A methodological proposal to evaluate the health hazard scenario from COVID-19 in Italy

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A R T I C L E I N F O

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A B S T R A C T

2019 Coronavirus disease (COVID-19) had a big impact in Italy, mainly concentrated in the northern part of the Country. All this was mainly due to similarities of this area with Wuhan in Hubei Province, according to geographical, environmental and socio-economic points of view. The basic hypothesis of this research was that the presence of atmospheric pollutants can generate stress on health conditions of the population and determine pre-conditions for the development of diseases of the respiratory system and complications related to them. In most cases the attention on environmental aspects is mainly concentrated on pollution, neglecting issues such as land management which, in some way, can contribute to reducing the impact of pollution. The reduction of land take and the decrease in the loss of ecosystem services can represent an important aspect in improving environmental quality. In order to integrate policies for environmental change and human health, the main factors analyzed in this paper can be summarized in environmental, climatic and land management. The main aim of this paper was to produce three different hazard scenarios respectively related to environmental, climatic and land management-related factors. A Spatial Analytical Hierarchy Process (AHP) method has been applied over thirteen informative layers grouped in aggregation classes of environmental, climatic and land management.

The results of the health hazard maps show a disparity in the distribution of territorial responses to the pandemic in Italy. The environmental components play an extremely relevant role in the definition of the red zones of hazard, with a consequent urgent need to renew sustainable development strategies.

The comparison of hazard maps related to different scenarios provides decision makers with tools to orient policy choices with a different degree of priority according to a place-based approach. In particular, the geospatial representation of risks could be a tool for legitimizing the measures chosen by decision-makers, proposing a renewed approach that highlights and takes account of the differences between the spatial contexts to be considered - Regions, Provinces, Municipalities - also in terms of climatic and environmental variables.

1. Introduction

The COVID-19 pandemic differs from all other disasters and diseases in both quality and quantity (Peleg et al., 2021). The global distribution and the number of cases and deaths far exceeded that of any other crisis since the Spanish flu of 1918 (Ashton, 2020). Its effects, now widely documented by spatially distributed data available at different scales (Sheng et al., 2021), show that the variability in both incidence and mortality is relevant between continents, across countries, and even between geographical regions within each nation (Saez et al., 2020). More than a year after the declaration of a pandemic emergency by the World Health Organization, the scientific literature has been enriched by studies and research that attempt to explain these differences by considering, among the others, geographical and environmental

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variables (Dettori et al., 2020; Saez et al., 2020; Xiao et al., 2021), as well as demographic and socio-economic factors (Abtahi et al., 2021; Deiana et al., 2021; Drefahl et al., 2020; Ehlert, 2021; Gangemi et al., 2020). The understanding of these factors, whose relative weight varies according to the specific reference context, is essential for the implementation of territorial policies and strategies of urban spaces' management oriented to risk mitigation and improvement of the quality of life with specific attention to the various components of public health.

In this work we focus on the hazard assessment, a component of the risk scenario analysis that occurs in the presence of extreme events such as those linked to the recent global pandemic. A risk scenario can be defined, in general, as the space in which the actors move and the territorial system components interact, including socio-economic dynamics (Las Casas and Scardaccione, 2006; Sangiorgio and Parisi, 2020). In the construction of risk scenarios, the requested context parameters concern systemic vulnerability, hazard and exposure. Systemic vulnerability is defined, as well, by a physical and a functional vulnerability. In the specific case of a global pandemic, physical vulnerability can be defined as the measure of the physical damage suffered by an individual as a result of an extreme event. A critical component of the physical vulnerability in the case of COVID-19 pandemic - in the light of all the studies still in progress on the causes of the virus, past pathologies negatively influencing the spread of COVID-19, the most accidental environmental factors - can be identified in the share of population over 65 years, the segment of the population that was the most vulnerable to COVID-19 in terms of number of deaths and infected (Esteve et al., 2020; Youmni and Mbarek, 2020). Functional vulnerability, on the other hand, concerns not the physical characteristics of the individuals but the consequences that could derive from their behavior. We identify this vulnerability, for example, in commuting flows and in an individual's own ability to carry out his normal activities. With reference to the global pandemic, we identify the functional vulnerability in the loss of the capacities of a worker to carry out his normal activities because he is infected by the virus. The systemic vulnerability is therefore the interaction of these two components - physical and functional vulnerability - and represents the intrinsic propensity of the population to suffer a certain degree of damage due to the effects of COVID-19. Hazard can be defined as the threat of stress or perturbation to a system and what it represents in terms of its consequences (Kasperson and Kasperson, 2001). The hazard is therefore an expression of the interaction of various factors - environmental, climatic and spatial - and represents, together with physical vulnerability and exposure, the functionality or dysfunctionality of a territorial system. The exposure, on the other hand, is identifiable in the total population at risk in a given area (Varnes, 1984). A system's functionality and dysfunctionality will be discussed in terms of the number of infected and recovery time in the discussion paragraph.

The basic hypothesis of this research is one of the factors that influence the spread of COVID-19 in Italy, namely how the presence of atmospheric pollutants can generate stress on the health conditions of the population and determine the preconditions for the development of diseases related to respiratory system and related complications, including life-threatening ones, which may explain the excess lethality of covid-19 which occurred in the Po Valley (Zoran et al., 2020).

In addition, the peculiar climatic conditions of the Po Valley itself, including thermal inversion, typical of the winter period, may have exacerbated the already compromised environmental situation deriving from air pollution (Ferrero et al., 2019).

We analyzed the data relating to COVID-19 - contagions and deaths at the provincial level - as of 30 April 2020, a useful date to observe the phenomenon without alterations because it refers to the 1st phase of the lockdown, and therefore no further effects could influence the spatial pattern of the epidemic diffusion process. We hypothesized the existence of a relationship between air-related pollutants and the spread and lethality of the virus in the outbreak of the epidemic. For this we considered a large geographical data-set from which we selected a set of indicators related to environmental, climatic and land conditions, finalized at realizing health hazard scenarios, through an interdisciplinary ecological approach specifically in order to evaluate the phenomena in their complexity (Murgante et al., 2020c).

To this end we analyzed the spread of COVID-19 in Italy, based on a theoretical and quantitative analysis on a large set of data - mainly open data - built and analyzed by means of spatial analytical techniques in previous works (Supplementary Materials, Table S1. - Data and indicators (Murgante et al., 2020c) and further improved and analyzed in the present research.

In particular, the effort made is to seek a methodology to integrate the concepts of human health and ecosystem functionality, using the Ecosystem Services approach that is recognized to be suitable for the purpose (Chiabai et al., 2018; Sandifer and Sutton-Grier, 2014). In fact, although the links between ecosystems, animals and other living organisms, and human health is a common focus within recent debates on revised health concepts (Charron, 2012; Chen et al., 2019; Lang and Rayner, 2012; Wallace et al., 2015), a comprehensive framework to effectively integrate research and policy on environmental change and human health (Ford et al., 2015) is still lacking. We used Habitat Quality and Degradation to model the linkage between human health, nature, biodiversity and ecosystem functionality (Sandifer et al., 2015) and Carbon Stock as proxies of the sustainability of land use changes especially with regard to well-being, air quality and climate change mitigation (Mononen et al., 2016).

