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Recognising na-tech events in Brazil: moving forward

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Abstract Loss of containment of industrial facilities and equipment triggered by natural hazards (called na-tech events) has been widely discussed in both the technical and scientific literature at least since the 1980s. Floods and landslides are amongst the most important immediate causes of na-tech events and may increase the risk to people and environment that is posed by facilities that handle hazardous materials. A na-tech event that occurred along the coastline of São Paulo state, Brazil, in February 2013, due to a precipitation event with a 1.5-h maximum rainfall of 209 mm, was the impetus for this study. We have investigated the availability of good data in some Brazilian accident databases aiming to support discussion about the increasing frequency and extent of na-tech events and the significance of the risk posed to humans by hazardous industrial facilities located in areas prone to occurrence of these events. The study has demonstrated that Brazil needs information sufficiently organised and accessible to enable evaluations of this risk, especially in coastal regions where there are predisposing factors for the occurrence of na-tech events. We propose both to include these events in the existing Brazilian accident databases and to optimise the databases by unifying or partially sharing the data. The ongoing initiative of the Brazilian National Civil Defence to improve its database can be expanded by recording na-tech events. Complementary research to identify potential sources of quality information on occurrences of na-tech events in the country is proposed in order to strengthen this initiative. Consequently, frequency analysis could be developed based on past incident data and the additional risk posed to humans by na-tech

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scenarios estimated and incorporated in a traditional quantitative risk assessment. Risk management in areas prone to na-tech events is expected to be improved.

Keywords Database · Quantitative risk assessment · Environmental management · Na-tech · Natural hazard

1 Introduction

Brazil has undergone an intensified industrialisation process since the 1950s, including the establishment of chemical and oil industries, amongst others, especially in coastal regions. At present, there are about 5000 chemical industries (pesticides, paints, and fibres, amongst others, with five or more employees) (IBGE 2013), three main petrochemical regions, 16 refineries, 19,700 km of pipelines (oil and natural gas), and a daily production of 2.1 million barrels of oil, predominantly from offshore drilling (ANP 2014). Approximately 78 % of the chemical industry and 66 % of the oil industry are concentrated in south-eastern[1] and southern[2] Brazil (IBGE 2013).

Industrial facilities that handle potentially environmentally hazardous materials (predominantly flammable and toxic liquids and gases) require analyses of the socio-environmental impacts and the definition of actions to mitigate, restore, or offset these impacts at a level considered adequate by environmental agencies before their implementation. In several of these cases, a traditional quantitative risk assessment (QRA) is also required, which allows for the evaluation of the human risk from these facilities whilst it is in operation, considering existing individual and societal risk criteria established in laws and regulations (IBAMA 2015a; CETESB 2014).

The Brazilian coastal region comprises approximately 8000 km of coast, encompassing the south-eastern coast, which includes São Paulo and Rio de Janeiro states and a portion of Espírito Santo and Paraná states, and is the most rugged stretch of Brazilian coastline. This region receives an annual mean rainfall between 1100 and 1500 mm, but with maximum annual rainfalls of greater than 4000 mm, the presence of overlapping soils, and tropical forest covering layers of coastal hills, it is subject to the strongest erosion and transport of soil within Brazil (Ab'Sáber 2005a, b).

The heavy rainfall across the south-eastern coast in 2013 resulted in damage to people and the environment along the highly industrialised and human-inhabited central coastline of São Paulo state. A few years earlier, another event that was also caused by intense rainfall occurred in Minas Gerais state, caused damage to the population and the environment that extended to the coastline of Rio de Janeiro state. These events, characterised by loss of containment of industrial facilities and equipment triggered by a natural event, in this case rainfall, are called na-tech events, a term originally coined by Showalter and Myers (1992).

Natural-event-triggered industrial structure damage studies have been published in the literature at least since the 1980s. Earthquakes are probably the most investigated initiating event, from methods to evaluate component failures and their effects (Kiremidjian et al. 1985) to those based on interview in order to investigate how the risk of earthquake-

[1] Espírito Santo, Minas Gerais, Rio de Janeiro, and São Paulo states.

[2] Paraná, Rio Grande do Sul, and Santa Catarina states.

generated hazardous material releases is perceived by local (Los Angeles area, USA) emergency managers of the public sector and the chemical process industries (Tierney and Anderson 1990). The strategy of listening to the people involved in emergency response was also adopted by Showalter and Myers (1992, 1994). They conducted a survey with emergency management agencies of 50 American states in order to investigate their perceptions of how natural (hurricane, tornado, flood, earthquake, and others) and technological events interact in the USA.

