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Neighborhoods with high exposure to technological risks in Paranaguá, Paraná, Brazil.

Bairros de elevada exposição a riscos tecnológicos em Paranaguá, Paraná, Brasil

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Abstract: Urban communities may be exposed to sudden technological events, such as explosions, or to recurring events, such as air pollution. The municipality of Paranaguá, on the coast of the State of Paraná, Brazil, has port and industrial activities intertwined with housing units. In 2024, the municipality began preparing the Municipal Risk Reduction Plan, which aims to propose and implement actions to prevent and mitigate disasters in urban peripheries. Within this municipality, the present study highlights the potential exposure of residents in port and port-adjacent neighborhoods to sudden explosion hazards and recurring poor air quality hazards. The methodology involved selecting variables for the respective processes. The results demonstrate that four of the nine neighborhoods studied are distinguished by the presence of flammable-liquid storage tanks, access roads, and transport pipelines, indicating their exposure to potential explosions. Similarly, three other neighborhoods stand out due to the presence of grain and fertilizer warehouses and the intensity of daily truck traffic, evidence of their exposure to poor air quality. These findings can assist in investigating, developing intervention proposals, and formulating local public policies.

Keywords: sudden technological risk; recurring technological risk; explosion; air quality; Municipal Risk Reduction Plan.

Resumo: Comunidades urbanas podem estar expostas a eventos de origem tecnológica repentina, como explosões, ou recorrentes, como poluentes no ar. O município de Paranaguá, na costa do Estado do Paraná, apresenta atividades portuárias e industriais imbricadas a núcleos habitacionais. Em 2024, o município inicia a elaboração do Plano Municipal de Redução de Riscos, que visa propor e implementar ações relacionadas à prevenção e à mitigação de desastres nas periferias urbanas. No referido município, a presente pesquisa destaca a potencial exposição de residentes de bairros da área portuária e retroportuária, ao perigo abrupto de explosão e ao risco recorrente da produção de baixa qualidade do ar. A metodologia envolveu a seleção de variáveis dos respectivos processos. Os resultados demonstram que quatro dos nove bairros estudados se destacam dos demais pela presença dos tanques de armazenamento de líquidos inflamáveis, suas vias e dutos de transporte, o que evidencia a exposição a potenciais explosões. Da mesma forma, outros três bairros se destacam pela presença dos armazéns de grãos e fertilizantes e a intensidade da circulação diária de caminhões, fatores que evidenciam a exposição à baixa qualidade do ar. Os resultados podem auxiliar no processo de investigação, elaboração de propostas de intervenção e políticas públicas locais.

Palavras-chave: risco tecnológico repentino; risco tecnológico recorrente; explosão; qualidade do ar; Plano Municipal de Redução de Riscos.

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1 Introduction

Population growth and industrial and technological development, coupled with increasing urbanization, particularly when unplanned, can result in incompatible land uses and expose residents to hazards of various origins that may lead to technological accidents (Secretaria Nacional de Defesa Civil, 2004). These accidents can affect communities and businesses alike, and their impacts and consequences for humans can be large- or small-scale, frequent or not, sudden or slow in onset (United Nations, 2015). Regarding the occurrence of accidents, Oliveira and Borges (2018) introduce the terms acute and chronic exposure to technological risk, referring respectively to sudden and recurring phenomena.

In addition, the hazard definition of the United Nations International Strategy for Disaster Risk Reduction (UNISDRR) incorporates process and human origin, among other aspects (UNISDRR, 2017). Once hazard sources are identified, characterizing exposure requires comprehensive, interdisciplinary information (Freitas & Gomez, 1996; Porto & Freitas, 1997). Despite the apparent simplicity of this concept, Bosque Sendra et al. (2004) note that its spatial delimitation depends on the nature of the substance involved and the process to which it is subject, the physical environmental conditions in which its effects may spread, and the number of people and activities likely to be affected, among other factors. Naturally, the closer the proximity to the hazard source, the greater the exposure (Oliveira & Borges, 2018).

Cahen (2006) and Zhou and Liu (2012) argue that land use must be controlled at new sites with large industrial facilities and chemical or petroleum storage depots. Pekalski et al. (2005) note that fires are the most common incidents in the process industry, but explosions cause the most severe losses. For Bouamrane et al. (2012), the road transport of hazardous materials is one of the main technological risks, exposing the population to pollution, explosion, and fire. This stems from its mobile and diverse nature, that is, by the variety of substances transported and the territories covered, particularly in densely occupied urban centers (Bencherif, 2024).

The municipality of Paranaguá, on the coast of the State of Paraná in southern Brazil, is home to Dom Pedro II Port, whose throughput of solid and liquid bulk cargo ranks it among Brazil's leading ports. The port-adjacent zone contains industrial facilities interspersed with residential areas. In this zone, Tonetti et al. (2016) documented a concentration of land uses with high pollution potential. Gouvêa and Tonetti (2017) identified the chemical substances handled or stored by local businesses and found that 40% of the businesses handled or stored flammable gases, liquids, or solids. Torrisi et al. (2017) and Gouvêa-Dantas et al. (2021) simulated boiling liquid expanding vapor explosions (BLEVEs) involving flammable-liquid storage tanks under specific conditions, demonstrating the exposure of nearby populations to these hazards and highlighting the need to review

and implement preventive measures within municipal management instruments.

Regarding air quality, Souza et al. (2020) highlighted the potential influence of truck traffic and fertilizer companies on air pollutant concentrations, specifically total suspended particulates and ammonia, respectively. Santos et al. (2022) corroborated these findings through air quality monitoring, concluding that the area surrounding port warehouses and access roads, compared with residential sectors, exhibited total suspended particulate concentrations above established limits. Furthermore, in an air quality monitoring study conducted in Paranaguá, Santana et al. (2020) associated excessive concentrations of suspended particulate matter with diameters of up to 10 μm with heavy vehicle traffic between 6:00 a.m. and 8:00 p.m. on weekdays, observed on 12% of the analyzed days. These authors (*op. cit.*) suggested that population exposure to these pollutants may be related to the high number of respiratory disease cases recorded in the public healthcare system.