A Multicriteria Analysis was performed over the database built in order to formulate three different hazard scenarios, each of them more related to environmental, climatic and land management-related factors, respectively. The method used is the Spatial Analytical Hierarchy Process (AHP) that, in several fields of applications, proved to be effective in reducing the decision-making process complexity and in supporting the evaluation of three alternatives hazard scenarios.

Hazard scenarios are useful to define the functionality of a system and to understand what policies to undertake in order to reduce the hazard, i.e. limit the effects of an extreme event (e.g. a global epidemic). The results obtained make it possible to deeply explore these aspects by matching factors that contribute to determining the hazard with respect to the spread of a virus such as COVID-19. The proposed methodology, based on the evidence of COVID-19 impacts directly suffered by people in terms of disease effects, death of relatives and strong economic long-term consequences, could be an effective driver in order to deliver appropriate climate mitigation policies based on sustainable land management objectives.

2. Materials, data and methods

2.1. Materials

2.1.1. Ecosystem services and human well-being

The approach adopted in the present research is to consider the loss of ecosystem services in relation to land use changes over the last 30 years, as a predisposing cause of spread of pathogens or even a contribution to the hazard. Therefore, some selected outcomes of an evaluation of ecosystem services' performance will represent input for the MCA on COVID-19 diffusion, an object of present research.

The importance of maintaining ecosystem services to guarantee a healthy environment and the human well-being (Fuller and Gaston, 2009) has increased in the years, so much so that they are also inserted in urban and territorial planning by means of ad hoc indicators spatially related (Alamgir et al., 2014; Alcaraz-Segura et al., 2013; De Araujo Barbosa et al., 2015; Maes et al., 2016). The scientific literature is rich in studies that declines the approach of ecosystem services in a perspective aimed at designing, optimizing or improving the performance of Green Infrastructures (Andersson et al., 2014; Coutts and Hahn, 2015; Escobedo et al., 2019; Lovell and Taylor, 2013).

In particular, the performance assessment of ecosystem services we chose investigates the main characterizing aspects: Habitat Quality and

Degradation and Carbon Stock and Storage[1] (Fig. 1).

With reference to Habitat quality, the main hypothesis is that the higher quality values correspond to the higher richness of species, related to high habitat functionality and biodiversity, or as a measure of the capacity of regulating and maintaining ecosystem services. This is also considered important, as the habitat quality can be seen as a measure of the effectiveness of conservation policies (Sallustio et al., 2017) and of the higher environmental performances (Balletto et al., 2015; Palumbo et al., 2020; Scorza et al., 2020a) following land management policies (Balletto et al., 2020).

Threats to habitat quality are considered spatially (Terrado et al., 2016) and related also to the concept of habitat degradation. This latter concept in particular, is noticeably influenced by the processes of urban growth, infrastructuring, presence of intensive and extensive agricultural areas, and, generally, territorial transformation, expression of anthropic pressure (Sallustio et al., 2017).

When considering the aspect related to carbon stock and storage, it has been included as an environmental factor representative of life quality. These include aboveground biomass, belowground mass, and Soil Organic Carbon (Houghton, 2003) and dead organic.

Variations in Carbon Stock, Habitat Quality and Degradation (see Fig. 1) are considered as measures of the sustainability in land management and transformation policies representing their resulting effects on the ecosystems' functionality. Therefore, such indicators may be considered geographical proxies of the pandemic spread identifying places where the resident population lives in worst environmental conditions and consequently may be more vulnerable to COVID-19 contagions. We believe that these indicators can be included in the database of territorial variables for the estimation of hazard maps also because they are representative of complex phenomena deriving from multiple factors such as: atmospheric conditions, pollution and climatic characteristics, favorable/unfavorable conditions for the spread of pathogenic organisms.

2.1.2. COVID-19 and environment

In epidemiological and health studies, there is often a need to compare mortality rates between different areas, taking into account both age and population distribution.

Standardized Mortality Ratio (SMR) is used to tackle such an issue (Gatrell and Elliott, 2002). In the areal units, and the age-specific rates of deaths in some wider population, the expectation of the number of deaths is calculated. Observed are compared to expected deaths obtaining a value: value of 1 indicates an expected level of mortality, values higher than 1 show a mortality higher than that expected, and values lower than 1 implies a reduced and lower than expected mortality is.

For the Italian case, COVID-19 associated SMR were calculated with reference to different moments of the virus outbreak and its spatial variability compared to other environmental, geographical and socio-demographic data and indicators (Beniamino Murgante et al., 2020a; 2020c, 2020b; Murgante et al., 2021).

2.2. Dataset building

2.2.1. Data collection

Data were referred to Italian Provinces, the intermediate level between administrative units as Municipalities and Regions. The Provinces/metropolitan cities were considered as the geographical units to compare the data, although, there is heterogeneity in terms of shape and size, and the consequent risk of confusing the spatial pattern drawn by the geographical units with the distribution of the relative population, with that of the underlying population, rather than of the phenomena under exam (Cressie, 1996; O'Sullivan and Unwin, 2010; Openshaw, 1983; Unwin, 1996). The data concerning total infected cases and deaths due to COVID-19 were considered, according to the Italian Ministry of Health and as collected by the Civil Protection, as of April 30, 2020. The selected time period is significant since it is representative of a 'frozen' condition of the COVID-19 epidemic in Italy. From the beginning of March until the end of April, the Italian nation has been completely blocked by the lock down by which, non-essential economic activities and all personal movements have been reduced to the essentials of necessity. The period, therefore, is suitable for a clean analysis from eventual externalities that would alter the results of the model. The data regarding death cases required a more in depth and thorough analysis as they were not originally available at Province level but only at the higher Region level. They were used both related to population and also synthesized in a Standardized Mortality Rate (SMR) in order to better relate the phenomenon to the overall age and spatial distribution of population. In particular, the demographic and socio-economic data come from the Italian Statistical Institute (ISTAT - Istituto Nazionale di Statistica), as population, total and organized in age groups, as well as mortality, differentiated by causes, at 2019. Environmental data, on the other hand, were taken from the Higher Institute for Environmental Protection and Research (ISPRA - Istituto superiore per la protezione e la ricerca ambientale), WHO (World Health Organization), ISS (institute higher of health) EEA (European Environmental Agency), Il Sole 24 Ore, Legambiente (no-profit association for environmental protection), ACI (Italian Automobile Club), ilmeteo.com and windfinder.com (weather and wind data). We also collected data on air quality ($PM_{2.5}$, PM_{10}, NH_3, CO, CO_2, NO_x) and weather conditions (humidity, wind, rain). A total of more than 80 different indicators at Province level were collected for the overall research on COVID-19 in Italy. Furthermore, as demonstrated by Murgante et al., (Beniamino Murgante et al., 2020a; 2020c, 2020b; Murgante et al., 2021), these data presented a high degree of spatial autocorrelation with significant indicators of pandemic spread and its effects on the population, in terms of contagions and death. For the scopes of the present research, we selected and organized a subset of such a big dataset.