In keeping with the above-mentioned strategy, the Joint Research Centre (JRC) and the United Nations International Strategy for Disaster Reduction (UNISDR) held a workshop in Italy, 2003. Thirteen European countries shared their experience in na-tech event data and management. Amongst the recommendations, a comprehensive na-tech database with reports and lessons learnt was proposed by the workshop participants (Cruz et al. 2006).

Although quantitative risk assessment (QRA) has been required for at least 30 years by Brazilian State and Federal environmental agencies as part of the licensing process, failure frequency analysis has neglected natural events as a possible cause of loss of containment scenarios.

Considering the two na-tech reports and climate forecasts for increased temperature and rainfall for a significant portion of the Brazilian coast (Marengo et al. 2011), have the frequency and extent of na-tech events increased? Is the risk posed to humans by hazardous industrial facilities as a result of potential accidents triggered by natural hazard significant in Brazil, and does it require further management?

To answer these queries, this paper proposes both to include na-tech events in the existing Brazilian accident databases and to optimise them by unifying or partially sharing

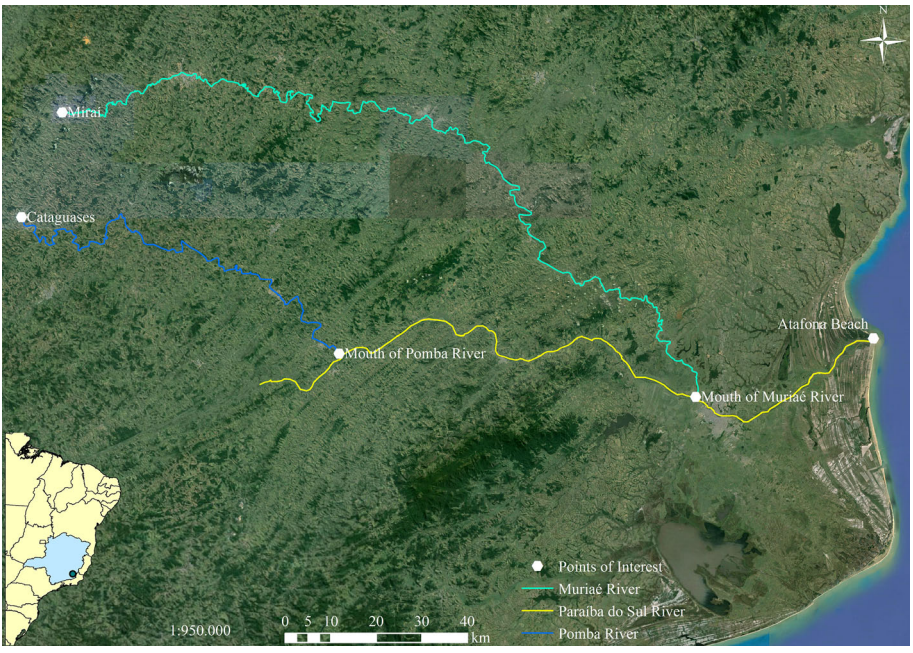

Fig. 1 Satellite photo of the municipalities of Cataguases and Miraí, Minas Gerais, and the Atafona beach, municipality of São João da Barra, Rio de Janeiro. (*Source*: adapted from Google Earth)

the data. Consequently, frequency analysis could be developed based on past incident data and the additional risk posed to humans by na-tech scenarios estimated and incorporated in a traditional QRA. Risk management in areas prone to na-tech events is expected to be improved.

The following sections are dedicated to present two flood-triggered chemical loss of containment that impacted the south-eastern coast of Brazil. It intends to illustrate how dangerous these na-tech events can be and to what extent detailed information is available. The relevance of good data is discussed in sequence taking as examples probabilistic and deterministic models developed or validated from past accident research. In sequence, we provide a discussion and recommendations on how to improve some Brazilian accident databases in order to clarify existent records of possible na-tech events and to properly register the new ones.

2 Selected non-na-tech and na-tech events in Brazil

There are examples of na-tech and non-na-tech events with significant socio-environmental impacts and the need for adequate management of this risk.