From the standpoint of the National Policy for Civil Protection and Defense (*Política Nacional de Proteção e Defesa Civil* – PNPDC), municipalities are responsible for mapping areas subject to disasters (*Lei nº 12.608*, 2012). This activity represents an initial step toward strengthening community resilience (Bang, 2022), understood as the ability of communities to cope with uncertainty and change through adaptation, learning, and self-organization (Buschbacher, 2014).

In 2024, the municipality of Paranaguá was included in a federal government program coordinated by the National Secretariat for Peripheries, called *Periferia sem Risco* (Peripheries Without Risk), for the development of the Municipal Risk Reduction Plan (*Plano Municipal de Redução de Riscos* – PMRR), aimed at proposing and implementing actions for disaster risk prevention and mitigation in urban peripheries. The initiative aims to shift the focus of public action from disaster response and emergency assistance toward risk prevention (Ministério das Cidades, 2024). The program introduces the technological hazard typology into municipal planning, whereas previous risk assessments had been limited to hydrological and geological hazards.

In this context, the PMRR aligns with the Sendai Framework (United Nations, 2015) and with Areosa's (2008, p. 45) remark that "if we want to prevent the undesirable effects of hazards [...], society needs to understand, reflect on, and manage such risks". This gives rise to the need to consider the combined effects and synergy of land uses involving communities in the face of technological hazards.

Thus, broadly speaking, the present study aims to highlight the potential exposure of residents of neighborhoods in the port and port-adjacent areas to the sudden explosion hazard and to the recurring poor air quality hazard, both resulting from the concentration of industrial-port

land uses in the urban area of the municipality of Paranaguá. This research is justified by the need for "spatial representation of hazards at different scales, based on an academically recognized conceptual framework, given its importance for research and teaching and its comprehensibility for the community" (Dagnino & Carpi-Junior, 2007, p. 51). In addition, Porto and Freitas (1997) note that risks grow faster than the capacity to analyze them, increasing societal vulnerability – particularly in countries such as Brazil, whose existing socioeconomic, technical, and institutional weaknesses make societies more vulnerable to technological risks.

Accordingly, urban planning must anticipate and manage the socio-spatial conflicts arising from changes brought about by interventions, a primary requirement to prevent vulnerable communities from suffering their negative effects (Cassilha & Cassilha, 2012). Thus, in the face of technological hazards, land use planning – as carried out in the preparation of municipal master plans – is an element of the multilevel security concept discussed by Christou et al. (2006), with the potential to incorporate more lasting actions through community participation. In line with this view, Leite & Campagnone (2020) advocate a collective construction process and guidelines converging toward community resilience and urban sustainability, including the development of action plans in response to accidents exacerbated by the effects of climate change.

2 Methodology

The present study can be considered partly exploratory because it seeks to demonstrate the relevance of technological risk in urban areas, and partly descriptive because it characterizes the phenomenon based on the spatial distribution of the variables analyzed (Gil, 2002). From this perspective, no causal relationships are established. Instead, the study identifies factors that may contribute to the occurrence of a given event, as reflected in the structuring elements of the landscape under investigation (Nucci & Presotto, 2009).

The study was conducted in the municipality of Paranaguá (Figure 1), located within the Atlantic Forest biome, bounded to the west by the Serra do Mar mountain range and to the east by the Atlantic Ocean. According to the Paraná Institute for Economic and Social Development (*Instituto Paranaense de Desenvolvimento Econômico e Social* – IPARDES), its territory spans 809.5 km^2 and has 149,819 inhabitants, approximately 95.6% of whom live in the urban area (IPARDES, 2025). Data from the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística* – IBGE) show that 68,839 of these inhabitants live in informal settlements (*favelas*), representing 47.2% of the population, the highest percentage in the state, where the average is 3.86% (IBGE, 2025).

Land use and occupation zoning established by Complementary Law 296/2022 served as the basis for the analysis. The law delimits the Organized

Port Zone and the Port-adjacent Zone (Paranaguá, 2022), where piers, warehouses, industries, and other related activities are primarily located.

To delimit the study area, information contained in the report prepared by the PMRR technical team of Paranaguá was considered (PMRR-Paranaguá, 2024). In this document, a workshop with the municipal steering committee, which included representatives from municipal secretariats, indicated that neighborhoods in the port area and part of the port-adjacent area are subject to technological risks related to explosion, fire, and leakage processes. Additionally, results from Tonetti et al. (2025) on the overlap of the direct influence areas of six companies in the port-adjacent zone were incorporated into the analysis.

Given the findings of the PMRR and considering community organization, the neighborhood was adopted as the unit of analysis. The neighborhoods selected for the study were Dom Pedro II, Industrial, Rocio, Serraria do Rocha, Vila Alboit, Vila Guadalupe, Vila Portuária, Vila Rute, and 29 de Julho (Figure 1). This scale was chosen because the neighborhood is the level at which residents can organize collective efforts to promote and implement technological risk mitigation measures. Furthermore, the diversity of substances and industrial processes involved made the use of atmospheric dispersion modeling or accident simulations impractical.

In these neighborhoods, land use was mapped through visual interpretation of the most recent (2024) *Google Earth Pro* imagery and verified by field visits conducted in January and February 2025 to resolve uncertain cases. The following land use categories were identified: companies storing or transporting flammable liquids, companies storing grain or fertilizer, other industrial and port-related land uses, institutional uses, commercial uses, truck parking areas, and residential uses. The distribution of flammable-liquid transport pipelines and the roads and railways used for transporting liquid and solid bulk cargo was obtained from the Neighborhood Impact Studies (*Estudos de Impacto de Vizinhança* – EIVs) prepared for the respective companies and made available on the municipal government's website (Paranaguá, 2025), as well as from the imagery and field visits.