As input data, the results from the Ecosystem Services' evaluation were considered. In particular Land 02, Land 03 and Land 04 derive from the ecosystem services performance assessment, all other data come from a previous data set processed (Beniamino Murgante et al., 2020b). The overall data set is organized in three main categories: Environmental, Climatic and Land (see Fig. 2).

2.3. Methods

The research conducted by the authors (Beniamino Murgante et al., 2020a; 2020c) allows us to support how the variables considered most significant in contributing to the spread of a pandemic can be aggregated into 3 classes: Environment, Climatic and Land. The methodological framework (Fig. 3) consists of two main steps: a first step including the dataset building, which includes both the data collection and the ecosystem services' performance assessment, followed by a second step in which we performed the spatial multi-criteria analysis for the realization of the hazard scenarios.

In order to obtain different hazard maps, each of them aimed at highlighting the role of the three aggregation classes, a multi-criteria analysis was performed by means of the Spatial Analytical Hierarchy Process (AHP) method (Saaty, 1980). This procedure is recognized to be a well-established and versatile method in approaching complex decision-making belonging to different scopes such as conflict resolution, resources' allocation or regional planning topics (Celli et al., 2018; Cieślak, 2019; De Marinis and Sali, 2020; Grimm et al., 2008; Karlsson

[1] The analyses were performed and based on the InVEST suite (Nelson et al., 2018). The spatially explicit models used in such a suite are used in the integration of ecosystem services into regional planning, thanks to the use of land use/land cover maps as spatial input to the suite, whose values are, depending on the aspect analyzed, updated with ad-hoc tables (Salata et al., 2017; Xie et al., 2018).

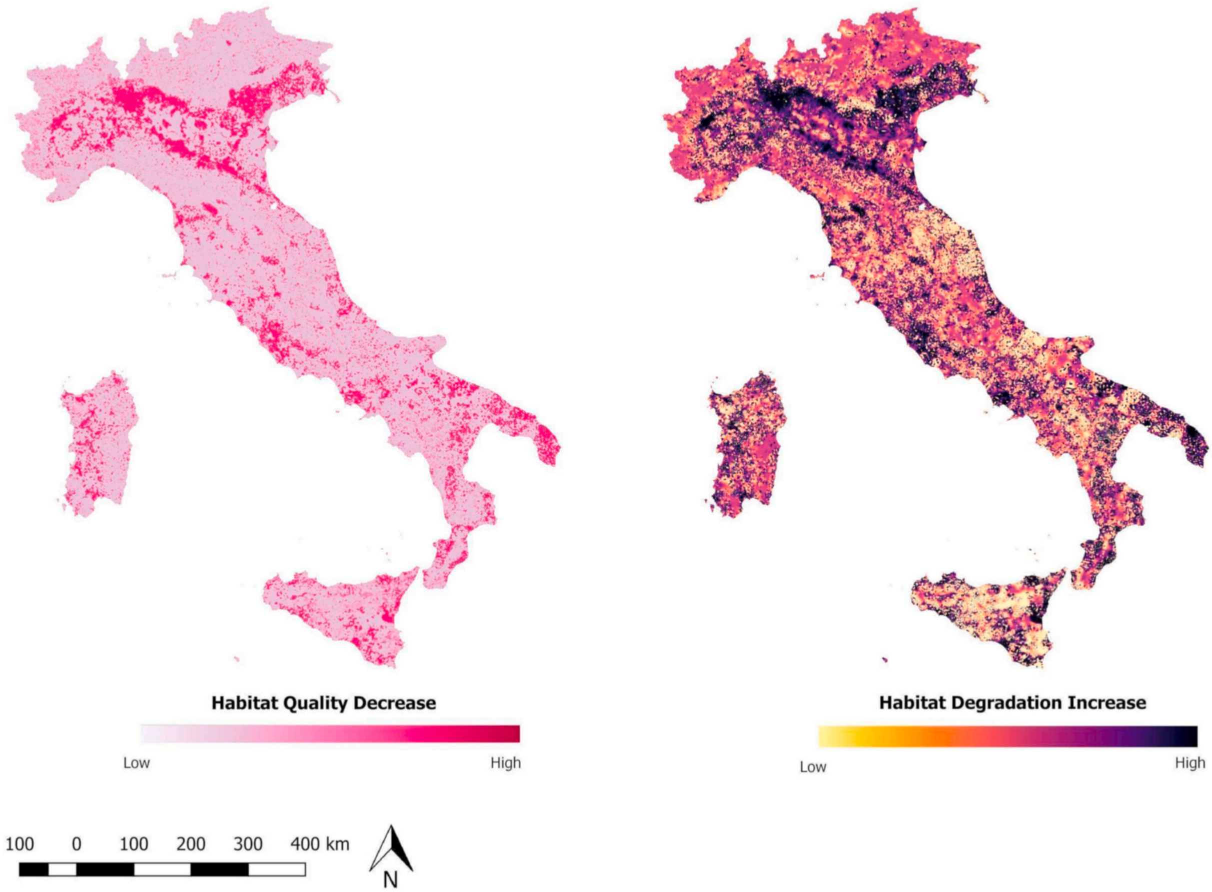


Fig. 1. Habitat quality decrease and habitat degradation increase (adimensional), 1990–2018.

et al., 2017; Mishra et al., 2015; Saaty, 1984), able to deal with both quantitative and qualitative criteria and finally allowing to formulate scenarios by comparing several alternatives. The selection of the alternative that best matches the decision criteria derives from the attribution of numerical weights, significant of the relative importance of each factors' class (Environmental, Climatic and Land).

The method involves three main steps:

1. Ecosystem service performance assessment and selection of three main variables as inputs for the multi-criteria analysis:
   a. Variation per-province of habitat degradation 1990–2018 (Land_02);
   b. Variation per-province of habitat quality 1990–2018 (Land_03);
   c. Average variation per-Province of Carbon Stock 1990–2018 (Land_04)
2. Data preparation from the wide COVID-19 database
   a. Environment (Env_01 - Env_06),
   b. Climate (Clim_01 - Clim_03)
   c. Land data (Land_01)
3. Multi-criteria analysis, organized in different steps:
   a. definition of the problem and the objective;
   b. definition of the hierarchical structure from top (general objective) to bottom (the set of alternatives);
   c. pairwise comparison between each of the classes of factors identified (Environmental, Land and Climatic);
   d. assessment of validity by means of the consistency test;
   e. determination of the weights' vector.

The relative significance of the selected criteria is rated by the nine-point scale where value 1 indicates equal importance and value 9 means the first criterion, extremely important with respect to the second criterion (Özdağoğlu and Özdağoğlu, 2007).

General benefits deriving from AHP consist in reducing the complexity of the decision-making system thus integrating an effective technique to check the consistency of the evaluations (Moreno-Jiménez et al., 2008). In this work AHP allowed us to compute three vectors and formulate three different hazard scenarios: the first maximizes the weight of the environmental factors, the second highlights the class of data relating to climate factors, the third aims to highlight the role of the factors concerning land management (see Fig. 4 and Fig. 5).

