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Learning from the COVID-19 pandemic in Italy to advance multi-hazard disaster risk management

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ABSTRACT

COVID-19 challenged all national emergency management systems worldwide overlapping with other natural hazards. We framed a 'parallel phases' Disaster Risk Management (DRM) model to overcome the limitations of the existing models when dealing with complex multi-hazard risk conditions. We supported the limitations analysing Italian Red Cross data on past and ongoing emergencies including COVID-19 and we outlined three guidelines for advancing multi-hazard DRM: (i) exploiting the low emergency intensity of slow-onset hazards for preparedness actions; (ii) increasing the internal resources and making them available for international support; (iii) implementing multi-hazard seasonal impact-based forecasts to foster the planning of anticipatory actions.

1. Introduction

The long-lasting COVID-19 pandemic crisis has drastically challenged all national emergency management systems worldwide. For more than two years our society has been dealing with a global slow-onset disaster whose emergency phase lasts for a prolonged period, with varying intensity levels, and well-defined cycles [54]. In the first phase of the pandemic spread, preparedness and prevention planning was not adequate to deal with such an unexpected event [7]. Moreover, the response systems were stretched to their limits, for example with the saturation of the health systems due to the overload in intensive care units [27]. To make the scenario more complex, the pandemic has interacted at several levels [32,33] with other natural hazards that occurred during the last few years all over the world. Noteworthy are the earthquake in Croatia, the tropical cyclone Harold, and the floods in Western Europe including Germany, Belgium, and the Netherlands, underlining the compound and cascading nature of disasters (Fig. 1).

The temporal and spatial overlaps of COVID-19 with other natural and anthropogenic hazards have highlighted the need to combine them into an integrated management model [19,21,33,42].

The Disaster Risk Management Cycle (DRMC) [2,8] is a common reference for the international Disaster Risk Management (DRM) community to describe the management of catastrophic anthropogenic and natural events, including single, compound, or cascading hazards worldwide. Implementing this approach, disasters are considered in separate and consecutive phases (e.g., preparedness, response, and recovery) by varying the duration of each phase and the specific actions to take according to the type of hazards. However, the current DRMC is not able to successfully cover the dynamics of multi-hazard risk scenarios, particularly those involving both sudden- (e.g., earthquakes or flash floods) and slow-onset hazards (e.g., pandemics, droughts, and long-lasting conflicts).

Acronyms: Anticipatory Action, AA; Disaster Risk Management, DRM; Disaster Risk Management Cycle, DRMC; Intensive Care Units, ICU; Italian Red Cross, ItRC; Local Administrative Unit, LAU; Nomenclature of Territorial Units for Statistics, NUTS.

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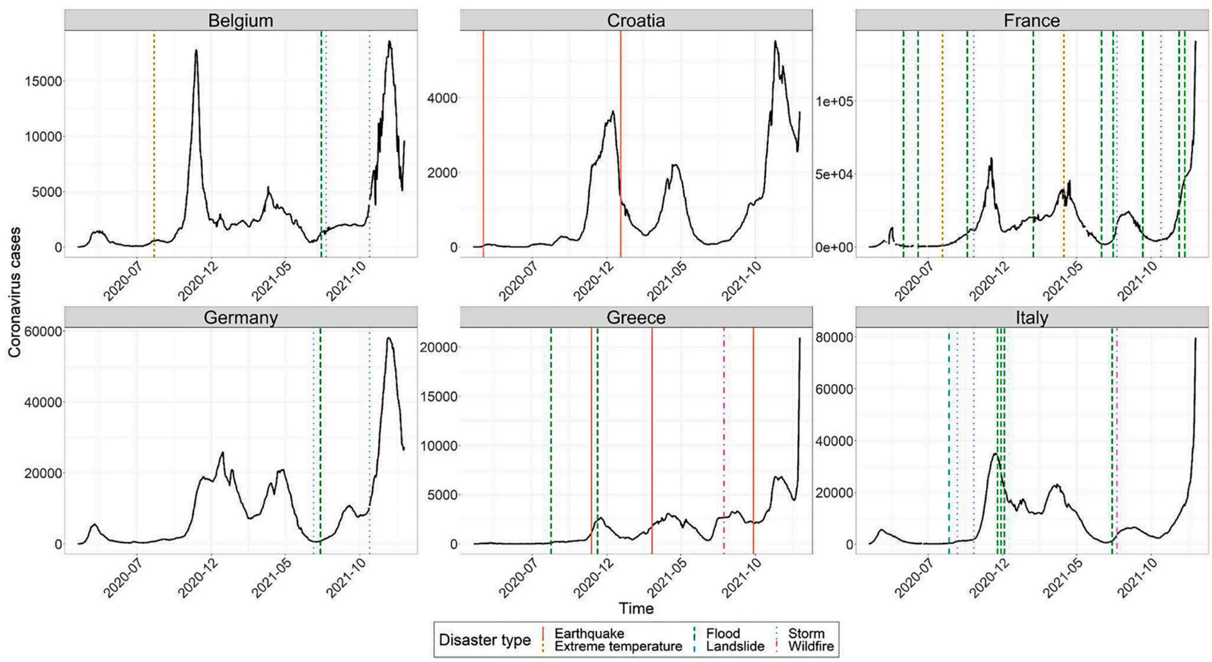

