Territorial representation of a vulnerability associated with the Seveso installations in a Nord Italian case study

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The process industry is recognized as a source of hazards, both instantaneous and distributed over time and space. The industrial plants are no longer recognized as single independent units; they are, on the contrary, completing parts of a much larger system generated from the flows that stream from one to another, generating a macro system rooted in the territory. Particular relevance has received major risk installations or "Seveso" plants within this complex context. Since the implementation of the European Directive "Seveso" in Italy is mandatory for the municipalities which host a Seveso plant in their territory, instruments that include the criteria for the areas around these plants are required by the Urban and Land use planners. The goal was to represent the territorial vulnerability associated with the Seveso installations and impose binding areas around them that identify the areas of exclusion and observation established in the legislation. A Nord Italian region was used as a case study as part of the research activities of the Responsible Risk Resilience Centre of Turin Polytechnic (R3C) within its third cluster, called "Measuring Urban Resilience". The minimum requirements for land and urban planning in areas in the vicinity of major risk installations, established in the Italian legislation, were used as a legal framework using an alternative place-based methodology. It was possible to geolocate the Seveso installations, and buffer zones were assigned for areas of exclusion and observation. In addition, the buffers were intersected with the national census sections to observe the number of inhabitants falling within these areas. Space-dependent analyses using the geographical information system (GIS) and the Geopandas python library were carried out, and thematic maps were generated at regional and local scales. The results contribute to increasing the awareness of the territorial vulnerability against the major risk accidents and support the resilience-based decision-making in designing technical measures.

Keywords: major risk accidents, GIS, Seveso installations, territorial resilience, vulnerability.

1. General Background

During the 1960s and 1970s in Europe, there was a tremendous increase in the demand for fuels, new construction materials, fibres and pharmaceuticals, favouring the rapid establishment and expansion of the process industry in that period. However, the hazardousness of the chemical plants, linked to negligence and the lack of knowledge at the time, has led to an upset list of major accidents (Prerna et al., 2017).

Nowadays, chemical plants are no longer understood as single independent units. On the contrary, they are recognized as parts of complex socio-ecological and technological systems (SETSs). For instance, these plants are internally comprised of many networks related to infrastructure, technical components, physical equipment, stored root materials, flows of matter and energy, operators, and organizational elements that interact based on standards, procedures, or instructions (Prerna et al., 2017). On the other hand, these technical systems are rooted in geographical realities in which social, cultural, ecological, and productive dynamics take place over time and space (Pereno and Barbero, 2020).

Currently, many industrial contexts remain underspecified. Hence, holistic risk management methods which can deal with the underspecification and tight complex couplings constitute an essential aspect. (Snowden and Boone, 2007). Therefore, a deeper analysis should be performed to understand the functioning and how the systems may lead to failed outcomes and their frequencies. On the other hand, the importance of generating a spatial and temporal representation of the vulnerabilities is recognized throughout the development of scenarios that create awareness and contribute to establishing the magnitude of safe distances.

Consequently, the interest in analyzing major industry events and interacting with their surrounding areas has grown in the last decades. Therefore, the industrial plants subjected to the so-called “Seveso” activities have been regulated by the different European Seveso Directives (I 82/501/CEE, II 96/82/EC, III 2012/18/EU) (Demichela et al., 2014; Pilone et al., 2017; Tillier et al., 2022). Moreover, several lessons from previous accidents have been formalized.

In Italy, the Seveso III Directive 2012/18/EU was ratified through the Legislative Decree No.105/2015 (Official Gazette, 2015). Similar to the previous one, it keeps the minimum criteria in the land use planning to grant the safety in the surrounding territory to the Seveso plants (Pilone et al., 2017).

However, it has been recognized that the provincial and municipal stakeholders must transpose the safety criteria from the national and regional laws, including the analysis of several government documents as ministerial decrees, guidelines, and sectorial regulations, which are currently valid. Then, the application of all these documents requires not only skills in hazardous analysis and their mechanisms of diffusion but also an excellent capacity to analyze and read the territory and the ecosystems, together with the capability of interpreting the mapping of the consequences of abnormal situations against the population and the environment (Camuncoli et al., 2012). Moreover, exposure to these abnormal situations in terms of population and environment is mainly identified as vulnerability (Demichela et al., 2014).