3. Results

In order to obtain three hazard scenarios, the environmental, climate and land factors were combined by means of the pairwise comparison that allowed to obtain different weights according to the most influential criterion. In Fig. 6 maps A, B and C represent scenarios I, II and III respectively. The results of these maps have been classified into five hazard levels: very low, low, moderate, high and very high. The division in hazard categories was carried out according to the Natural Breaks method which allows to group similar values in an optimal way, maximizing the differences between the classes and minimizing the average of a squared deviation in each class (JENKS, 1967). Natural breaks is a common method for spatial data classification (Golian et al., 2010), often used in order to classify natural hazard and risk levels deriving from an AHP analysis (Fariza et al., 2018; Febrianto et al., 2017; Stefanidis and Stathis, 2013).

The comparison between the maps shows a high degree of hazard in the provinces of Northern Italy and in particular in the Po Valley for all three scenarios. This is significant because of a mix of factors that negatively affect the pathogen spreading. In the rest of Italy, although some provinces emerge where the hazard is on average more critical, the

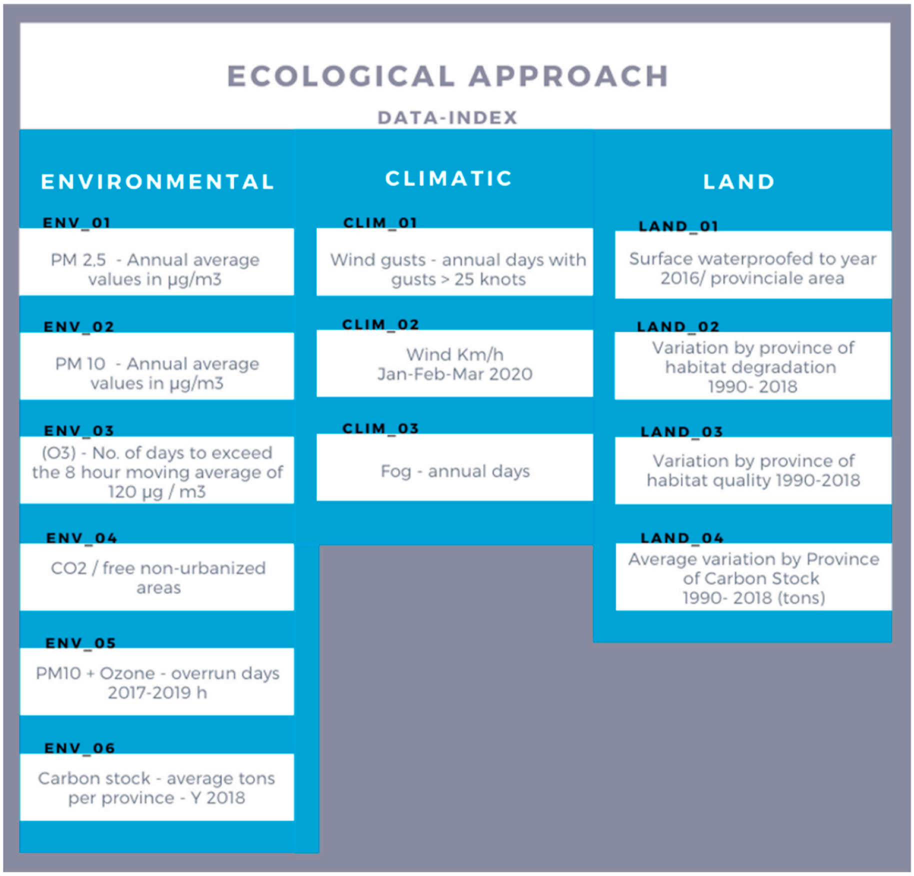


Fig. 2. Data-set of environmental, climatic and land.

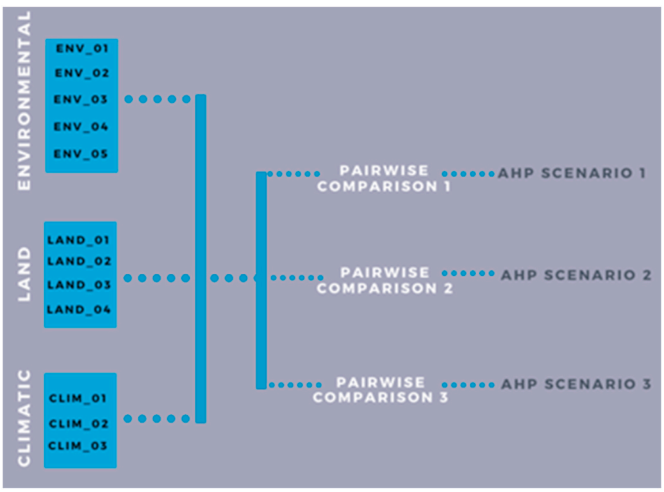
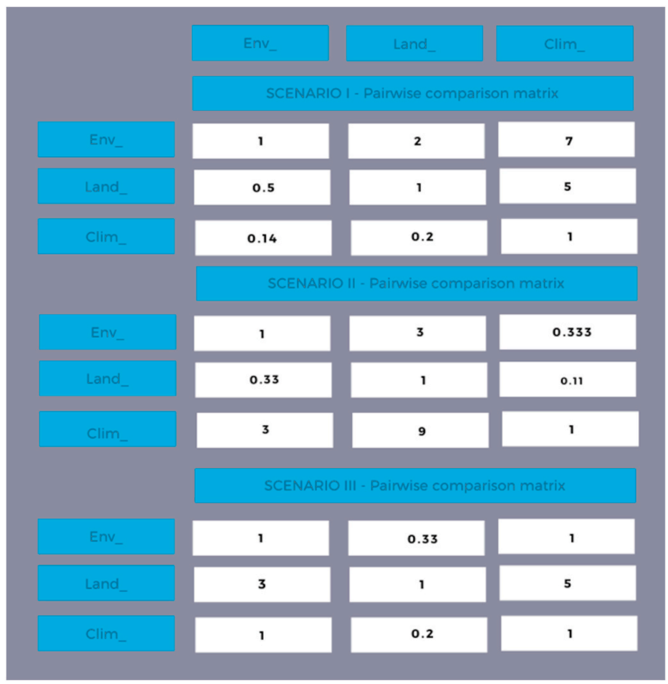


Fig. 3. Methodological framework.



