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RESEARCH

Mortality from extreme meteorological and hydrogeological events in Italy: a rising health threat connected to climate change

Claudia Dalmastri[1] · **Raffaella Uccelli**[1]

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Abstract
The aim of the present work is to assess mortality associated to extreme meteorological and hydrological events (storms, floods, landslides, avalanches) for the period 2003–2020 in Italy. These extreme events are particularly worrying phenomena due to their increasing frequency and intensity connected to climate change. The considerable rise of extreme meteorological events in Italy has been having a dramatic impact on the environment and territories, particularly on intrinsically fragile ones, and on resident populations. More than 90% of Italian municipalities are at risk for extreme events, with more than 8 million inhabitants exposed. Number of deaths and SMRates due to such extreme events (X International Classification of Diseases: X36, X37 and X38) in Italy were calculated from regional to municipal level by ENEA mortality database (data source ISTAT). Geographic maps were elaborated by QGIS software (QGIS, RRID:SCR_018507) version 3.28. In the selected period, 378 overall deaths were detected: 321 deaths due to landslides and avalanches, 28 to cataclysmic storm, and 29 to floods. The regions with the highest mortality levels and/or number of municipalities involved and the municipalities at highest risk were identified. In consideration of the forecasted increase of such extreme events in Italy, the knowledge of Italian areas at highest risk can be used in the decision-making processes to assess priorities, allocate financial resources, define warning measures, and undertake preventive or mitigation actions. Moreover, the attributable mortality levels can be a useful basis for further risk assessment research aimed at estimating the cost in terms of human lives' loss associated to such events in future climatic scenarios.

Keywords Mortality · Climate change · Extreme meteo-hydrogeological events · Landslides, avalanches, cataclismyc storms, floods · Italian regions and municipalities

Introduction

Since the 1970s, human activities have been causing a rapid increase of the average global temperature, with adverse impacts on both human health and the environment (Weilnhammer et al. 2021, Rocque et al. 2021). Fossil fuels combustion has been responsible for the emissions into the atmosphere of large amounts of carbon dioxide (CO_2) and other greenhouse gases which, trapping the heat in the troposphere, have been affecting the global climate. Besides the rising of temperature, climate change is responsible of many other environmental adverse phenomena. They include the increase in both intensity and frequency of extreme weather events (heat waves and cold spells, storms, inland and coastal floods, draughts), the rising of the sea level, the melting of glaciers, the increase of stratospheric ozone (O_3) and other air pollutants, with consequent alterations in natural ecosystems' equilibrium and crops' production (Stott 2016; Weilnhammer et al. 2021; WHO 2020).

These extreme events have been increasing in Europe, causing substantial damages to nature, buildings, infrastructures, and human health. The 2022 summer was the warmest one ever recorded in Europe (Masselot et al. 2023) with large areas destroyed by forest fires whereas, on the other hand, certain areas have been experiencing severe cold spells. Basing on future climatic scenarios, annual precipitation and heavy rainfall are likely to increase in northern Europe, with droughts becoming less frequent. Central Europe is likely to

✉ Claudia Dalmastri
claudia.dalmastri@enea.it

[1] Department for Sustainability, Laboratory Health and Environment – Research Center Casaccia, Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Via Anguillarese 301, Santa Maria di Galeria, Rome 00123, Italy

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experience lower summer rainfall but more severe extreme weather events (heavy precipitation, river floods, drought, and fires), with annual alternance between precipitation and aridity. In southern Europe, annual precipitation and summer rainfall are forecasted to decrease, whereas aridity, droughts and fire are all likely to increase (EEA 2023).

In Italy, the considerable rise of such phenomena has a heavy impact on the environment, on territories - particularly the intrinsically fragile ones - and on resident populations. Most Italian municipalities (93.9%) are at risk for landslides, floods and/or coastal erosion. It has been estimated that 1,3 million inhabitants are at risk from landslide and 6,9 million from floods. The regions with the highest number of populations at risk are Emilia-Romagna, Tuscany, Campania, Veneto, Lombardy, and Liguria. As far as buildings are concerned, 3,9% of them are in areas at high or very high risk of landslides, and more than 10,7% in areas at medium risk of floods (Trigila 2021).

Extreme weather events impact human health both directly causing injuries up to the loss of human lives, diseases, and mental disorders, and indirectly leading to damage to infrastructures and properties, water contamination, and geographic redistribution of infectious diseases. Health impacts from extreme events due to climate change may be even heavier on vulnerable populations such as the elderly, the infants, sick people, and socially isolated individuals (Weilnhammer 2021).