In 2003, a residue storage reservoir dam, associated with the pulp production in the municipality of Cataguases, Minas Gerais state, was breached. Twenty million cubic metres of toxic waste from the pulp bleaching process, containing sodium hydroxide and chlorine, contaminated small rivers that flow into the Pomba and Paraíba do Sul rivers and through the municipality of São João da Barra, Rio de Janeiro state, approximately 170 km downstream to the Atlantic Ocean (Fig. 1). The rural area of Cataguases was most affected, with flooding of residences, crops, and pastures (Brazil 2003; MMA 2003). The water contamination interrupted the clean water supply to 500,000 individuals, mainly in Rio de Janeiro state (Pedrosa 2007).

This non-na-tech event, which was classified as having a high environmental and social impact by the government and the press, stimulated the creation of the Brazilian National Plan for Prevention, Preparedness, and Rapid Response to Environmental Emergencies with Hazardous Chemical Materials (P2R2). Coordinated by the Brazilian Federal government, the main objective of the P2R2 is to prevent accidents that involve hazardous materials and to improve the systems of preparedness for and response to chemical emergencies in Brazil. The following are amongst the products of the P2R2: (1) maps that designate areas and activities prone to accidents involving hazardous substances and (2) databases with various purposes, including a record of accidents (Brazil 2004).

2.1 Mining-waste dam rupture in Miraí, Minas Gerais state, 2007

In January 2007, after 10 days of rain (217.2 mm total accumulation), a bauxite residue (mud) storage reservoir dam that belonged to a mining operation located in the municipality of Miraí, and located 22 km from Cataguases, was breached. Two million cubic metres of mud flooded a portion of the urban and rural area of the municipality, flowing into the Muriaé and Paraíba do Sul rivers, reaching the Atlantic Ocean (Fig. 1). Approximately 3800 individuals of the 12,428 inhabitants were affected. The water supply in Miraí was interrupted for 48 h, power lines and sewer lines were destroyed, and the local agriculture was damaged (Brazil 2007).

2.2 Debris flow and flood in Cubatão, São Paulo state, 2013

In February 2013, after an intense rain (1.5 h maximum rainfall of 209 mm and 24 h accumulation of 272.2 mm) within the Baixada Santista region, located in the central coastline of São Paulo, there were landslides in Serra do Mar and floods in the municipality of Cubatão, displacing 1200 people and leaving another 330 homeless; there was one death caused by a mud flow that reached a portion of the Imigrantes highway (SP-160). Residences were damaged, and the supplies of water and energy and communication systems were interrupted (São Paulo 2013). The debris flow and flood events affected at least two oil-related installations and one drinking water treatment plant (ETA Pilões) located in the Cubatão river basin (Fig. 2). An approximately 200 m tall debris flow destroyed a portion of the ETA Pilões, dragging five chlorine gas (Cl_2) cylinders, each with an individual capacity of 900 kg. After 6 days of search efforts, the three cylinders were found less than 4 km from the ETA at the Itutinga Pilões Centre. On the seventh day, a cylinder was found, full of water and with the top valve broken, adjacent to the Vila dos Pescadores (17 km from the ETA), and another was located within the Vicente de Carvalho region (29 km from the ETA) in the channel of the port of Santos, municipality of Guarujá. Within the region of low altitude (below 10 m), the Cubatão river overflowed the riverbanks and flooded the Cubatão Terminal (an oil storage depot) and a portion of an oil refinery. In both cases, the oil-contaminated water treatment systems overflowed into the Cubatão river. At the depot, the containment basins of two tanks also collapsed, but there were no leaks detected (CETESB 2015).

Fig. 2 Satellite photo of the Baixada Santista region. 1. ETA Pilões (drinking water treatment plant), elevation: 200 m. 2. Oil Terminal, elevation: <10 m. 3. Oil Refinery, elevation: <10 m. Itutinga Pilões Centre, Vila dos Pescadores, and Vicente de Carvalho are the sites where the five chlorine cylinders were found. (*Source*: adapted from Google Earth)

The above-mentioned 2007 and 2013 na-tech events have common characteristics because they occurred close to important water bodies for human supply and for industrial use. The transport by flooded rivers of various residues (e.g. bauxite mud and oil) and the chlorine cylinders increased the extent of damage caused by these events and most likely imposed additional damages to society beyond the flooding itself. These events were also characterised by features common to other na-tech events, such as the simultaneity of events (i.e. occurrences of heavy rainfall and releases of hazardous substances into the environment) and multiple sources of the release of hazardous substances during a single natural event (Krausmann et al. 2011a; Sengul et al. 2012).