SCENARIO I - Pairwise comparison matrix

	Env_	Land_	Clim_
Env_	1	2	7
Land_	0.5	1	5
Clim_	0.14	0.2	1

SCENARIO II - Pairwise comparison matrix

	Env_	Land_	Clim_
Env_	1	3	0.333
Land_	0.33	1	0.11
Clim_	3	9	1

SCENARIO III - Pairwise comparison matrix

	Env_	Land_	Clim_
Env_	1	0.33	1
Land_	3	1	5
Clim_	1	0.2	1

Fig. 4. Pairwise comparison matrices for each of the three scenarios.

three scenarios show a greater variability. It can be observed, moreover, that the Provinces characterized by an average greater hazard along the peninsula, are not all adjacent to each other. This is the case for example of the Provinces of Terni, Rome, Frosinone - in Central Italy - Naples, Avellino and Brindisi - in Southern Italy - and are characterized by a territorial morphology also very different from one another. This directly affects both Climatic and Environmental Factors but, indirectly, also those related to Land Management. Over the last 50 years, in fact, the Provinces of the Po Valley have recorded a much greater variation in urban growth than the others (Romano et al., 2017a). The same study shows that in the remaining part of Italy the regions of Lazio - to which the Provinces of Rome and Frosinone belong -, Campania - to which the Provinces of Naples and Avellino belong - and Puglia - to which the

	SCENARIO I	SCENARIO II	SCENARIO III
ENVIRONMENTAL	0.589	0.231	0.184
CLIMATIC	0.332	0.077	0.654
LAND	0.075	0.692	0.155

Fig. 5. wt resulting from AHP.

Province of Brindisi belongs - stand out.

The simultaneous observation of the three maps makes it possible to highlight the factors that contribute most to the dangerousness of a territory. In fact, looking at the two Provinces of Basilicata Region, it can be seen that they have the same level of hazard in scenario 2 while the results are opposite in scenarios 1 and 3. The hazard level of the Province of Potenza depends, in fact, more on the Environmental Factors.

Furthermore, as far as the main islands (Sardinia and Sicily) are concerned, one can see that they have a low and very low level of danger in all scenarios (Deiana et al., 2020).

The second scenario, which assigns a greater weight to Climatic Factors, is the more critical by analyzing both the number of Provinces, the population and the area included in the highest hazard level (Very High Level).

Finally, in all three scenarios the Province of Milan is included in the "Very High" Hazard Level, a result that can be confirmed in the absolute data concerning deaths cases for COVID-19 at 30 April 2020 in which Milan is the first Province of Italy and in the number of infected (Third Province of Italy).

COVID-19 maps were realized starting from the cases and death cases, as portrayed in Fig. 7, mapping the relative weight of cases (a) and death cases (b) over the population (2019). Both maps shows a relative concentration of COVID-19 cases and death cases mainly in Northern Italy and in the Po Valley area, with 'legs' spreading towards the Southern parts of the Po Valley towards the Adriatic Coast, and affecting also, other Northern Italian Provinces, mainly in the Alpine Mountain Chain provinces. Here as well, the division in categories was carried out according to the Natural Breaks method. The SMR - Standardized Mortality Ratio (c) confirms such a distribution, with a 'core' of heavily affected provinces particularly in Lombardy, Piedmont, Emilia-Romagna, Liguria, Val D'Aosta and Trentino Alto Adige, together with some scattered provinces along the Adriatic coastline.

The Fig. 7 (a) and (b) also recalls the significant role of commuting.

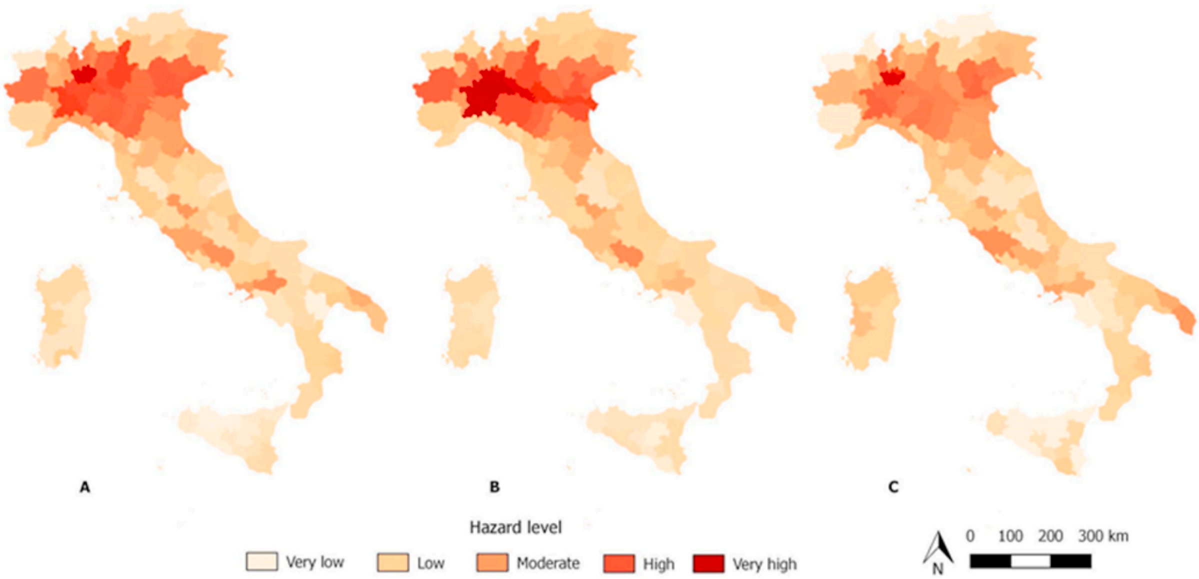


Fig. 6. Hazard maps according to scenarios I (A), II (B) and III (C).

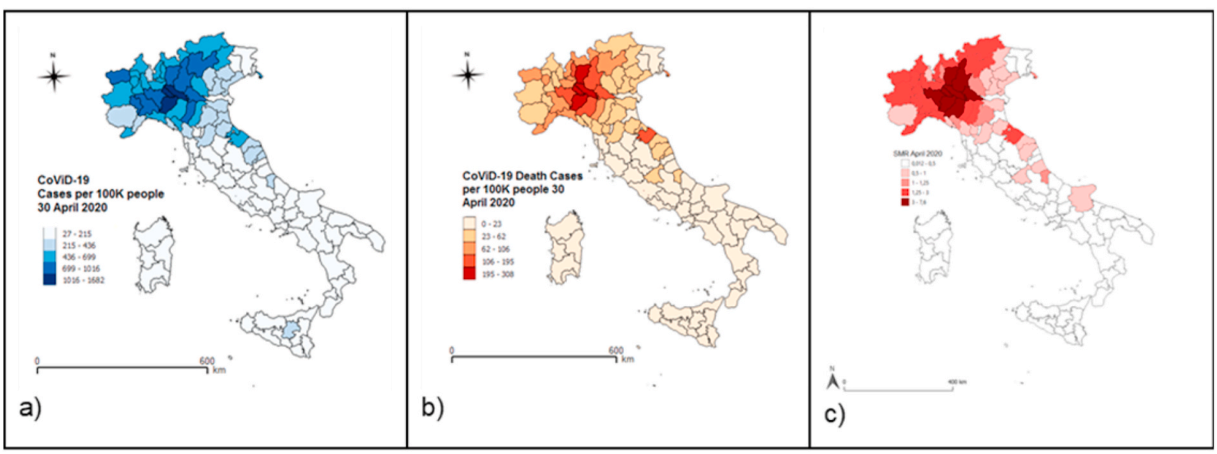


Fig. 7. SMR - data on 30 April 2020.