In 2015, a systematic study reviewed, for the first time, the literature on the health impacts of landslides (Kennedy et al. 2015), in terms of both mortality and morbidity, also including sex as risk factor and triggered by other natural hazards.

Among the geo-hydrological hazards, floods and landslides are particularly frequent and destructive, every year causing harm to people. Salvati and colleagues (2018) analysed data on 1292 landslide and 771 flood fatalities that occurred in Italy over the 50-year period from 1965 to 2014, aiming at determining their dependence on age, gender, and the circumstances of death.

Projected future increases of direct damages from floods associated to a mean global temperature increase of 2 °C are higher by 1.4 to 2 times compared to those expected from 1.5 °C global warming increase, and 2.5 to 3.9 times higher for a temperature increase of 3 °C (IPCC 2022). Furthermore, age may represent a risk factor in facing extreme weather (EPA 2023) and geo-hydrological events. In Italy, the elderly are increasing, since the percentage of Italian population over 65 years of age raised from 16% in 2001 to 21% in 2020 (ISTAT 2020), reaching 24.1% at the beginning of 2023 (ISTAT 2022). Therefore, Italians appear to be at high risk of extreme events due to climate changes from both geographical and demographic point of view.

To capture the complex set of interactions by which the climate change has been affecting human health, indicators were designed as workable tools (climate change impacts, exposures, and vulnerability indicators, CCIEVIs) (Di Napoli et al. 2022). As an example, studies were performed to establish and validate different health vulnerability and adaptation indices in flood events in China (Zhong et al. 2021). A recent overview of systematic reviews (Rocque et al. 2021) included studies referring to climate change from Countries all over the world. The two most common climate impact categories considered in the reviews where meteorological and extreme weather events whereas the most common health outcome categories were mortality, infectious, respiratory, cardiovascular, and neurological diseases.

The objective of the present investigation is to assess, through the current available flow data, the number and spatial distribution of deaths in Italy due to extreme meteorological and hydrological events such as landslides, avalanches, storms, and floods. Mortality data are the only health data available for all Italian municipalities and can be referred to such specific external causes of death. Furthermore, the provided historical picture of mortality levels associated to such extreme events will allow to identify particularly vulnerable geographic areas, and to offer a useful basis for further studies aimed at estimating the cost in terms of human lives' losses under future climate scenarios.

Materials and methods

The present study has been carried out by the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) mortality database (data source: National Institute of Statistics - ISTAT), which includes cause specific mortality records for all the Italian municipalities from 1980 to 2020.

Italian number of deaths due to extreme meteorological and hydrological events were extracted for the 2003–2020 period at regional, provincial, and municipal level. The following external causes of death with reference to the 10th International Classifications of Diseases (ICD) were considered: landslide and avalanche (10 ICD X36), cataclysmic storm (10 ICD X37) and flood (10 ICD X38).

Standardized mortality rates per 100,000 (SMRates) (standard population source: 2011 Italian census) for all ages and for males and females together, and the relative 95% Confidence Intervals (95% CI) were calculated at regional level and for all the Italian municipalities. For each region and for each province, the number of municipalities with death cases and the number of those with more than one death were computed.

Municipalities with death cases were also characterised on the basis of the ISTAT altimetric zone classification (ISTAT 2018) in mountainous, hilly and lowland ones.

Moreover, they were also classified on the basis of the urbanization level based on population density (high, intermediate and low density municipalities), defined by the statistical office of the European Union, Eurostat 2006 (ISTAT 2018).

Geographic maps were elaborated by QGIS software (QGIS, RRID:SCR_018507) version 3.28.

Results

In the 18 year examined period, 378 overall deaths (297 males and 81 females) due to extreme meteorological and hydrological events such as landslides, avalanches, storms, and floods were detected. In detail, 321 deaths from landslides and avalanches, 28 from cataclysmic storms, and 29 from floods were found.

Table 1 shows the number of overall deaths for all these external causes by region and by province, and the number of municipalities involved. The number of municipalities with more than one case of death is also reported. The number of deaths and SMRate values are reported on the region maps in Figs. 1 and 2, respectively.

The Regions with the highest number of deaths are Trentino-Alto Adige, Lombardy, Sicily, Piedmont, Veneto, and Abruzzo (Fig. 1). Molise is the only region with no death cases.