In the next section, the contributions of databases to the diagnosis of na-tech events and to risk estimation and management are discussed.

3 Na-tech events and information demands

Although predominantly from official sources, the previous reports of the three leaks do not provide sufficient data for the identification of the component failure modes, the amount of the substance released into the environment, and the evaluation of the damages caused to the environment and to the human populations. For example, in the case of the event in Cubatão, even though it was a recent occurrence, there is no information regarding the number of chlorine cylinders in use, the quantity of chlorine effectively lost, and the possible damage to the aquatic life of the Cubatão river basin.

Information systems—here understood as structures for the collection, treatment, storage, and availability of data—should be planned and adequately maintained and operated. Consequently, they can allow for increased vigilance at sites that can potentially generate na-tech events by anticipating adaptation actions for the population and businesses and structuring emergency-response actions that are compatible with natural events and with na-tech events.

Databases of occurrences (accidents or near-misses, losses of containment) are an essential component of these systems, and they could be analysed, if properly fed, to uncover important aspects of the na-tech events of 2007 and 2013, such as the type and territorial extent of the damage, their causes, and the existence and efficacy of emergency-response plans, as well as to improve or develop simplified equipment-vulnerability models that can be used in QRA (Krausmann et al. 2011b).

Various procedures that allow for the estimation of risk indices (individual and societal risk) based on available historical data have been proposed. The expected frequencies and magnitudes of seismic events and subsequently estimations of the vulnerabilities of equipment to natural events were calculated by Salzano et al. (2003) for unpressurised storage tanks and by Antonioni et al. (2007) for pressurised tanks. The buckling frequency of unpressurised and pressurised tanks have been estimated for na-tech scenarios triggered by floods, and the models were validated by the results retrieved from the accident databases (Landucci et al. 2012, 2013).

However, were these databases planned for na-tech events? Necci et al. (2014), when discussing the effects of lightning (a na-tech event) on aboveground tanks that store flammable substances, reported that only 34 of the 1,030 reports of accidents retrieved from European and North American accident databases had sufficient details on the protection and mitigation safety barriers necessary for developing the proposed study. The results of Santella et al. (2011), who analysed American databases, or of Cozzani et al.

(2010), who studied European and North American databases, indicate the need for structuring databases to satisfactorily describe na-tech events. Nevertheless, these authors were still able to identify information that supported the development of deterministic models (Antonioni et al. 2009; Landucci et al. 2012) and probabilistic models (Santella et al. 2011), which enable estimations of the risk posed by industrial facilities subject to na-tech events.

The absence of a database specific to na-tech events also applies to Russia, where an accident database was recently started to collect information concerning several types of technological accidents, such as breaks in power transmission lines, train derailments, or fires and explosions in coal mines. Amongst the causes of such events, natural causes were responsible for approximately 10 % of the events that occurred between 1991 and 2010, and approximately 8 % of this total (0.10×0.08) was attributed to na-tech events (Petrova 2011).

Renni et al. (2010) and Krausmann and Baranzini (2012) have discussed the European Commission's efforts in structuring a specific database (European Commission 2011), which is understood to be necessary based on a broad discussion and understanding of the relevance of these events, which can impose significant losses considering the effects of climate change, for example, on hydro-meteorological events.

In response to the increased interest in adequately recreating the history of European and global losses for multiple purposes, the European Union recently released a study by the Joint Research Centre (JRC) that provides recommendations for standardising databases of losses from disasters within Europe and procedures for compiling the loss data at a global level. The goal is to enable the identification, assessment, and monitoring of disaster risks in accord with The Hyogo Framework for Action, considering risk modelling as a critical application tool (De Groeve et al. 2013).

Other existing free-access databases can provide relevant insights when planning an information system. For instance, the criteria to report either a major accident or a disaster have been observed in both EMARS (EU 2015) and EM-DAT (Guha-Sapir et al. 2015) databases, respectively. EMARS, established by the EU's Seveso Directive 82/501/EEC in 1982, contains reports of chemical accidents and near-misses from EU, Organisation for Economic Co-operation and Development (OECD) and United Nations Economic Commission for Europe (UNECE) countries as well as other countries. The criteria require amongst other items: (1) at least one death or one person outside the establishment hospitalised for at least 24 h, or (2) significant or long-term damage to freshwater and marine habitats (EU 2012). EM-DAT was created by the Centre for Research on the Epidemiology of Disasters (CRED) in 1988 and contains over 18,000 registers on natural and technological disasters in the world from 1900 to present. The criteria to report on an event as a disaster require amongst others at least 10 deaths or 100 people affected.