The history of hazardous accidents related to explosion, fire, and leakage was obtained from Appendix G of PMRR-Paranaguá's technical report No. 1 (2024). The occurrence of other companies handling hazardous products in the neighborhoods, in addition to flammable-liquid tanks, was obtained from a fire department survey image showing the distribution of these companies in Paranaguá (Defesa Civil Paraná, 2013).

Neighborhood population data were obtained from the IBGE (2025) neighborhood-level statistical reference tables, based on the 2022 Demographic Census. The number of trucks circulating through each neighborhood was estimated using information from the EIVs available on the Paranaguá municipal government's website, under the Municipal Urban Planning Secretariat section (Paranaguá, 2025). EIVs for companies handling and storing liquid bulk cargo (represented in this study by

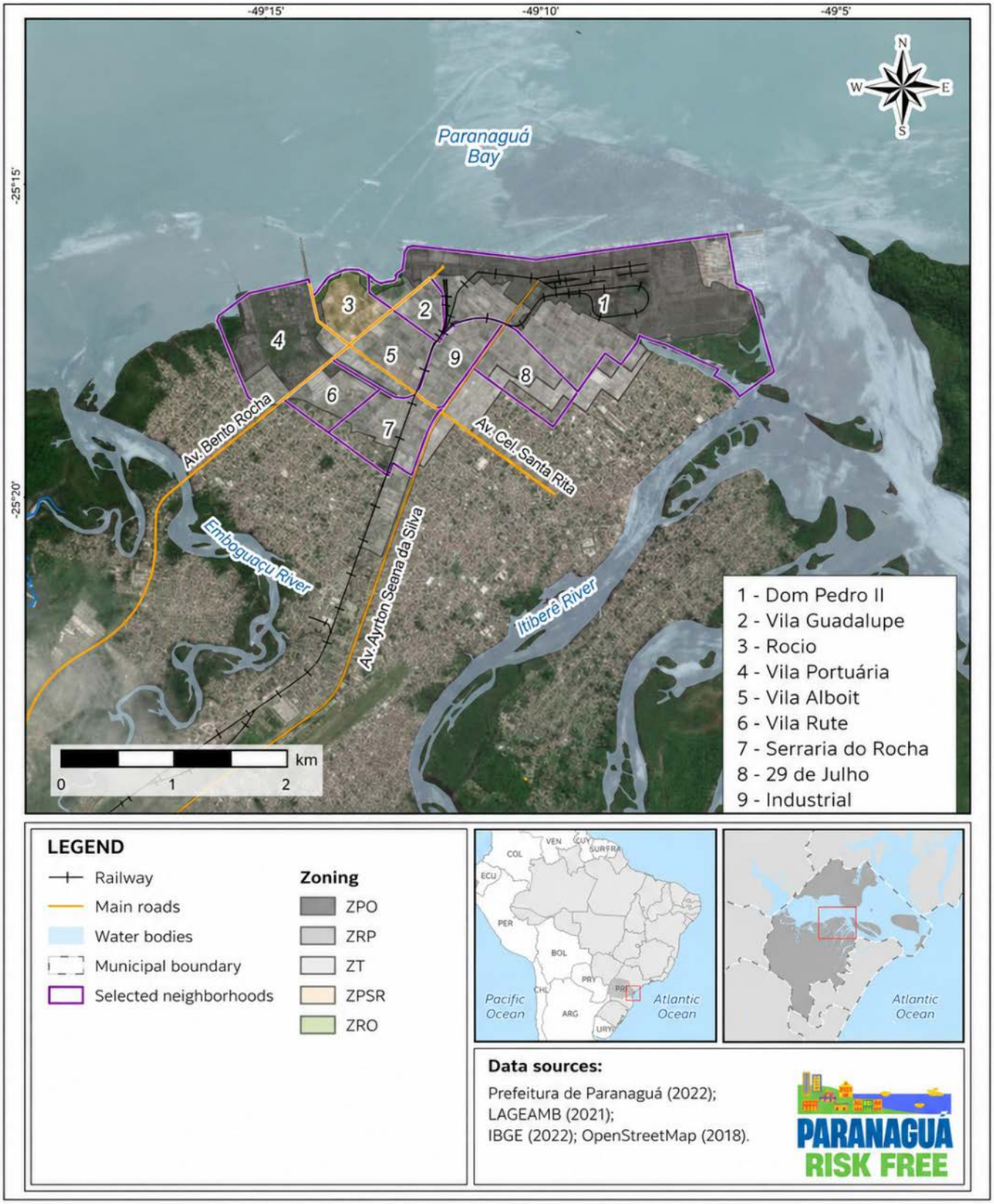


Figure 1 Municipality of Paranaguá and the neighborhoods studied.

flammable liquids) and solid bulk cargo (represented by grain and fertilizer) were selected. EIVs from companies outside these categories were used to estimate the daily number of trucks associated with the "other industrial-

port uses" category. For each EIV, the potential daily truck traffic and the storage area were recorded. The average ratio between these variables was then applied to the collected data to estimate the daily number of trucks associated with each company category traveling through the study neighborhoods.

It was not possible to estimate the daily number of railcars by land use category, although the overall daily volume is approximately 550 railcars (Portos do Paraná, 2025). Truck parking areas were excluded from the estimates because they were considered waiting areas for entering or leaving company facilities. This methodological approach was adopted to ensure a practical and efficient data collection process. Although it has limitations in representing local conditions, these limitations can be partially addressed by comparing the estimates with information published on the websites of local companies involved in handling liquid and solid bulk cargo.

The results were analyzed through visual interpretation of thematic maps and correlation charts for the sudden explosion hazard and the recurring poor air quality hazard.