The SMRates are very small due to the relative few cases. They range from 0,005 per 100,000 to 0,479 per 100,000 of Aosta Valley which must be included among the regions at higher risk. SMR values higher than 0,1 were also observed in Trentino-Alto Adige and Abruzzo (0,398 and 0,102, respectively).

The municipalities affected by death cases are 247 and their geographical distribution is shown in Fig. 3. The regions with the highest number of municipalities involved, are Lombardy and Trentino-Alto Adige (both with 44 municipalities), Piedmont (28 municipalities), Veneto (23 municipalities), Abruzzo and Emilia-Romagna (both with 12 municipalities), and Calabria, Liguria and Sicily (with 10 municipalities each) (Table 1; Fig. 3).

The SMRate ranges for the Italian municipalities which suffered for deaths caused by such external causes are reported in Fig. 4. It can be observed that municipalities with the highest SMRate values are mainly located in Trentino-Alto Adige, Aosta Valley and Abruzzo, while some isolated municipalities with high values can be mainly observed in Piedmont, Lombardy, Friuli-Venezia Giulia, Emilia-Romagna, the Marches and Sardinia.

On the basis of the ISTAT altimetric classification, about 50% of municipalities with death cases were mountainous, 32% hilly and less than 20% flat.

As far as the Eurostat urbanization level is concerned, about 50% of municipalities with death cases had low population density (classified as rural), 38% intermediate density and less than 13% high density.

Discussion

Extreme events have been increasing in both frequency and intensity, and their number is expected to further raise in the future, as consequence of climate changes. Extreme temperatures can impact human health directly, especially affecting vulnerable individuals, but also indirectly through the effects on the environment. Extreme hot temperatures, for example, can dry up rivers and lakes affecting all the living organisms depending on them and can make soils drier with increased fire risks and reduced agricultural productivity (EEA 2023).

Although global warming may bring some localized benefits, such as less severe winter in temperate climates and increased food production in some areas, the overall effect is negative, with impact on both the environment and human health due to the dramatic rise of meteorological and hydrogeological extreme events such as landslides, avalanches, and floods (WHO 2021).

Despite the growing scientific awareness of the link between climate change and health, the actions taken so far are not sufficient to counter their effects. Facing hydrometeorological events is a priority and a governance challenge, and instruments for strategies are under investigation to be improved (La Jeunesse and Larrue 2020). Proper indicators are needed to investigate exposure of populations to extreme events and to estimate the expected health outcomes. Among them, mortality data are largely used as indicators in epidemiological studies on climate change and, nevertheless they represent only the tip of the iceberg of the real impact on human health, they have the advantage of being current flow data available for most countries.

The number and frequency of extreme events have recently dramatically raised also in Italy, as shown in periodic reports by the Italian Institute for Environmental Protection and Research (ISPRA), the Italian National Research Council (CNR) and by some environmental associations such as Legambiente (Bianchi et al. 2021, 2022; CNR 2020; CNR 2023; Trigila et al. 2021; Zanchini et al. 2021). In particular, a consistent increase in the number of landslides and floods was reported by ISPRA from 2009 to 2014 (Trigila et al. 2015). From January to May 2023, 122 extreme weather events were recorded in comparison with the 52 recorded in

Table 1 Number of deaths from landslides, avalanches, cataclysmic storms and floods by region and by province. For each province the number of municipalities involved and the number of those with more than one case of death are also reported

Regions	Provinces	N. of deaths	N. of munic.	N. of munic. >1 deaths
ABRUZZO		**24**	**12**	
	L'Aquila	< 3	2	0
	Chieti	4	3	0
	Pescara	14	5	4
	Teramo	4	2	1
BASILICATA		**< 3**	**2**	**0**
	Potenza	< 3	1	0
	Matera	< 3	1	0
CALABRIA		**12**	**10**	**1**
	Reggio Calabria	3	3	0
	Cosenza	< 3	2	0
	Catanzaro	< 3	1	0
	Crotone	3	3	0
	Vibo Valentia	3	1	1
CAMPANIA		**5**	**4**	
	Naples	4	3	1
	Salerno	< 3	1	0
EMILIA ROMAGNA		**14**	**12**	
	Bologna	< 3	1	0
	Modena	3	3	0
	Parma	< 3	1	0
	Piacenza	< 3	2	0
	Ravenna	4	2	1
	Reggio Emilia	< 3	2	0
	Rimini	< 3	1	0
FRIULI-VENEZIA GIULIA		**10**	**9**	
	Udine	9	8	1
	Pordenone	< 3	1	0
LAZIO		**12**	**7**	
	Rome	8	3	1
	Frosinone	< 3	2	0
	Viterbo	< 3	1	0
LIGURIA		**19**	**10**	
	Genoa	10	4	1
	Imperia	< 3	1	0
	La Spezia	6	3	1
	Savona	< 3	2	0
LOMBARDY		**55**	**44**	
	Milan	7	4	1
	Bergamo	11	7	3
	Brescia	7	6	1
	Como	5	5	0
	Mantova	< 3	1	0
	Pavia	< 3	1	0
	Sondrio	6	6	0
	Varese	4	3	1
	Lecco	9	7	1
	Lodi	1	1	0
	Monza e Brianza	2	2	0
THE MARCHES		**10**	**9**	