Fig. 1. COVID-19 daily new cases for Belgium, Croatia, France, Germany, Greece, and Italy (black lines) from March 2020 to December 2021 using data from Ritchie et al. [36]. Other disasters that happened in the same time frame (vertical coloured lines) obtained from the EM-DAT database [18] are superimposed to highlight the emergence of multi-hazard risk conditions.

Many authors have already discussed some of the limitations of the current disaster management approach. Nojavan et al. [29] highlighted the need for new practical insights into disaster management and proposed a new conceptual model that encompasses three main themes: hazard assessment, risk management, and management actions (the latter includes the phases of the DRMC). Staupe-Delgado [43] focused on the limitations of the current DRMC when dealing with slow-onset hazards and disasters, calling for the need to improve the sudden-onset logic to secure proactive response to slow-onset disasters. Sawalha [39] proposed a conceptual model that incorporates contemporary management concepts into the traditional disaster management cycle. Bosher et al. [6] proposed a helictical conceptual framework questioning the reliability of the current circular representation and triggering discussions on how to best capture the dynamic nature of disasters. Among these models, the Green Paper on Disaster Management [13] proposed a different perspective on disaster management for both sudden- and slow-onsets. They present the DRM phases occurring in a parallel way along time increasing or reducing their intensity according to the management needs. Nevertheless, none of these models fully address the issues of multi-hazard risk management which also involves slow-onset events. This is most likely due to the complex spatial and temporal interactions across the different hazard, exposure, vulnerability, and impact levels [11,16,17,22,37,41,45] that are difficult to comprehensively integrate into a single DRM framework [26,31].

Italy has been facing such a complex multi-hazard risk scenario during the COVID-19 crisis, managing the pandemic and other natural hazards. As the first country in Europe affected by COVID-19, Italy implemented strict mobility and social restrictions while experiencing severe consequences on its population and economy. During the COVID-19 outbreak, the Italian emergency response system was challenged by the sudden increase in resource demand in terms of the number of required emergency responders, Personal Protective Equipment (PPE), and Intensive Care Units [5,35]. In addition, eight other disasters occurred in Italy overlapping with the COVID-19 emergency (Fig. 1). In particular, from March 2020 to December 2021 four floods, two storms, one landslide, and one wildfire occurred in Italy, leading to human and economic losses [18].

The overlap of the natural hazards with the pandemic has led to 'asynergies' in the impacts [33,38] and management practices. In particular, the evacuation procedures within Italian emergency response plans for floods did not rapidly integrate protective measures required to limit the further spread of the virus, such as social distancing. Such conditions increased the vulnerability of communities leading to the additional spread of COVID-19.

Nevertheless, the interactions with other hazards during the pandemic also led to decreased impacts in case of hazard synergies. Specifically, the social restrictions for the pandemic introduced at a national level substantially reduced the impacts of other hazards due to the lower number of exposed people. For example, this synergy occurred in Italy during the collapse of the Caprigliola bridge over the Magra river in April 2020. In this case, the limited traffic due to the COVID-19 mobility restrictions meant that only minor injuries were caused [40].