In this work, vulnerability assessment is the first part of operationalizing resilience considering the theoretical concepts defined by Brunetta et al. (2020). Given all the above, the goal was to represent the territorial vulnerability associated with the Seveso installations in a Nord Italian Region and impose binding areas around them which identify the areas of exclusion and observation established in the Italian legislation. In addition, the principal government instruments to manage the major risk accidents in Italy and its minimum requirements for land and urban planning in areas surrounding these plants were used as a legal framework using an alternative place-based methodology using geographical information systems (GIS) and Geopandas python library.

2. Case study

The case study selected in this work was the overall Piedmont Region, located northwest of Italy with the administrative capital city of Turin. It is Italy's second-largest region by area, seventh by population, and second by the number of municipalities. The region is divided into the following provinces: Alessandria, Asti, Biella, Cuneo, Novara, Vercelli and Verbano-Cusio-Ossola and the metropolitan city of Turin.

Most of the population lives in the plain in Piedmont, particularly in Turin and the surrounding towns. In the past, the region underwent rapid development in production activities. The industry was highly developed within town centers without regulations, with consequent inconveniences connected to the pollution problem. The automotive sector with the current Stellantis group (previously FIAT) and companies connected with this sector plays a vital role in the territory's industry. However, the chemical, food, textile, and clothing sectors are also important. The concentration of several industrial activities has led to considerable urban congestion, and companies are therefore concentrated in a small, densely populated area.

3. Evolution of the framework to cope with Seveso Activities

First, the Council of the European Communities created an industrial safety Directive in 1982, the first Seveso Directive, which introduced the concepts of a competent authority, notification, a safety report, inspections, accident reporting, and emergency plans. After some disasters, the initial Directive was improved, issuing the second one in 1996, which introduced the concept of a safety management system, domino effects to neighbouring plants, land use planning, and care in plant modifications. In addition, the number of requirements was strengthened after critical disasters in Europe in 2003. The new Seveso Directive III in 2012 emphasized the preparation of emergency plans, involving the public in consultation and decision making, and defining criteria for "dangerous substances", taking account of the classification of the Globally Harmonized System (GHS) (Prerna et al., 2017).

4. Land Use Planning Associated with Seveso Installations in Italy

Although some modifications and improvements regarding the Land Use Planning are present in the Seveso Directive III (Salvi et al., 2022), the safety criteria for protecting people and the environment around Seveso plants are yet regulated in Italy by the Ministerial Decree D.M. 09/05/2001 (Official Gazette, 2001).

According to Camuncoli et al. (2012), Italy introduced the land use planning criteria associated with the "Seveso" installations when introducing the 09/05/2001 - Ministerial Decree on the minimum requirements for land planning and urban planning in areas in the vicinity of major risks installations. It occurs after implementing the European Directive "Seveso II" through the Legal Decree No. 334 of 17/08/1999 (Official Gazette, 1999).

The Ministerial Decree defined restrictive criteria for the typology and density of the urban activities included in the areas of influence of the Seveso plants (Pilone et al., 2017). Since the appearance of this decree, the implementation of an analysis of the territorial and environmental vulnerable elements has been mandatory for the administrations of municipalities that host a Seveso installation (or those which might be affected by an accident even if they do not host a Seveso installation) (Demichela et al., 2014).

As an output, the local stakeholders must draw a Technical Document (ERIR- Elaborato Tecnico per il Rischio di Incidente Rilevante) and insert it in the local masterplan, to establish the measures and distances around Seveso plants to avoid major consequences (Pilone et al.- 2017). The ERIR has three principal phases:

i. Data collection of the production activities and identification of the territorial and environmental receptors.
ii. Evaluation of the territorial and environmental compatibility.
iii. Planning Strategies imposing critical areas.

4.1. Data collection

This stage includes extensive data collection throughout the entire territory, and it requires acquiring naturalistic, urban, and chemical information by consulting different kinds of documentation.

The territorial analysis divides urban areas and buildings into vulnerability six categories, A to F when F is more vulnerable and estimates the number of people generally present in the potential damaged area and the mobility capacity of these people. In contrast, the environmental vulnerabilities are less clear on how to be assessed (Pilone et al., 2016). Finally, the 09/05/2001-Ministerial Decree offers a list of vulnerable elements, grouped into two categories: i) very high environmental vulnerability elements; and ii) relevant environmental vulnerability elements.

4.2. Evaluation of the compatibility

The territorial compatibility is defined in a matrixial way by four categories of the effects of the accidental top event (Elevated Lethality, Start of Lethality, Irreversible Damage, and Reversible Damage) and six-level of the probability of occurrence (Demichela et al., 2014).

On the other hand, for the environmental analysis, a case-by-case environmental compatibility evaluation is highly recommended to correctly identify the different receptors and assess the industry's effects on the territory and vice versa. The levels of damage are assessed depending on the estimated time needed for a complete recovery: Serious (>2 years) and Significant (<2 years) (Pilone et al., 2016).