3 Results and discussion

Distinguishing and characterizing neighborhoods exposed to sudden and/or recurring technological hazards requires identifying and mapping hazard sources. To this end, the land use survey of the study area (Figure 2) reveals the intermingling of different land uses, with a certain spatial organization between businesses and residences across the neighborhoods. Among these industrial and port-related uses, the storage of flammable liquids, grain, and fertilizer stands out. Storage of flammable liquids is more concentrated in the central and western portions, grain storage in the northern portion, and fertilizer storage in the central and eastern portions of the urban study area (Figure 2). Residential use occurs in the southwestern portion but is also interspersed among other uses in the central, eastern, and northwestern areas. Residences are generally concentrated within each neighborhood. Truck parking areas are present in almost all neighborhoods, along with other businesses such as general warehouses, container facilities, and port maintenance and support operations.

Silva et al. (2025) observed a 33% decline in residential use in this area, along with increases of 135% in liquid bulk storage areas, 117% in solid bulk silos, and 32% in general warehouses. The expansion, concentration, and distribution of these land uses support the air quality monitoring results reported by Gurgatz et al. (2017), who found that the port and port-adjacent region and their access roads had significantly higher atmospheric pollutant levels than the more distant residential areas of these neighborhoods, as these land uses represent sources with high pollution potential (Tonetti et al., 2016).

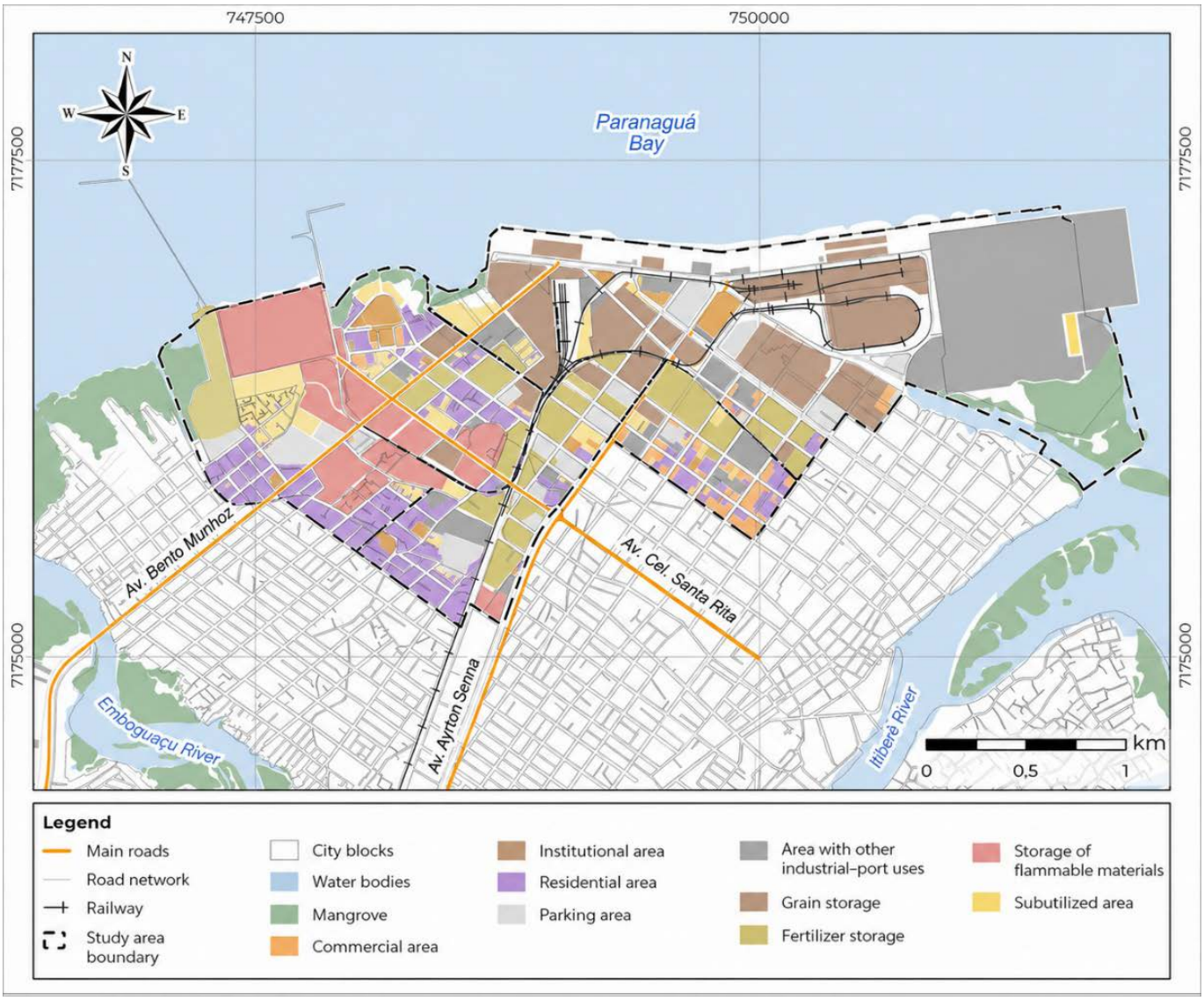


Figure 2
Land use in the neighborhoods studied.

The presence of flammable-liquid storage tanks in the Vila Portuária, Vila Rute, Vila Alboit, and Serraria do Rocha neighborhoods indicates an explosion hazard and the close proximity of these facilities to residential areas (Figure 3). Pipelines connecting the storage units to each other and to the port's liquid bulk piers are also present. In some sections, these pipelines are exposed, whereas in others they run mainly underground beneath public roads or railways (Figure 4). The roads and railways used to transport flammable cargo are also relevant, as they run alongside or through residential areas at several points within these neighborhoods.