Table 1 (continued)

Regions	Provinces	N. of deaths	N. of munic.	N. of munic. >1 deaths
	Ancona	3	2	1
	Ascoli Piceno	< 3	1	0
	Pesaro	< 3	1	0
	Macerata	4	4	0
	Fermo	< 3	1	0
PIEDMONT		**34**	**28**	
	Turin	14	8	2
	Alessandria	< 3	2	0
	Biella	3	3	0
	Cuneo	7	7	0
	Novara	< 3	2	0
	Vercelli	3	3	0
	Verbania Cusio Ossola	< 3	2	0
APULIA		**10**	**8**	
	Brindisi	< 3	2	0
	Taranto	5	3	1
	Foggia	< 3	1	0
	Lecce	< 3	2	0
SARDINIA		**5**	**2**	
	Olbia Tempio	5	2	2
SICILY		**35**	**10**	
	Catania	< 3	2	0
	Messina	28	5	2
	Siracusa	< 3	1	0
	Caltanissetta	4	3	1
TUSCANY		**17**	**7**	
	Grosseto	< 3	2	0
	Pisa	< 3	1	0
	Pistoia	< 3	1	1
	Livorno	9	2	1
	Massa Carrara	3	1	1
TRENTINO-ALTO ADIGE		**73**	**44**	
	Trento	24	16	4
	Bolzano	49	28	10
UMBRIA		**< 3**	**1**	
	Terni	< 3	1	0
AOSTA VALLEY		**11**	**8**	
	Aosta	11	8	2
VENETO		**29**	**23**	
	Venice	< 3	2	0
	Belluno	13	10	3
	Padova	4	3	1
	Vicenza	5	4	1
	Verona	< 3	1	1
	Treviso	3	3	0
TOTALE		**378**	**247**	**54**

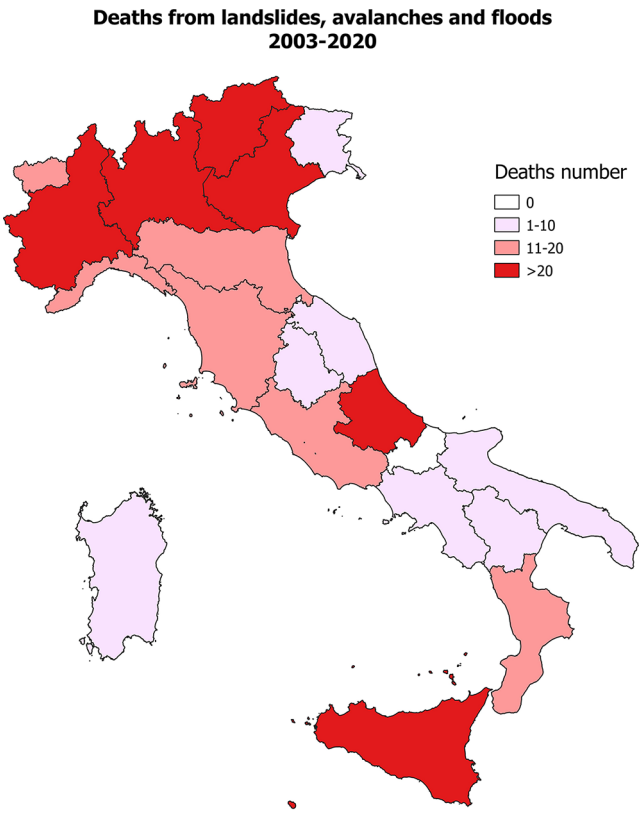

Fig. 1 Geographic map of the number of deaths from landslides, avalanches, cataclysmic storms and floods by region in the period 2003–2020