4.3. Planning Strategies

The compatibility assessed should guide the stakeholders in defining specific regulatory and cartographic provisions for the areas exposed to hazards. Then, circular areas are plotted to indicate the potential damage connected to the stored type of substance (exclusion and observation areas). The two areas are drawn up starting from the border of the plant. They have sizes that depend on the level of criticality that has been assigned according to the type of substance stored and the foreseen accidental top events identified. Depending on the case, the exclusion area can be 100, 200, or 300 m, while the observation area must extend to at least 500 m from the plant boundary. A ranking of "very critical/critical/not critical" is assigned to each activity, corresponding with the territorial elements inside the plotted areas and their associated categories regarding the number of inhabitants (Camuncoli et al., 2012).

5. Regional Regulation

Moreover, in July 2010, the Piedmont Region implemented these national laws through a technical report on major industrial risks in a document that is known as "Guidelines for the assessment of industrial risk in land use planning: Strategic Environmental Assessment and Technical Report on Major Industrial Risks" (DGR, 2010).

The Piedmont guidelines recall the 09/05/2001- Ministerial Decree and offered further pointers not considered by national laws. For instance, another methodology for assessing the compatibility is related to Sub-thresholds plants, non-Seveso activities, and the Seveso ones. In those cases, the assessment of the territorial criticality is based on the type of stored substances: for each typology of them, the regulations identify specific distances of potential damage (i.e., toxic substances=1500 m, potential damage distance, flammable substances = 500 m). A "very critical/critical/not critical" ranking is assigned to each plant, evaluating the specific territorial and vulnerable environmental elements included in the potential damage distance.

Additionally, the Piedmont guidelines state several protection measures to mitigate the vulnerability of the Seveso installations. Moreover, inherently safer design could be developed as a different engineering approach to cope with the vulnerabilities.

6. Summing up the crucial aspects

In synthesis, the management of the major industrial risk represents one of the essential Italian territorial plans related to managing the emergency in the municipalities. Pilone et al. (2016) described Seveso installations in Italy are required to present periodically safety reports related to their potential risk and possible impacts. Subsequently, regulators must review all safety reports submitted and verify if the current installations are of an acceptable standard and if the new ones fulfilled the established criteria (Prerna et al., 2017).

However, there remains a need to integrate all those safety reports on the municipal and regional scales from a systemic approach, associated with other risks, the urban dynamic, and its trends over time and space. In addition, deeper analysis should be addressed to asses the environmental vulnerability in line with Sikorova et al. (2022).

Public stakeholders require instruments that contribute to increasing awareness in the decision-making process of industrial emergencies.

7. Procedure

The place-based methodology used in this work simplifies the territorial vulnerability estimation as part of the Responsible Risk Resilience Centre of Turin Polytechnic (R3C) research activities. Specifically, the results belonged to the planned activities within the third cluster of R3C called "Measuring Urban Resilience". Space-dependent analyses were developed using open data and geographical information systems (GIS). In addition, thematic maps were generated at the regional and local scale (as a pilot example), related to the critical zones and the number of people exposed. This analysis was carried out in the following four steps:

Firstly, the industrial buildings classified as major risk installations were identified as punctual elements on the territory. It was possible to geolocate these industries, using a dataset provided by Piedmont Region[a].

Secondly, using these points, which identify the centroid of the establishments, it was possible to define the boundaries, according to the requirement established in the legal framework discussed before, by extracting, with a selection by location, the polygons of the industrial areas identified by the mosaic of the Piedmont Region[b].

The third step was to establish the exclusion and observation areas. Different thresholds were established, realizing the differences in the chemical-physical characteristics of the substance involved in the accident.

Since each threshold could depend on several accidental hypotheses according to the Piedmont guidelines (toxic, energetic, environmental), the most used and restrictive thresholds were applied for this regional preliminary assessment. In particular, the thresholds used are 100 and 300 meters for the exclusion areas and 500, 1000, and 1500 meters for the observation areas.

Subsequently, it was estimated how much population would be affected by the Seveso plants in case of an accident, considering average population density (persons by hectare) in line with similar research (Landucci et al.,2022).