In fact, distribution follows the main terrestrial communication routes with the metropolitan city of Milan at the top.

By comparing our hazard maps and the spatial distribution of the SMR index, some matches emerge. In fact, the SMR has its highest values in the Provinces of the Po Valley area and Northern Italy in general. The Provinces that in our Hazard Maps never exceed the "Low" level, are those in which an increase in the mortality rate (SMR<1) has not been reported.

The opposite is not true: there are in fact some Provinces, many of which are located along the Alpine Arc, where the SMR is greater than 1 - e.g. Trento, Bolzano, Aosta - but the Hazard level ranges between "Very Low" and "Low".

The analysis carried out in terms of scenarios, shows the amount of areas (Fig. 8) and population over 65 (Fig. 9) in each risk level and for the three different scenarios.

These analyses quantifying also the number of provinces involved in the most hazardous areas (Fig. 10), there is a convergence in highlighting quite well-delimited areas in terms of risk. Only few provinces present very high or high risks, suggesting that actions can be concentrated towards few areas in case of virus outbreaks.

The radar graph shows (Fig. 11), for each province, the hazard level from "Very low" to "Very High" for the three scenarios. Its analysis provides an immediate reading of the most important factors influencing the hazard scenarios for each province. To make some examples, in the province of Terni the scenario I results in a higher hazard level than the other two scenarios. It can be deduced that the hazard derives mainly from environmental factors.

It is interesting to examine some scenarios and risk levels as regards the real cases and death cases observed in Italy. We can notice in particular, as the more external provinces of the radar graph represent the ones at highest risk, and particularly for the environmental hazard scenario. We can spot all the Po Valley and neighboring provinces - as those in Lombardy, Emilia Romagna and part of Piedmont. There is the exception of the Province of Rovigo, considered at high environmental risk, while it actually presented very little cases - and it is favored by a location on the Po delta and far from main road arteries if compared to the other ones.

The scenario furthermore does not explain some important cases in the Alpine mountain area, such as the provinces of Trento, Bolzano, Aosta, where a relevant pandemic diffusion were registered, but non appearing here as areas at considerable risk.

Other averagely high mortality cases were not considered at risk: let us consider the case of Friuli Venezia Giulia provinces in Northern Italy - North Eastern Italy in particular. Correctly not considered as a Northern Italian region at risk, it did present some considerable death cases in the Province of Trieste and in part of the Province of Udine, although easily attributable to concentration of rest homes and hospitals.

High risks were also considered in the scenarios for provinces hosting the major metropolitan areas. Milan, Turin, Verona - in the North - Bologna, Florence, Rome -. in the Centre -, Naples, Bari and the other major cities in the South and islands. The striking element is that such provinces did not present a very high impact of COVID-19 in relative terms: provinces such as Milan and Turin - metropolitan cities - presented relative cases lower than the neighboring provinces.

Other Northern and Central Italian provinces as Verona, Bologna and Florence, quite close and connected to the core of the Po Valley COVID-19 outbreak presented even lower cases, while other Central and Southern Italian metropolitan cities - provinces presented lower values of COVID-19 cases and death cases. Environmental conditions alone could not be therefore considered alone, here, as determinant of a high risk. Other research (Murgante et al., 2020a) showed that a minor spatial homogeneity could help in understanding that in terms of spatial autocorrelation.

4. Discussions

The proposed methodology and the hazard scenarios produced in this work are expressed in terms of system functionality and dysfunctionality in case the extreme event consists in the spread of a pathogen capable of determining a pandemic. The graph (Fig. 12) shows the functionality and dysfunctionality of a system, for two different scenarios: business as usual and sustainable scenario. Considering the curve of the business as usual scenario, under standard conditions (t_0-t_1) the system is functional, i.e. it is able to respond to the needs and demands of society. At time t_1, in the presence of an extreme event (such as a global pandemic), functionality decreases, for example due to the number of infected people or the number of hospitalized people, up to a minimum value that can no longer be supported by the system. We are therefore in the dysfunctionality quadrant. If the system is no longer able to react, it collapses (dashed curve); in case of reaction it gradually re-acquires its functionality until it returns to the first quadrant, that of functionality. The recovery time of functionality depends on the initial conditions of the system expressed in this work in terms of hazard. It is deductible that acting on the hazard increases the level of functionality of the system and in case of an extreme event the *functionality recovery time* will be much shorter than the business as usual scenario: $(t_1\text{-}t_2) < (t_1\text{-}t_3)$. The sustainable scenario represents, therefore, a system in which efforts (territorial policies, environmental investments, etc.) are realized in a medium/long term perspective with effective results in reducing health hazards. The relevant keywords driving such sustainable policy making are: land take, pollution reduction, air quality, climate regulation, protection of ecosystems' functionalities, ecosystem services provision. As

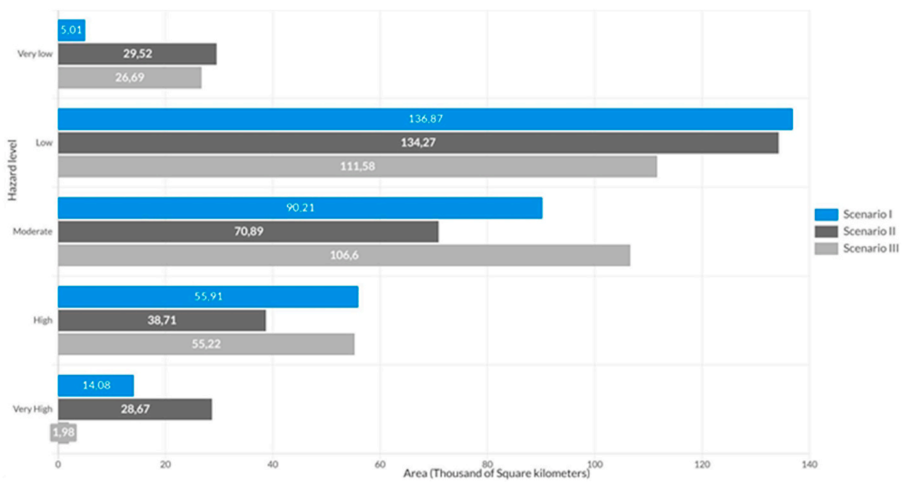


Fig. 8. Comparison between the three scenarios in terms of areas.