Starting from such a complex management setting, our main research question was: *how has the COVID-19 pandemic challenged the DRM paradigm for multi-hazard risk management involving both sudden-onset and slow-onset hazards?*

Moving from the current DRMC (Section 2.1), we identified its limitations when dealing with: (i) slow-onset risk events, such as pandemics or droughts (Section 2.2); (ii) multi-hazard risk conditions triggering or exacerbating critical risk management settings and negative feedback loops (Section 2.3). To overcome these limitations, we defined an advanced DRM model building upon the proposed alternative DRM models available in the literature. We then supported the identified limitations by analysing Italian Red Cross (ItRC) data dealing with past and ongoing emergencies including the COVID-19 pandemic management from March 2020 until July 2021 (Section 3).

The ItRC is an Operational Structure of the Italian Civil Protection System ([12]; Legge n. 225, 24 febbraio [24]; https://cri.it/, accessed on 26 June 2022) and one of the leading organisations in the provision of structures, health services, and support to the population before, during, and after emergencies. Like all the other Red Cross and Red Crescent National Societies, ItRC is auxiliary to the public power for humanitarian assistance and has an active role in the domestic emergency management systems. Specifically, the ItRC is involved in a wide range of activities requiring continuous and specialised training, such as logistic support in emergency and early recovery, search and rescue with specialised staff; healthcare, first aid; relief and humanitarian aids distribution; water sanitation and hygiene promotion (WASH); Emergency Response Unit (base camp) module coordination in international emergencies and operation coordination support. Several other Operational Structures contribute to the Italian National Civil Protection Service, such as the National Fire and Rescue Service, Armed and Police Forces, Research Institutes, National Health Service, and organised voluntary civil protection, providing their own expertise to the whole disaster risk management. Among all the DRM actors, the ItRC represents the largest Emergency management–related non-profit organization in Italy with more than 160,000 volunteers and 500 employees in headquarters and local branches. Therefore, the ItRC represents one of the largest and most important operational structures of the Civil Protection System in Italy and its data can be considered representative of the Italian disaster management dynamics during the COVID-19 pandemic.

From the data analysis, we identified four key challenges when dealing with multi-hazard DRM including pandemics: the spatial-temporal differences between sudden- and slow-onsets disaster management (Section 4.1); the high demand for emergency response resources (Section 4.2); the need for the DRM system to adjust the response to cope with the pandemics (Section 4.3); the emergence of an unpreparedness negative loop (Section 4.4).

Overall, our study provides insights and lessons learned from the management of the current pandemic seen through the lens of a multi-hazard risk perspective that can be transferred to other slow-onset hazards such as droughts (Section 5). Limitations, wider implications and future developments are discussed in Section 6. As a final result, we provide main recommendations on the most urgent multi-hazard risk challenges that should be included within future management strategies (Sections 7).

2. A framework for multi-hazard risk DRM

Within this section we conceptualise the current DRMC limitations when dealing with multi-hazard risk conditions, organised in a framework. We built the framework for multi-hazard risk DRM moving from the traditional DRMC (Section 2.1), incrementally introducing the challenges of pandemics (Section 2.2) and multi-hazard risk management (Section 2.3). The conceptualization builds upon and further elaborates knowledge and information from the existing literature.

2.1. Traditional DRMC with consecutive phases

The DRMC is based on a series of consecutive phases. Its conceptualization has represented a significant shift from post-disaster assistance to pre-disaster planning [8]. The shift in the intervention scheme enabled emergency management authorities to focus on the reduction of and preparedness for impacts, hence triggering operational improvements and raising awareness to achieve better planning of disaster management.

Based on the current DRM principles, disaster risk management is performed by differentiating actions and resources, according to the current system phase: mitigation, prevention, and preparedness before the disaster; response during and immediately after the disaster; recovery once the disaster has occurred and the response phase has been concluded [1,9,48]. While phases' number and their naming vary in the literature [8,28], in this study we refer to three main phases (before, during, and after the event) that are named as follows: preparedness, response, and recovery. A typical example of a single-hazard risk, managed by consecutive phases, is represented in panel (a) of Fig. 2.

