natural hazard emergencies are relatively more frequent (as observed during the climate flooding episodes recorded in 2023 and 2024, all of which saw water level above the wharf floor). As such, it becomes evident that existing normative requirements are not sufficient to prevent and mitigate port-related emergencies in the climate emergency scenario we see in southern Brazil. As such, it can be stated that such requirements are not fully applicable for floodable ports, as is Porto Alegre. Nevertheless, even though a climate risk assessment was predicted to be carried for the port in 2024, the events of May 2024 brought such magnitude of rainfall, together with such severity and increment of the impact chain, that even if a plan had been devised at that point using ANTAQ guidelines and based record of previous events, no such predictions would have been sufficient to prevent or mitigate most of the impacts of that event on the floodable port.

Silveira et al., (2024) showed that not only different sectors of Guaíba had different flooding patterns, but that such phenomenon was caused by a previously unidentified marked stream gradient between the Jacuí River delta and the southern part of Guaíba. Consequently, any robust plan of adaptation of the Porto Alegre port to withstand flooding episodes would benefit from applying sectorized risk assessment and emergency protocols, taking the distinct patterns into account.

Finally, based on water level measurements from the most recent flooding events (September and November, 2023, and May 2024) recorded by Tidesat (Fagundes et al., 2021), an approximate expected time period for upstream

stormwater to reach the Guaíba is between seven and ten days, with sharper increases in water level seen around 72 to 48 hours before arrival of the water surge. Accordingly, such information is also useful as basis of implementation for an alert system for the port.

5 Final Remarks

The analysis of existing regulation, plans, and protocols for the port of Porto Alegre shows they are insufficient to manage this floodable port, as we define it, based on recent flooding episodes and climate projections. Thusly, it becomes necessary to implement a Climate Risk or Climate Emergency Plan for the Port, in order to enforce preventive, mitigating and responsive measures for predicted flooding scenarios and limit the impacts that previously unconsidered natural hazards can cause to infrastructure and property in the port and its surrounding area. Moreover, the required Climate Emergency Plan will support the initial adaptations of the port facilities to withstand future flooding events as a floodable port, and possibly pave the way for it to reach a characterization as flood resilient port. Nevertheless, it is noted that this study's analysis was focused on the flooding component of natural hazards not uncommon for the region, and a robust Plan should assess the risk and impact of other climate-related natural hazards.

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