Another interesting aspect observed in EM-DAT and also in DesInventar (LA RED 2015) is the strategy to recover old information from press agencies and newspapers sources. DesInventar, created by groups of researchers, academicians, and institutional agents linked to the Network of Social Studies in the Prevention of Disasters in Latin America (Red de Estudios Sociales en Prevención de Desastres en América Latina—LA RED) in 1994, has currently provided information about disasters of small, medium, and high impact in 22 countries in Latin America, excluding Brazil, four in Asia, two in Africa and one in Oceania.

A country-focused database is a characteristic of ARIA (BARPI 2015) that lists over 40,000 accidents and incidents, of which about 37,000 of which had occurred in France. They were mainly caused by industrial or agricultural facilities with impact on health or

public safety, agriculture, nature, or the environment. ARIA was established in 1992 and is operated by the French Ministry of Ecology, Sustainable Development and Energy.

Databases that are planned to meet quantitative goals can support risk estimates used in both land-use planning and environmental licensing, e.g. for the typical case of estimating the risks imposed by pipelines where failure modes, likely scenarios, and the frequencies of these scenarios, are extracted from databases such as the European Gas Pipeline Incident Data Group (EGIG 2015) and the Conservation of Clean Air And Water in Europe (CONCAWE 2015).

Thus, not only the existence of a database, but also the planning of its contents to meet specific objectives, such as a QRA, is essential and may be realised by the combined efforts of institutions that act in the prevention of, preparedness for, and response to industrial accidents.

In Brazil, this study identified a few databases that regularly report events of releases of hazardous materials into the environment.

The P2R2 envisioned the creation of an accident database of the releases of chemicals into the environment. According to the website of the Brazilian Ministry of Environment (MMA), there are a number of descriptive statistics for the period between 2006 and 2010. The occurrences of releases were regularly distributed throughout the year, with approximately 75 reports/month and a predominance of accidents involving the road transport of these substances, approximately 550–900 reports/year. Vehicular diesel fuel and gasoline are the most frequently reported releases, with 190 and 75 reports/year, respectively (MMA 2015). On the website of the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), the agency (linked to the MMA) responsible for executing Brazilian environmental policies, yearly reports of occurrences of releases between 2006 and 2014 can be ordered. The site of occurrence, substance, type of transport, environmental goods affected, and, in certain cases, cause of and quantity of the release can be individually identified (IBAMA 2015b). Both websites lack options to search by keywords, which would facilitate the retrieval of specific occurrences (for example, those involving natural causes, retrieved to better understand the occurrence of na-tech events in Brazil).

Nevertheless, the Brazilian Civil Defence (BCD) has developed the Risk Management and Disaster Response programme, which includes the development of the Brazilian Atlas of Natural Disasters for the period between 1991 and 2010, and the Disaster Database and Record, a database planned to record various types of occurrences of hydrometeorological and geological phenomena, the handling of hazardous materials, including radioactive substances, and occurrences of diseases relevant to public health (Brazil 2015).

Another Brazilian federal initiative, the Brazilian National Centre for Natural Disaster Monitoring and Alert (CEMADEN), proposes to develop multidisciplinary inventories of disasters in Brazil, including the characterisation of these disasters in terms of their socio-environmental, meteorological, hydrological, and geological information and in terms of their impacts on the population and the economy of the region associated with these disasters. The monitoring results performed by the centre starting in December 2011 were not yet available at the end of this study.

In São Paulo, the State Civil Defence (SPCD) maintains occurrence records, the access to which is restricted to those who are interested in applying and registering for access. The CETESB, state environmental agency, maintains a database that contains approximately 10,000 occurrences, the majority of which involve releases of hazardous substances into the environment (CETESB 2015). The reports begin in 1978 and refer to the agency's participation in responding to these occurrences. The database allows for the retrieval of occurrences based on several search keys, including the cause of the occurrence. However,

available information is limited, which reduces the understanding of the occurrence. For instance, the search indicated three occurrences between 1978 and November 2015 when the key "natural" was chosen without specifying to which natural event the database refers.