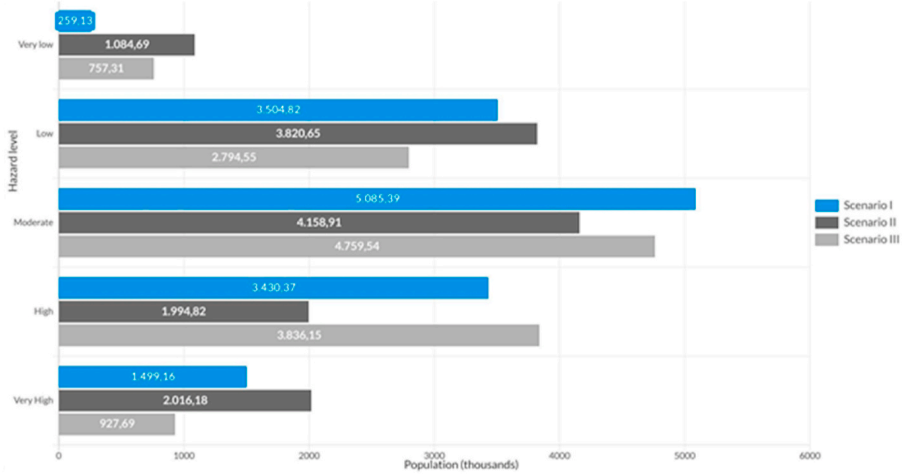


Fig. 9. Comparison between the three scenarios in terms of population over 65.

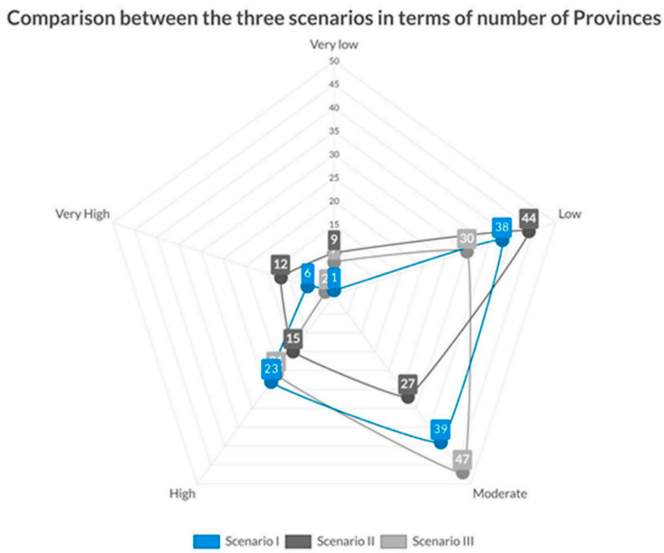


Fig. 10. Comparison between the three scenarios in terms of number of provinces.

can be seen from the results, the comparison between the different scenarios allows to interpret the hazard of a territory in relation to the spread of a pathogen according to three different Factors classes: climatic factors; Environmental Factors; Land Management-related Factors.

Explicating land management policies in terms of performance means redefining the methodological framework in order to overcome the limits of sectoral policies, to act according to a place-based approach and to develop additional evaluation criteria of the policies with respect to traditional territorial planning. The attention to human health and well-being is one of the aspects that traditional planning, from the urban to the national scale, has neglected (Capolongo et al., 2018; D' Alessandro et al., 2017a, D' Alessandro et al., 2017b). The need to integrate these aspects within the various levels of planning is highlighted by several authors (Brown and Grant, 2005; Corburn, 2004; Duhl and Sanchez, 1999; Garcia et al., 2003; Nieuwenhuijsen and Khreis, 2018) and is even more important because of the close link between health and climate change (Kovats et al., 2003). With reference to the global pandemic linked to the spread of COVID-19 in Italy, the provinces most affected are Bergamo, Brescia and Milan (Lombardy Region). It is significant that the Lombardy Region, with the Regional Law num. 12 of 2005 (Urban Planning Law), introduced the hygienic-sanitary evaluation of urban plans whose outcome, however, is not mandatory for the plan approval. This evaluation supports the decisions of the municipalities regarding the approval, request or refusal of additional documents (Capolongo et al., 2016). The integration into Urban Planning Law of mandatory evaluations of human health and well-being aspects would allow direct intervention on the Factors used to build hazard scenarios and increase the functionality of a system making it more sustainable.

While the problems related to pollution are well known and investigated (Cersosimo et al., 2020; De Feis et al., 2020), despite it is not easy to find effective policies able to improve the situation, and aspects associated to climate change begin to be considered (Maragno et al., 2020; Pasi et al., 2019; Pietrapertosa et al., 2019), also in this case with few initiatives aimed at improving the situation, the issues linked to land management are often considered as a futile exercise that constrains economic development. It is important to analyze in a more deep way the aspects connected to a correct Land Management in order to allow decision makers to understand its importance.

In many cases an approach based only on the attempt to observe obsolete laws (Romano et al., 2018; Scorza et al., 2020b) has led to neglect of the heavy effects that can be found in terms of land take (Romano et al., 2017b; Romano and Zullo, 2014a, 2014b, 2016) and loss of ecosystem services (Geneletti, 2013; Geneletti, 2016; Geneletti et al., 2020; Hanzl, 2020). This lack of attention has been analyzed in several studies at national level in Italy (Cosentino et al., 2018; Martellozzo et al., 2018; Munafò, 2020), these researches highlight the negative consequences of past uncoordinated urban and regional planning in Italy, more particularly Martellozzo et al. (2018) developed two simulations of land use change at 2030 according to two criteria “sustainable” and “business-as-usual” collecting in both cases important values particularly in the northern part of Italy. This means that Post-COVID-19 land management and planning have to cater to these aspects.

In this last period there has been a propensity to suppose that density was an important factor in COVID-19 spread. Often a confusion between crowding and density occurs. In crowded places it is more possible to transmit the virus, but there is no relationship between density and crowding, it is possible to find crowded places even in the most remote areas and there is no direct correspondence between density and demographic size. While in more densely populated areas it is easier to find better healthcare infrastructures and better working conditions. This study goes in the same direction of other researches (Hamidi et al., 2020; Harris, 2020; Beniamino Murgante et al., 2020a; Paez et al., 2020) which demonstrated that density is not a key factor in COVID-19 spread, while a settlement organization based on urban sprawl can be more