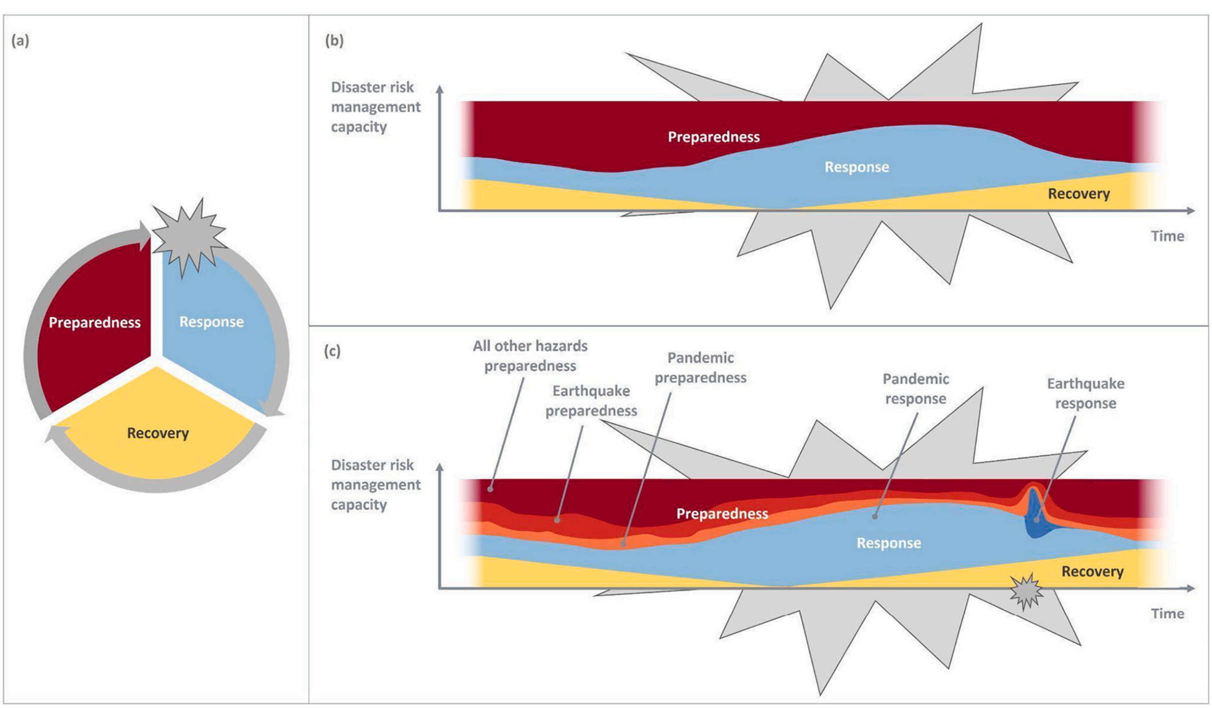

Fig. 2. The traditional DRMC with consecutive phases (a), parallel phases DRM for slow-onset hazards (b) adapted from [13], and parallel phases DRM with split strands for multi-hazard risk management (c). The width of the overall band in panels (b) and (c) represents the total capacity which is constrained by the number of resources (e.g., means, human resources, and financial support) that a disaster risk management system has in place (For an interpretation of the references to colour in this figure, the reader is referred to the web version of this article).

2.2. Parallel phases DRM for pandemics

The conceptualization of the traditional DRMC with consecutive and separate phases (Section 2.1) cannot successfully capture the spatial and temporal characteristics of pandemic management. Compared to rapid-onset events such as flash floods, pandemics are usually slow-onset hazards characterised by extended spatial coverage, long duration, and a series of waves with alternating low and high-intensity periods.

The spatial and temporal characteristics of pandemics require a huge amount of resources employed in response activities for a very long time. However, we can exploit low hazard intensity due to the sequence of pandemic and inter-pandemic phases to continue carrying out preparedness. The 'Continuum of Pandemic Phases' conceptualization by [54] has already introduced the need of managing the long pandemic crisis, commonly considered as one long response phase, passing from a response to a preparedness phase according to the different hazard intensity levels (measured by the number of pandemic cases). Nevertheless, also the Continuum model shows consecutive and separate phases as the traditional DRMC (Section 2.1). This perspective does not allow to fully capture hybrid conditions where, for example, the response is performed during preparation activities.