Finally, a specific analysis was developed for a lubricant and oil additive production plant, which occupies 266 660 m^2, as a pilot case study. The previous four steps of the methodology were implemented at the local scale. This operation was carried out using the Python library Geopandas and QGIS in the municipality of interest. A first analysis intersected the exclusion and observation areas, with the ISTAT (National Institute of Statistics) census sections referring to 2011, enabling a count of the resident population in the areas at risk. In a second analysis, an attempt was made to relate the population data more precisely, applying the population density calculated from the census sections to the volumes of individual buildings extrapolated from the official cartography of the Piedmont Region (BDTRE).

8. Results and Discussion at Regional Scale

Figure 1 offers the glocalization of the 78 industries classified as Seveso installation at the regional scale and the different distances imposed as an exclusion and observation area.

In Figure 1, it can be appreciated how the density of points of different Seveso installations constitutes a complex network of permanent hazard factors rooted in the territory of the Piedmont Region. In addition, a quadrilateral can be noted that matches with a zoom of this representation for the Metropolitan City of Turin (see Figure 2).

[a] Regione Piemonte. Dati Piemonte. https://www.dati.piemonte.it/#/home
[b] Piedmont Geoportal https://www.geoportale.piemonte.it/cms

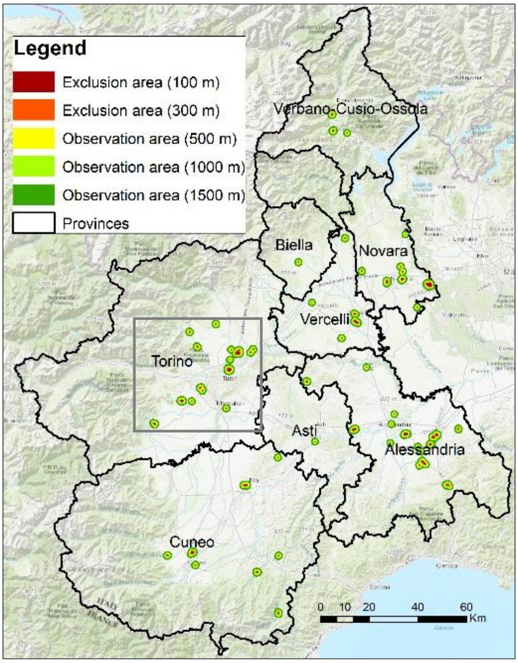

Fig. 1. Seveso installations are localized in Piedmont and binding areas at the regional scale.

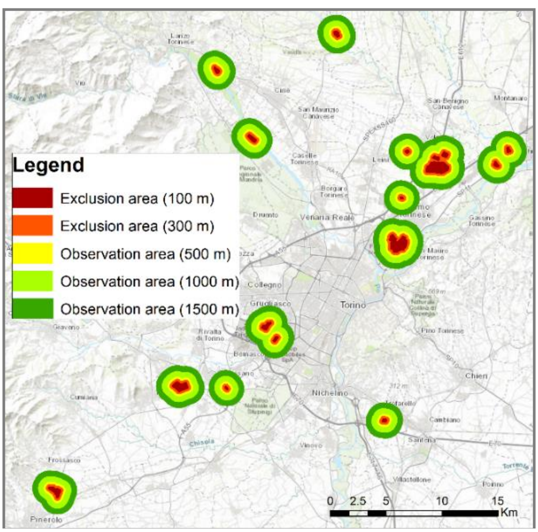

Fig. 2. Seveso installations are localized in the Metropolitan City of Turin.

The analysis of Figure 2 can better illustrate the different binding areas applied and how they can interact with each other being able to cause domino effects with neighbor plants. Moreover, it can also be elucidated how the area of potential damage can affect municipalities that do not host Seveso plants.

Additional details about the kind of Seveso activities are shown in Figure 3.

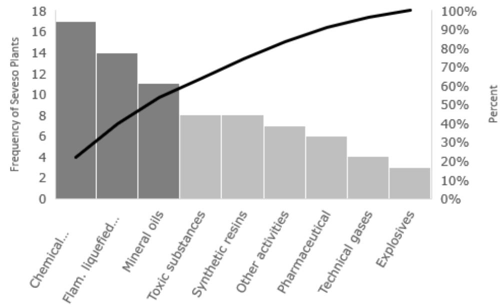

Fig. 3. Pareto diagram for categories of Seveso Activities.

As can be appreciated, the primary or intermediate chemical production, the storage and bottling of flammable liquefied gases, and the storage and treatment of mineral oils; are the principal three categories (highlighted in Figure 3) that accumulated more than 50 % of the Seveso installations in the Piedmont Regions.

In Figure 4 can be noted how the Provinces of Alessandria, Novara, and Torino are included in more than 75 % of the Seveso Installations in the Piedmont region.