According to Bencherif (2024), the risk associated with the transport of hazardous materials is difficult to assess due to the interaction of multiple factors, including the diversity of transported products, each representing a specific risk; the diversity of risk sources (transport mode failure, containment failure, and human error); and the diversity of transport modes used. Given the number of trucks (Table 1) circulating daily through these neighborhoods carrying hazardous materials, understanding vulnerability

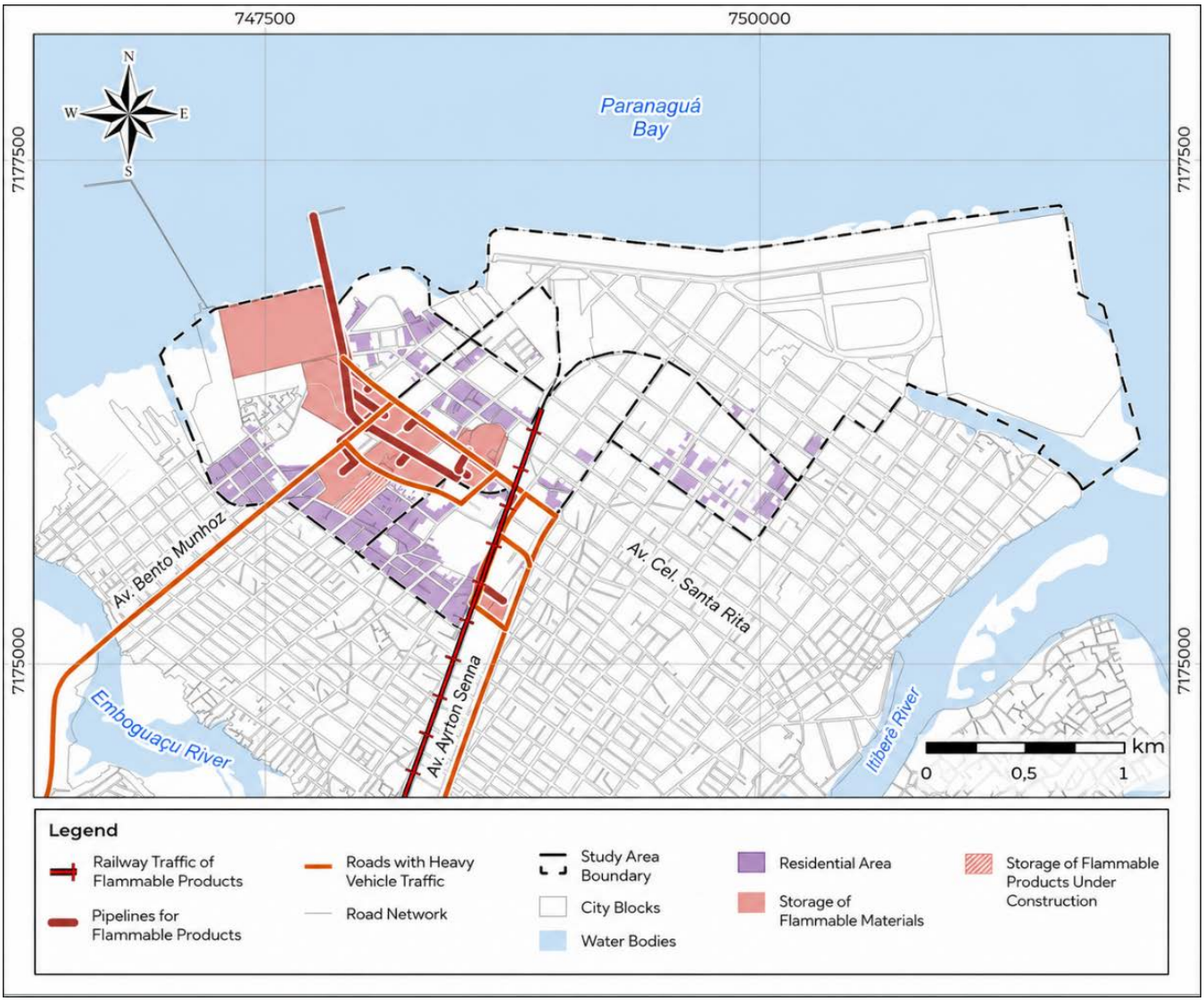


Figure 3 Urban variables of the sudden explosion hazard in the neighborhoods studied.



Figure 4 Flammable-liquid transport pipelines exposed (A) and underground (B and C), connecting the tanks and piers on Av. Col. Santa Rita in Paranaguá (22 J, 748010.20 m E, 7176429.97 m S).

and preparing the community for potential accidents are essential for building resilience.

Table 1 shows a gradient of exposure to the explosion hazard, considering primarily the relative proportion of the area occupied by flammable-product storage use in relation to the total area of the studied neighborhoods. The Vila Portuária neighborhood has the highest percentage of tank occupancy. However, in the Vila Rute neighborhood, 14 new tanks are under construction on a block of approximately 24,600 m^2. Upon completion of this construction, this neighborhood will reach an occupancy percentage of 44.35%. This situation is further aggravated by the greater proximity between these land uses in Vila Rute than in Vila Portuária (Table 1, Figure 3), together with the presence of pipelines and roads and railways used to transport flammable liquids. In the Vila Rute neighborhood, an ethanol leak from a storage facility occurred in 2022, reaching the stormwater drainage system in the Rocio neighborhood (PMRR-Paranaguá, 2024).

In the Vila Alboit neighborhood, land use conditions are similar to those currently found in Vila Rute, with a history of leakage in 2023, in this case involving naphtha (PMRR-Paranaguá, 2024). This event required the temporary removal of part of the resident population as a preventive measure against the risk of explosion and/or fire that had emerged (PMRR-Paranaguá, 2024). In the same neighborhood, an explosive event occurred in 2014 at a grain storage company located among companies storing flammable liquids (PMRR-Paranaguá, 2024). Gouvêa-Dantas et al. (2021) hypothesized the occurrence of synergistic events between

Table 1 Urban variables of the potential sudden explosion hazard in the neighborhoods studied.