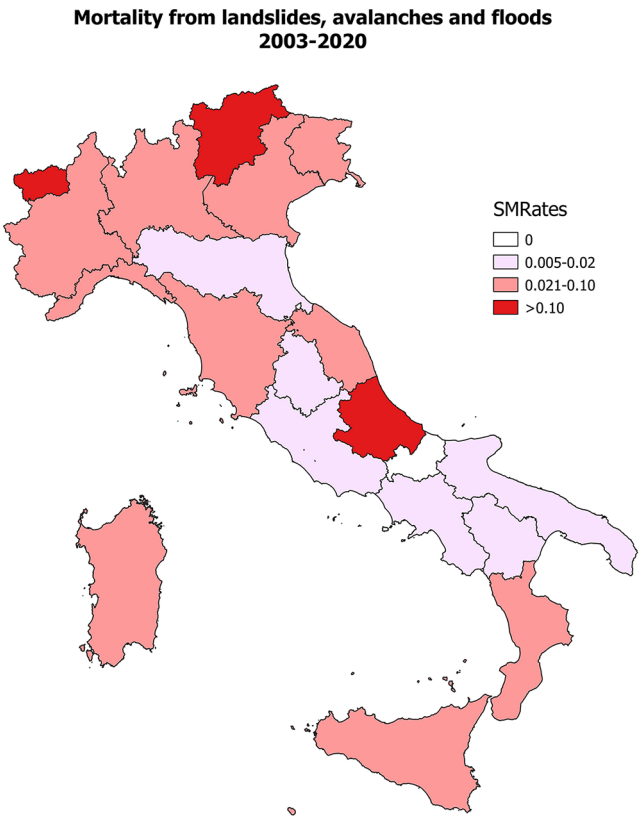

Fig. 2 Geographic map of the regional standard mortality rates (SMRates) per 100,000 (standard population: 2011 Italian census) due to landslides, avalanches, cataclysmic storms and floods in the period 2003–2020

the same months of 2022 (+135%). The six most affected regions were Emilia-Romagna, Sicily, Piedmont, Lazio, Lombardy, Tuscany (Legambiente 2023).

The present study offers a picture of Italian mortality from 2003 to 2020 due to extreme events (landslides, avalanches, storms, and floods), in terms of geographic distribution from the national to the municipal levels. Mortality is the only health indicator available for all Italian municipalities, allowing to investigate the whole Italian territory. Of course, the real impact of extreme events is underestimated because it cannot take into account the people who survived, some of them with severe physical and psychological trauma (Rosinger 2022).

A consistent difference in the death number was observed between sexes, as also reported by Salvati and colleagues (2018), the males being over-represented in comparison to females (79% and 21%, respectively). The reason of such difference is difficult to be understood but it may be linked, at least in part, to different lifestyles (also connected to work activities, home-work transfers, and different time spent outdoor) and would require further investigation.

Trentino-Alto Adige, Lombardy, Sicily, Piedmont, Veneto, Abruzzo and Aosta Valley emerged as the regions at highest risk in terms of mortality levels and for the inclusion of a considerable number of municipalities affected by death cases inside the regional borders. Other regions showing high numbers of municipalities involved and, in some cases, with relatively high SMRates, were Emilia-Romagna, Calabria and Liguria. Some isolated municipalities with high SMRate values were also observed in Friuli-Venezia Giulia, Emilia-Romagna, the Marches and Sardinia.

Unfortunately, the low number of deaths observed did not allow a statistical analysis of the impact from the different type of extreme events considered, limiting the knowledge of the specific mortality attributable risk and the relative impact in each region.

On the basis of the orographic characteristics of the different Italian regions, we can observe how mountainous regions (Trentino-Alto Adige, Lombardy, Piedmont, Veneto, Aosta Valley, Abruzzo and Sicily) are those at highest risk from such extreme events, independently from their collocation in the northern, central or southern part of Italy, even though the northern regions which are characterised by the significant presence of Alps, seem to be at highest risk. This was also confirmed at municipal level through the ISTAT altimetric classification showing that about 50% of municipalities with death cases were mountainous.