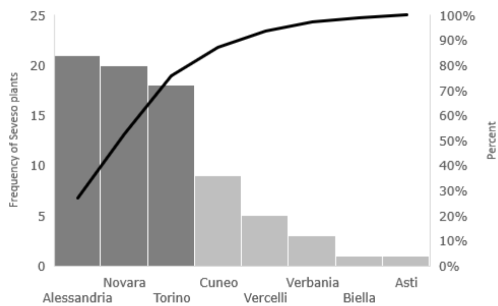

Fig. 4. Pareto diagram for the frequency of Seveso Installations by province.

A different panorama is offered by analyzing Figure 5.

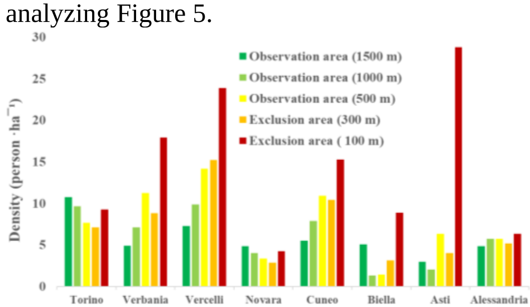

Fig. 5. Density of inhabitants (person·ha^{-1}) in the areas of observation and exclusion by province.

The density of people in the Seveso exclusion areas in Asti, Vercelli, Cuneo, and Verbania is higher regarding other provinces that accumulated more Seveso installations, which shows the large number of people who are vulnerable in the most critical area in case of an accident. The observation areas in the range of 500 m to 1500 m, the same three provinces, and the metropolitan city of Turin presented the higher density index of persons by hectare.

9. Result and discussion in a reduced scale

Not many referenced methodologies for the territorial vulnerability at this scale are yet available using the GIS tools. However, previous research has recognized that approaches used at a larger scale for vulnerability analysis and risk analysis may be inadequate and too general to be effective at a minor scale (Pilone et al., 2016).

Nevertheless, this application constitutes a first attempt that can be approached as an early warning system, constituting a preliminary criterion for population safety. At the same time, specific scenarios are developed concerning the substance's hazardousness, its use, and the physic-chemical mechanisms associated with the identified events top events. Figure 6 offers details of the spatial analysis carried out.

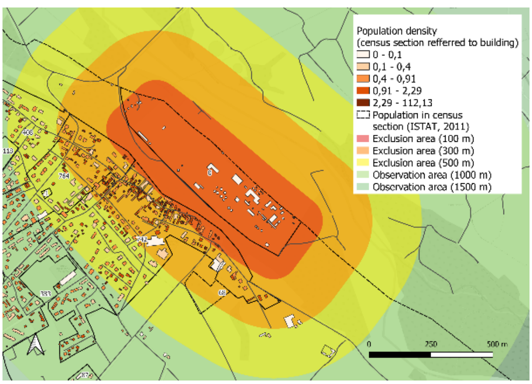

Fig. 6. Representation of the spatial analysis in the lubricant and oil additive plan selected as a study case at a local scale.

The previous image shows the buffer zones of each distance studied and the density of population index by a unit of volume of individual buildings (persons by cubic meters). These results increase awareness about what kind of infrastructure could be more crowded around the plant. . Finally, it supports the decision-making process regarding emergency intervention and evacuation plans.

The buildings identified as targets and the number of people estimated are not far from those reported in public documents for a radius of 500 m (Prefecture of Turin, 2007), which validates the procedure used.

10. Conclusions

The legal framework evolution to cope with the Seveso activities and its land-use planning criteria was summed up at the national and regional level in Italy, highlighting its complexity for the stakeholders and the outdated of some current instruments.

In addition, the research presents an alternative methodology to assess the number of inhabitants that fall in the exclusion and observation areas of Seveso installations at the regional scale, allowing a first prioritization of mitigation and adaptation actions at regional scales. Moreover, offer valuable information at the local scale about the more crowded buildings including in the critical areas. However, the methodology is limited by the availability of the input data and the following simplifications and assumptions.

The results presented in the paper increase the awareness of vulnerable territorial scenarios of major industrial accidents in the Piedmont region. The methodological approach can be transferable to other use cases in diverse territories, providing a more robust baseline for land use planning and emergency response.

In this way, further research is required not only to improve the current vulnerability estimation of the environmental elements but also on how to integrate this assessment with the territorial one.

Finally, this integrated industrial vulnerability package should be inserted in the emergency responses as part of a multi-risk approach, including key stakeholders as a common operational picture to strengthen the resilience-based decision-making in Italy.

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