Neighborhood	Area (m²)	Tanks (%)	Pipelines	Other businesses with hazardous products	Explosion history	Fire history	Leakage history	Daily truck capacity	Railway
Vila Portuária	769,106	37.86	Y	Y	Y	Y	Y	324*	Y
Vila Rute	273,655	35.34	Y	N	N	N	Y	261*	Y
Vila Alboit	400,697	25.29	Y	Y	Y	N	Y	295*	Y
Serraria do Rocha	428,759	4.27	Y	Y	N	N	Y	102*	Y
Rocio	278,207		Y	N	Y	N	N	Y	N
Dom Pedro II	2,687,379		N	Y	N	Y	Y	N	Y
Industrial	293,077		N	Y	N	N	N	N	Y
29 de Julho	394,514		N	Y	Y	N	N	N	N
Vila Guadalupe	138,506		N	Y	Y	N	N	N	N
Total	**5,663,900**	**9.39**						**982**	

Legend: Y = present. N = absent. approximate number of trucks that can be handled per day by flammable-liquid storage companies in the neighborhood.

these companies, that is, an explosion at the solid bulk storage company triggering another at the liquid bulk storage company and simulated a BLEVE. In this simulation, the authors obtained a radius of up to 951 m for the potential accident, with the possibility of fatalities occurring. This radius would encompass the entire study area.

Among the neighborhoods containing flammable-liquid storage tanks, Serraria do Rocha has the lowest percentage of occupied area (Table 1). The presence of pipelines and roads used for transporting flammable liquids, as well as the accident history discussed in the previous paragraph, should also be considered. However, in this case, the relevant relationship involves the flammable-liquid company and another company storing fertilizer containing ammonium nitrate, as indicated by the hazardous-products map produced to support activities involving accidents with hazardous materials in Paranaguá (Defesa Civil Paraná, 2013).

In this context of technological accidents, it is worth highlighting the integration between the Mutual Aid Plan (*Plano de Auxílio Mútuo* – PAM) and the Civil Defense Centers (*Núcleos de Defesa Civil* – NUDEC), established in Paranaguá to provide its members with strong coordination and optimized resources. This enables companies to act jointly during accidents and fosters closer ties between these companies, the community, and public agencies, so that, when such accidents occur, their impacts can be minimized (Defesa Civil Paraná, 2025).

The other neighborhoods studied lack flammable-liquid storage tanks, but other relevant factors emerge (Table 1): Rocio has pipelines and trucks carrying flammable liquids; the Industrial and Dom Pedro II neighborhoods have railcar traffic and other hazardous products; and the 29 de Julho and Vila Guadalupe neighborhoods have a history of explosion and fire.

Salazar-Bano et al. (2024), studying the risk faced by urban residents near a pipeline in Quito, note that understanding and managing risk is essential to building these communities' resilience, which requires involving them in developing public policies and implementing preventive measures. Otherwise, the authors (*op. cit.*) note, risk becomes normalized and disregarded over time. In this regard, Cahen (2006, p. 294) highlights the following Seveso II directives: "emergency plans inside and outside the company, regularly updated and tested; information and promotion of a risk-based culture for the local public". Furthermore, Salazar-Bano et al. (2024) call for improved signage for underground pipelines based on risk level, as well as public disclosure of risks in irregular occupations within the pipeline safety zone. This underscores the need to monitor such occupations in Paranaguá and confirm whether safety zones exist for buried or exposed pipelines along Paranaguá's public roads (Figure 4).

Beyond the characterization presented here, further studies should examine other potentially explosive substances such as ammonium nitrate, present in the mineral fertilizer stored in the warehouses in the study

area. The scope of the consequences of possible accidents also warrants closer examination, considering the conditions of each substance and any potential synergy between them, including scenarios for each situation and the vulnerability of exposed communities. Urgently, emergency plans must be developed and implemented in the identified neighborhoods within a public-policy context of risk culture involving both science and the participation of those affected.

Regarding poor air quality, the studies reviewed (Gurgatz et al., 2017; Santana et al., 2020; Souza et al., 2020; Santos et al., 2022) highlight the activities of grain and fertilizer companies, as well as truck traffic. Their substantial presence in the study area is visually evident, as is their proximity to residential use (Figure 5). The road and rail traffic used to transport these products is also notable, with its convergence concentrating road traffic on Bento Munhoz and Ayrton Senna avenues.

Table 2 presents a gradation of the neighborhoods' exposure to the recurring hazard of poor air quality, based on the combined figures for

Figure 5

Urban variables of the recurring poor air quality hazard production in the neighborhoods studied.