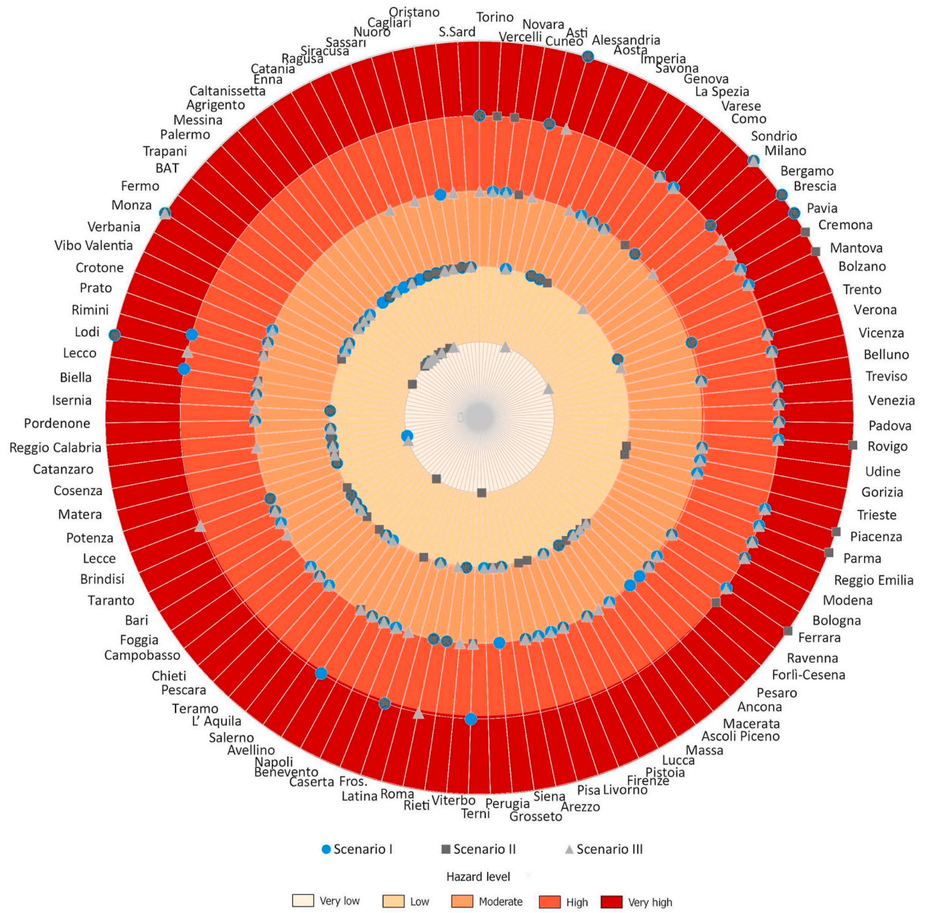


Fig. 11. Radar graph.

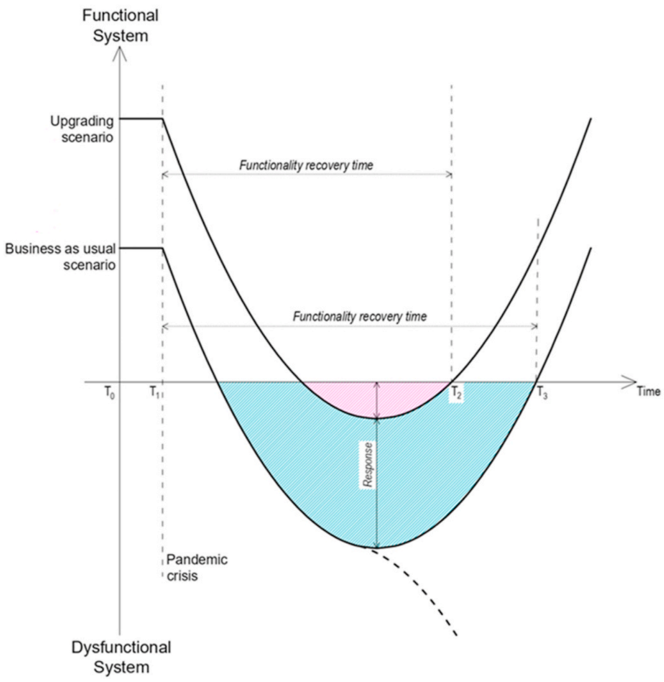


Fig. 12. Functional and Dysfunctional system.

dangerous from a socio-economic, organizational and environmental point of view.

This was highlighted in the several research mentioned above. With reference to the Italian case, a part from the proximity to the initial COVID-19 outbreak in Italy, Northern Italian provinces and Po Valley's ones in particular, were mostly affected where they presented an average level of population density as well as a high proportion of inbound and outbound commuting, therefore behaving more as traffic generators than as attraction poles, as metropolitan cities generally are. This is also demonstrated by recent data regarding the pandemic's evolution in which the north of Italy shows a higher number of cases despite the large amount of vaccines inoculated to the population (83.35% of the population vaccinated with at least one dose in January 2022 in all the Italian territory). Lombardy, Emilia Romagna and Veneto (regions of northern Italy) are the regions with the highest number of infections in January 2022.

5. Conclusions

The mapping of environmental risks has made it possible to improve knowledge of the Italian case, during the COVID-19 pandemic, representing different levels of territorial vulnerability deriving from the progressive weakening of territorial structures (e.g. public health services) with respect to ineffective and sustainable environmental policies of the territory management policies.

The analysis of the COVID-19 outbreak in Italy, limited to the first wave of diffusion, was considered important in observing the dynamics of a phenomenon not affected by other forms of intervention, as specific containment policies, vaccination and other health policies implemented by governments in the following months and stages of the pandemic. This allowed us to concentrate on the vulnerability of the spatial systems when affected by a sudden, unexpected shock, and on the spatial issues to be considered when tackling such a set of unprecedented emergencies, particularly in orienting land policies of health and environmental protection.

The results of the health hazard maps show a disparity in the distribution of territorial responses to the pandemic in Italy. The environmental components play an extremely relevant role in the definition of the red zones of hazard. This highlights the increasingly urgent need to renew sustainable development strategies in order to implement a collaborative effort to make the community system more resilient in the face of environmental, climatic and health shocks. In today's situation, a system of this kind would allow for the recovery of the socio-economic gaps produced by the still ongoing COVID-19 epidemic.

The comparison of hazard maps related to different scenarios aimed at maximizing different factors (environmental, climate and health), provides decision makers to orient policy choices with a different degree of priority according to a place-based approach aimed at satisfying the principles of sustainability from all points of view. In particular, ensuring transparency, which is in fact a necessary prerequisite for successful health surveillance, and minimizing harm. Indeed, in pandemic management, containment measures such as restrictions on individual freedom may be necessary to protect the health of citizens. Such restrictions, in the case of the COVID-19 pandemic, also proved to be useful in reducing air pollution, thus preventing the system from collapsing and even helping it to recover (dotted curve in Fig. 12). Environmental protection and pollution prevention could therefore be understood as complementary measures to strictly emergency measures, allowing the level of restrictions to be modulated in the event of a pandemic. The geospatial representation of risks could be a tool for legitimizing the measures chosen by decision-makers, proposing a renewed approach that highlights and takes into account the differences between the contexts (Regions, Provinces, Municipalities), also in terms of climatic and environmental variables. In such sense, it could be worthwhile rethinking the geographical scale of the policies to be put in action, from the Region to Provinces or Metropolitan Cities, given the more disaggregated level of data available and response to the policies.

Future research developments will concern the proposal of a risk map that could be realized by integrating the proposed methodological framework with demographic data and data on past diseases that could constitute factors of vulnerability at local level.

Author contributions

This paper is the result of the joint work of the authors. The first draft was written by BM, BaG, SL, PA, BG, DM, CP. Specifically, 'Introduction' was written by all authors; BaG, DM, BG; SL, PA wrote 'Ecosystem services and human well-being'; SL, PA, BaG wrote 'COVID-19 and environment'; BG, MB, SL, PA, BaG wrote 'Data collection'; SL, PA, MB, BaG, BG wrote 'Result'; SL, PA, BaG, DM, CP, AA wrote 'Discussion' and MB, BG and SF. wrote 'Conclusions'. All authors have read and agreed to the published version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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