Except for the database of the BCD, the other databases lack the aforementioned search tools or enough details that would allow for the direct, or even indirect, identification of na-tech events. In certain cases, these databases also lack updated data, and a strategy for recording failure modes and immediate causes of releases should be established to support the development of simple quantitative procedures for estimating the frequency and impacts of releases.

4 Discussion

Predisposing factors for the occurrence of na-tech events along the coastal portions of south-eastern and southern Brazil, especially those caused by floods and landslides, are as follows: (1) areas prone to these natural hazards, with the presence of steep slopes, rivers that originate from or cross these slopes, (2) several industrial centres (the majority of these are located close to the ports of Rio de Janeiro, São Sebastião, Santos, and Paranaguá) that store large quantities of hazardous substances and transport these substances by pipelines, highways, and railroads, and (3) areas of high population density interspersed by water bodies.

The influence of these predisposing factors is evident during the na-tech event of 2013 that occurred in Cubatão, a intensively industrialised city of approximately 120,000 inhabitants with urban area interspersed by the Cubatão river, an oil refinery, a steel industry, several chemical industries, oil-derivative storage depots, and an extensive pipeline network. The loss of containment of hazardous materials by equipment and structures, such as pressurised vessels and reservoirs located at ground level, and the consequent release of chlorine and oil residues into the environment, respectively, illustrate the potential for amplifying the level of socio-environmental damage caused by a single natural event, in this case, a heavy rainfall.

Traditional QRAs based on scenarios for loss of containment have been performed in Brazil since the 1980s for the environmental licensing of industrial facilities that handle hazardous substances. The impacts of releases are quantified by mathematical models that simulate physical processes, such as fires, explosions, or toxic dispersions, and their frequencies are estimated based on generic equipment and human failure data from international sources. Risk indicators can thus be expressed in terms of societal risk and an individual risk (typically considering human fatality as the endpoint), which are evaluated based on criteria proposed in existing regulations (IBAMA 2015a; CETESB 2014).

The use of international data can also be applied to estimate the extent to which these industrial facilities pose risks of na-tech scenarios to the human population and to the environment by simply considering, for example, the parameters proposed by Antonioni et al. (2009) and Landucci et al. (2012, 2013) for evaluating risks from equipment and natural events, providing an estimate of this contribution. However, the estimate of the contribution of na-tech events within a QRA can possibly be improved by evaluating similar previous accidents occurred in Brazil based on retrieved records of various origins, such as the aforementioned Brazilian accident databases, newspapers, and the technical and scientific literature. Current accident database records might also be improved by

incorporating metrics relevant to the na-tech event of interest (e.g. in the typical case for floods, records of the maximum water depth and water velocity parameters are necessary).

Similar to Europe and the USA (Galderisi et al. 2008; Krausmann and Baranzini 2012), the management strategies for natural accidents and for technological accidents have been developed in parallel in Brazil, where there has been no convergence of the two for addressing na-tech events. Within Brazil, there are two lines of effort to record these types of occurrences: that of the Environmental Agencies, involving the release of chemical materials into the atmosphere (MMA 2015; IBAMA 2015b), and that of the Civil Defence, which is associated with the occurrence of hydrometeorological and geological phenomena, namely, natural disasters (Brazil 2015). Within São Paulo, the data recorded by the SPCD are not easily retrievable, whereas those available from the CETESB, although easily recovered, do not provide greater detail, especially on the immediate causes of the occurrences of events.

As previously mentioned, elucidation of the relevance of na-tech events in Brazil, implying in the investigation of the frequency and extent trends of na-tech events that have occurred over the last 30–40 years, whilst also considering, for example, the effects of climate change under discussion, can be achieved by expanding the actions already underway at the federal and state levels for establishing and maintaining records of occurrences that involve releases of hazardous substances into the environment, for example, by establishing a record of na-tech events through maintaining a single database or even sharing portions of existing databases to recover this type of information.

The planning of this database, whether new or comprising existing databases, must consider the need to retrieve data relevant to QRA, such as those related to the natural event (for example, rain intensity, water velocity, and water depth, in the case of floods), the substance released, the inventory, dimensions, and construction materials of the equipment affected, the failure modes that led to the loss of containment (rupture, hole), the presence of physical barriers that reduced the impact of the natural event on the equipment (e.g. if dikes surround the tanks), the sequence of events regarding the dispersion of the substance in water or in the atmosphere, the occurrences of explosions and fires, the socio-environmental goods affected, the types and numbers of loss of containment scenarios caused by the same natural event, the remediation activities, and the lessons learned.