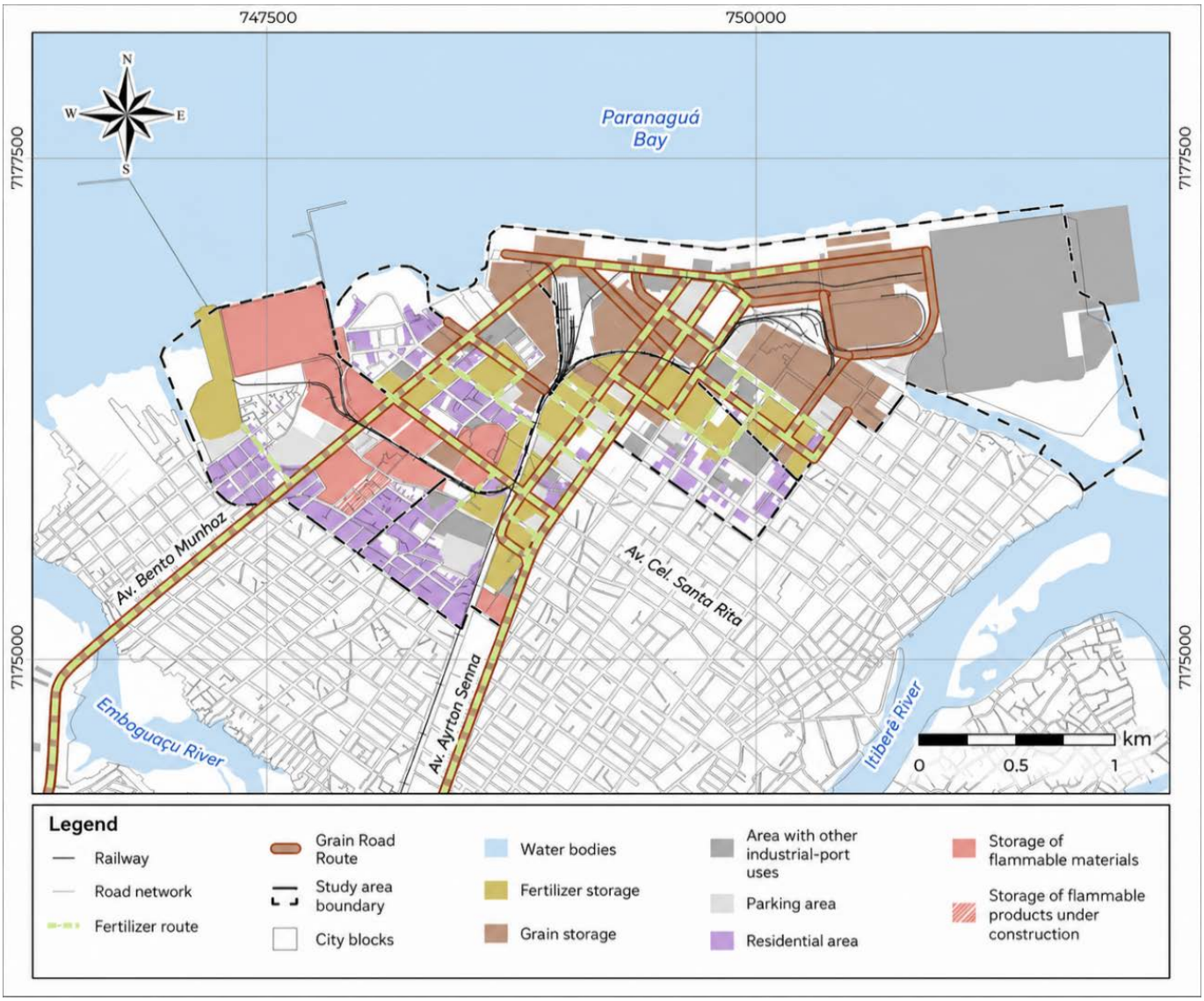


Table 2 Urban variables of the recurring poor air quality hazard production in the neighborhoods studied.

Neighborhood	Area (m²)	Total Industrial-Port use (%)	Grain storage (%)	Trucks/ day	Fertilizer storage (%)	Trucks/ day	Other businesses (%)	Trucks/ day	Parking (%)	Total trucks/ day
Vila Guadalupe	**138506**	**74.56**	**49.42**	**375**	**7.38**	**20**	**17.75**	**49**		**444**
Industrial	293077	62.81	13.97	217	28.71	168	2.51	15	17.6	400
Dom Pedro II	2687379	60.49	23.32	2363	1.97	105	31.66	1700	3.53	4168
Vila Portuária	769106	59.47			13.15	202	37.86	334	8.45	536
Vila Alboit	400697	56.85	7.46	120	19.89	159	27.79	315	1.69	594
Vila Rute	273655	48.1					44.35	261	3.75	262
Serraria do Rocha	428759	41.35			17.34	148	15.05	194	8.95	342
29 de Julho	394514	40.03	2.83	80	21.14	166	13.84	109	2.2	355
Rocio	278207	15.6	6.88	78	3.57	20	5.14	28		126
Total	**5663900**	**54.88**	**14.06**	**3233**	**8.75**	**988**	**27.19**	**3005**	**4.86**	**7227**

these companies and others that contribute to increased truck and train traffic, particularly in the first five. Among these, Vila Guadalupe stands out, with nearly 75% of its area occupied by industrial-port uses, of which grain storage alone accounts for 50% of the neighborhood.

The estimated number of trucks attracted by these companies to each neighborhood is striking, especially in Dom Pedro II. Furthermore, the total of 7,227 trucks per day is concentrated during business hours and on weekdays, in light of the findings of Santana et al. (2020). The Vila Portuária, Vila Alboit, Serraria do Rocha, and 29 de Julho neighborhoods also stand out, given the significant presence of fertilizer companies. However, Vila Portuária and Vila Alboit are more relevant, with total industrial-port occupation values of 59.47% and 56.85%, respectively.

In 2025, the truck yard known as the Pátio de Triagem of the Port of Paranaguá received 2,523 trucks loaded with grain and meal within 24 hours, setting a new record (Portos do Paraná, 2025). Considering that the Dom Pedro II and Vila Guadalupe neighborhoods are the main destinations for these trucks, these figures closely align with the estimates presented in Table 2 for these neighborhoods. Similarly, the Paranaguá Container Terminal (TCP) reported that 2,781 units entered or left its gates on April 16 (TCP, 2025). Treating container units as equivalent to trucks, this company alone already exceeds the estimated value for the Dom Pedro II neighborhood in the "other businesses" category. This information supports the daily truck-volume estimates presented in Table 2.

The concentration of these urban elements in the study area reinforces the link between this category of technological risk and public health issues, particularly respiratory conditions, in the neighborhoods of Paranaguá's port and port-adjacent area. Santana et al. (2020) note that the number

of people with respiratory diseases in Paranaguá is higher than in other municipalities with colder climates and equal or larger populations.

By analogy, Liu et al. (2019), studying particulate matter inhalation across 652 cities worldwide, found a link between elevated concentrations of this material and daily all-cause, cardiovascular, and respiratory mortality. Santos et al. (2016) similarly showed that exposure to traffic-related air pollution is associated with reduced lung function in exposed workers. Santos et al. (2019), in turn, found that elevated blood pressure in hypertensive and/or diabetic workers is significantly associated with exposure to fine particulate matter, mainly from vehicles.