Fig. 3 Geographic map of the 247 Italian municipalities with death cases from landslides, avalanches, cataclysmic storms and floods in the period 2003–2020

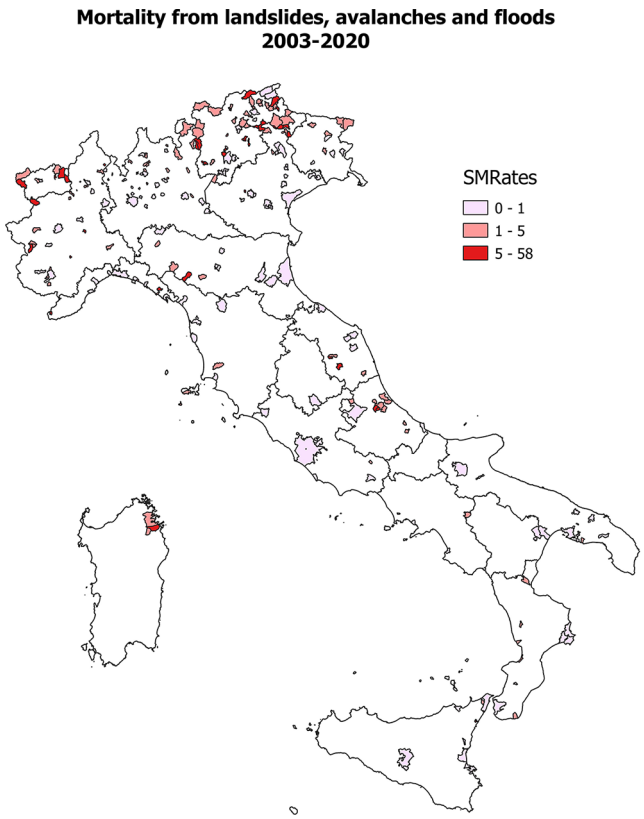

Fig. 4 Geographic map of the municipal standard mortality rates (SMRates) per 100,000 (standard population: 2011 Italian census) due to landslides, avalanches, cataclysmic storms and floods

As far as the urbanization level is concerned, the inverse association of affected municipalities with population density highlights how less inhabited areas are particularly at risk. A hypothesis could be that these areas are intrinsically more dangerous than cities in case of extreme events possibly due to less infrastructural protections or even to longer times needed for rescue to arrive and be operative.

This study allowed the definition of mortality levels due to such extreme events and the identification of geographic areas at risk inside the Italian territory. The regions and municipalities at high risk in terms of mortality, as well as the territories where these municipalities are more concentrated, should be considered as priority areas for specific investigations, and adequate resources should be devoted at mitigating the factors involved. This knowledge can be useful to set up the best strategies to prevent or to face extreme events. Moreover, it can offer a useful historical basis for further risk assessment research aimed at estimating the additional cost in terms of human lives' loss due to the increase of such events, applying future climatic scenarios' models.

Suggestions for risk mitigation should be addressed to national and local authorities and must be connected to prevention of such catastrophic outcomes, focusing primarily on fragile territories. The first necessity is to implement long-term action plans aimed at ensuring safety of people, buildings and goods. Secondly, when the preventive actions result insufficient, it is important to be prepared to activate health structures facilities, also in terms of bed numbers and proper therapies for physical and psychological trauma occurred in the resident population. Moreover, emergency strategies to avoid human consumption of contaminated food and water, potential cause of epidemics, should be immediately activated after the event. Thirdly, technical plans aimed at the restoration of all environmental, infrastructural, economic and social conditions existing before the event must also be immediately operative and effective (La Jeunesse and Larrue 2020; Rosinger 2022, WHO 2021).

In conclusion, considering the forecasted increase of such extreme events in Italy as well as in Europe and all over the world, the knowledge of areas at high risk can be used in several decision-making processes to assess priorities, define warning measures, and undertake preventive or mitigating actions to face further disasters.

Moreover, socio-economical evaluation in terms of costs associated to premature deaths or those necessary for the cure and assistance of affected people, many of them

permanently impaired, could be carried out for the different climate scenarios.

Author contributions Both authors Claudia Dalmastri and Raffaella Uccelli contributed to the preparation of the present article: study conception and design; data collection and analysis; writing and editing. Both authors approved the final manuscript.

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Data availability Single mortality data can be requested directly to Istituto Nazionale di Statistica, ISTAT (Italy), https://www.istat.it/, the official repository of these sensitive data.

Code or data availability (software application or custom code) QGIS software (QGIS, RRID:SCR_018507) version 3.28.

Declarations

Ethics approval No ethical approval was required since the study is based on anonymous mortality data, not associable to specific individuals.

Competing interests The authors declare no competing interests.

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