The efficacy of the implemented emergency-response actions is also of interest. Was there a plan for emergency—response that considers na-tech scenarios? Were the actions implemented as planned? How did the action to address the situation progress with the sequence of events after the spill? Was there a need to share human and material resources to respond to the natural event? Was there socio-environmental damage? What were the economic losses?

Relevant insights, such as the strategy present in EM-DAT and DesInventar to recover old information from press agencies and newspapers sources, or a database which mainly reports on national events, such as ARIA, are already part of the BCD database. Moreover, the establishment of criteria to report on major accidents and disasters, as present in EMARS and EM-DAT, can better delimitate these concepts, providing more adequacy to the register of an event and agreement with international efforts for reporting accidents and disasters, e.g. JRC and The Hyogo Framework for Action.

The search tools present in the database of the BCD, such as those for the delimitation of the period, region (of country, state, or municipality), type of natural event or hazard (flood, landslide) of interest or keywords, are similar to those provided by JRC's enatech

database, indicating that small changes in this database would be sufficient to retrieve na-tech events.

Databases are usually a portion of information system, as in the case of the database of the BCD. As a strategy, this system must provide intense guidance for those responsible for recording the na-tech event, with a list of data of interest by hazard (na-tech event), a suitable collection time (moments before, during, or after the event), an event-measuring instrument, a method to populate the database, a review of the data, and the ability to upload reports, studies, and images, amongst other sources of data that might be uploaded to the database. A system similar to that recently proposed by the European initiative for managing emergent risks, such as risks from na-tech events, that incorporates knowledge, monitoring, and mapping tools (Jovanovic et al. 2012) could be implemented.

The systematic recording of na-tech events would support analyses of their occurrence at temporal and spatial scales, providing data on factors such as the intensity and frequency of occurrence, which are essential for conducting a QRA, and, based on this QRA, to know the significance of the risk posed to humans by hazardous industrial facilities as a result of potential accidents triggered by natural hazards.

The consideration of na-tech scenarios, whose relevance can be better evaluated based on the given records of the region of interest, will enable the development of more accurate risk indices to be included in QRAs for industrial facilities that handle hazardous materials and that are located in regions prone to occurrences of na-tech events. It is understood that this level of accuracy can contribute to improving risk management practices for hazardous industrial facilities not only in Brazil but worldwide, especially for land-use planning purposes, a responsibility of municipalities in Brazil.

5 Conclusions

This study has demonstrated that Brazil needs information sufficiently organised and accessible to enable evaluations of the risk posed to humans from na-tech scenarios that affect industrial facilities that handle hazardous substances, especially in coastal regions where there are predisposing factors for the occurrence of these events.

However, there have been several initiatives to systematise information on natural and technological accidents that can provide information that, with adjustments, can be applied to address na-tech events in Brazil. The compilation of the records stored in current databases to create a database designed for the retrieval of information on na-tech events can provide a starting point for a greater level of integration amongst the diverse government stakeholders that are involved in managing accidents and, consequently, optimising actions and resources to respond to a na-tech event.

The ongoing initiative of the BCD could be extended to include na-tech events in its database. However, these government efforts must be strengthened and complemented by research to identify potential sources of quality information on the occurrence of these events in Brazil to optimise the existing accident databases by unifying or partially sharing the data to provide a single database from which to retrieve these occurrences will be possible, based on public consultation.

The possibility to retrieve records that are organised consistently in time and space and include information appropriate for the quantification of the frequency of occurrence of a na-tech event and the intensity of its impacts allows one both (1) to discern the risk posed to humans by na-tech scenarios in the QRAs of industrial facilities that handle hazardous

substances and that are located in regions prone to occurrence of na-tech events, and (2) to elucidate the potential damage to the environment that are not usually considered in a QRA.

This additional contribution to the QRA may become relevant in the planning of land uses by new industrial facilities at sites prone to natural hazard events, with the possibility of intervention in the project to reduce any such susceptibility and risk. It is also important for existing industrial facilities to incorporate na-tech scenarios into emergency-response plans.

A record of na-tech events in Brazil that is consistent in time and space can contribute to the understanding of their occurrences within the region (South America) and within the Southern Hemisphere, supporting analyses of the prevalent hazards in tropical and equatorial coastal regions with high human population densities.

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