Nevertheless, the synergy between land uses and the cumulative effects of long-term recurring exposure warrant consideration. The absence of clear boundaries for poor air quality is equally concerning. Thus, the neighborhoods to the northwest and southeast of the companies and roads in and around the study area (Rodrigues, 2016) gain prominence due to the predominant wind directions in these areas. As a result, the neighborhood as the unit of analysis limits the delineation of the exposure area actually affecting the urban area. To address this, two approaches could better represent local reality: local physical conditions, as discussed by Bosque Sendra et al. (2004), and atmospheric dispersion modeling or simulations, such as those presented by Zhou and Liu (2012) and Sánchez et al. (2018). Both can help delimit the exposure area and predict the adverse impacts of this type of event.

In turn, analysis at the neighborhood level provides some input for public-health decision-making. For example, it can alert community health workers to pay closer attention to monitoring respiratory symptoms among residents of these neighborhoods. Overlaying studies that spatially map sick individuals could reinforce the need for preventive measures in these communities.

The estimated total of 4,882 people exposed to these hazards varies among neighborhoods, ranging from 37 people in Guadalupe to 1,300 in Serraria do Rocha (Table 3). The gregarious nature of residential use can facilitate the planning, monitoring, and implementation of actions related to the respective risks, which vary considerably from one neighborhood to another. Structural housing conditions, access roads, population density, and building types, among other factors not addressed in this study, also differ. These differences indicate greater vulnerability in some communities relative to others. Such information is relevant for control measures in the event of an accident or for ongoing monitoring.

Taken together, the maps showing the distribution of land uses and other elements related to this recurring hazard, in association with the corresponding correlation charts, align with the findings of Gurgatz et al. (2017), Santana et al. (2020), Souza et al. (2020), and Santos et al. (2022). These results draw attention to the poor air quality in this area and the

Table 3. Estimated population and percentage of residential land use in the neighborhoods studied.

Neighborhoods	V ila Guadalupe	Dom Pedro II	Industrial	Rocio	29 de Julho	Vila Alboit	Vila Rute	Vila Portuária	Serraria do Rocha	Total
IBGE, Census, 2022	37	72	96	192	522	682	965	1,016	1,300	4,882
Residential use (%)	0.9	0.28	4.68	16.76	14.28	15.79	30.4	8.99	27.24	8.08

consequences of recurring exposure for its residents (Santos et al., 2016; Santos et al., 2019).

In this sense, implementing land use planning that accounts for the complexity of these interactions (Figure 6), together with urban security based on risk analysis, can help balance the relationship between utility and risk (Zhou & Liu, 2012). Such planning should not disregard social processes alongside technological and scientific ones (Freitas & Gomez, 1996), and should incorporate the knowledge and participation of those who feel exposed to these risks (Porto & Freitas, 1997).

4 Concluding remarks

Delimiting the area of exposure to technological hazard sources is not an easy task. Given the diversity of substances and interactions involved, the possible areas and configurations are as numerous as the possible combinations.

In the municipality of Paranaguá, among the neighborhoods studied



Figure 6

Visual synthesis of the complexity of interactions between the proximity of residential use and hazard sources that result in technological risk in the study area: (A) flammable-liquid storage (22 J, 748061.95 m E, 7175877.62 m S); (B) truck traffic intensity (22 J, 746471.66 m E, 7174775.62 m S); (C) grain storage (22 J, 7750499.68 m E, 7176325.20 m S); and (D) fertilizer industry and storage (22 J, 747306.46 m E, 7176167.82 m S).

Source: drone imagery from the technical team of the *Paranaguá Sem Risco* Project, PMRR (2024).

in the context of the technological risk component of the Municipal Risk Reduction Plan, four stand out: Vila Portuária, Vila Rute, Vila Alboit, and Serraria do Rocha. In these neighborhoods, the presence of flammable-liquid storage tanks, their associated roads and hazardous-product transport pipelines, and the number of trucks carrying hazardous cargo each day evidence residents' exposure to the explosion hazard – without ruling out the occurrence of impacts and consequences in the other neighborhoods studied.

Likewise, three other neighborhoods stand out: Vila Guadalupe, Industrial, and Dom Pedro II. In these neighborhoods, the presence of grain and fertilizer warehouses, other industrial-port land uses, road and rail infrastructure, and the intensity of daily truck traffic highlight residents' exposure to the poor air quality hazard. This type of exposure can be harder for those affected to notice, given the difficulty of linking cause and effect due to the slow onset and wide dispersion of its consequences within the population.

This research thus compiles, in maps and tables, information on the elements that stand out in the urban structure and that drive dynamics favoring residents' exposure in the neighborhoods of Paranaguá's port and port-adjacent zone. This information helps close a gap that has hindered the adoption of measures that could be highly useful for planning, monitoring, and implementing prevention, mitigation, and containment actions in risk situations.

However, this study is not conclusive; on the contrary, it helps underscore the pressing need to examine the urban technological risk issue that has long affected the municipality. More integrated studies across different scientific disciplines are needed here. These studies should link the chemical and physical properties of the substances involved, along with the technological processes to which they are subjected, to social factors, while also distinguishing community vulnerabilities across neighborhoods. This is particularly relevant when considering the synergy between land uses and cumulative impacts, which should be estimated during the environmental assessment of new developments in the area. Likewise, studies should examine the unequal distribution of technological risks across Paranaguá's urban area, bringing this issue into the environmental justice debate. Given that these risks exist, ignoring or underestimating them will not make them diminish or disappear, it will only increase the consequences of the impacts associated with the hazards presented.

Accordingly, public policies linking governance, monitoring, and risk communication are needed to bring the community together with other stakeholders in investigating issues and developing intervention proposals.

In urban landscapes, neighborhoods bring together shared histories and concerns, along with a degree of organization and identity among residents. The spatial arrangement of land uses for detecting the presence

or proximity of hazard sources in this territory, as well as its characteristics, can make the neighborhood the least restrictive unit of exposure for studying and acting on technological risk – with particular attention to impacts that are difficult to notice, such as respiratory effects. This unit of analysis can also be essential for studies investigating community resilience, by adopting criteria and corresponding parameters for evaluating this concept in relation to issues linked to technological risk.

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