For these reasons, we introduce a 'parallel phases' DRM model (Fig. 2, panel (b)). This model is adapted from the one proposed by [13], in which "disasters are managed in a parallel series of activities rather than in a sequence of actions. The different strands of activities or actions continue side by side, expanding or contracting as needed".

In our representation of the 'parallel phases' DRM model, we represent the total system's capacity (y-axis) by the width of the overall band. For the sake of simplicity, we assumed a constant width for the overall band, although in reality, the system's capacity can vary over time.

We applied the 'parallel phases' DRM model to represent the dynamics of the pandemic crisis management. In addition, this model successfully captures the spatial and temporal characteristics of other slow-onset hazards, such as droughts [13]. Like pandemics, drought events usually show characteristics of a wide spatial extent, spanning over multiple years, and seasonality [3,34,46,51].

The 'parallel phases' DRM well depicts how to exploit hazard seasonality to implement preparedness and recovery actions during low-intensity response periods. Such an approach allows the DRM system to prevent any future impact exacerbation.

2.3. Parallel phases DRM for multi-hazard risk

The DRM increases in complexity in case of multi-hazard risk conditions. The parallel phases model applied to pandemic management (Section 2.2) can be further generalised to cover all activities carried out by the DRM system. The activities refer to all hazards that can impact the system and encompasses preparedness, response, and recovery.

According to this generalisation, the dark red strand in panel (c) of Fig. 2 does not only cover COVID-19 preparedness, but also preparedness activities for all the other hazards. As an example, the dark red preparedness strand in panel (c) of Fig. 2 is split into a series of sub-strands, each one referring to the resources employed to prepare for pandemics, floods, and all the other relevant hazards. The 'parallel phases' model with split bands shows how the DRM system can continuously exploit the slow-onset hazards' dynamics for preparedness actions during the 'inter-pandemic' phases, while also preparing for any other hazard that can have relevant impacts on the system.

If the system is overexposed to respond to a slow-onset crisis and one or more events occur in the meanwhile, it could face severe impacts. Moreover, these multi-hazard impacts are likely to be higher than those occurring without an ongoing slow-onset crisis. These multiple impacts lead to a higher demand for emergency response resources. To capture the condition of two or more disasters overlapping in time, the response strand in panel (c) of Fig. 2 can also be further divided. As an example, in the case of an earthquake occurring during a pandemic crisis, the response strand in panel (c) of Fig. 2 is split into two sub-strands.

The pandemic's overlap with another event may change the distribution of available resources. Specifically, part of the available resources should be redirected to respond to this additional event both from the ones deployed to respond to the pandemic and from the ones dealing with recovery or preparedness activities. If such a condition persists over a prolonged period, the capacity of the system to invest in preparedness activity for any other hazard is significantly reduced, leading to a loop of higher and higher impacts.

3. Exploited data

Within this section we describe the datasets used to evaluate the current DRMC challenges when dealing with multi-hazard risk conditions (Section 2) analysing the ItRC management during the COVID-19 pandemic (Section 4).

For our analysis, we considered data from the Italian Red Cross and the 'Our world in data' database. For sake of synthesis, we report the used variables, their underlying information, and the link to their datasets (if open access) in Table 1.

Specifically, we obtained the Italian Intensive Care Unit (ICU) occupancy (variable 1 in Table1) from the open-access 'Our world in data' database on a daily basis. We considered this variable as a proxy of the pandemic intensity.

We retrieved the 'Emergency intervention data' (variable 2 in Table 1) from the 'virtualSON - *Eventi Nazionali*' platform of the ItRC. The term 'intervention' is used here to refer to any response action, usually on a specific location, carried out by one or more operators during their shifts. The dispatch of an ambulance, the delivery of relief aid, and the use of a dewatering pump are examples of typical ItRC interventions.

We classified the interventions according to their spatial dimension and duration. For the spatial dimension, we followed the NUTS classification (European [14]), while for the duration we referred to the information already available in the ItRC dataset (hours, days, weeks, and years). We used the result from this classification to determine the characteristic spatial-temporal dimensions of disasters in Italy (Section 4.1).

We use the term 'operators' to refer to ItRC human resources including staff members and the large share of volunteers playing a key role in the ItRC core activities. 'Person-days for other emergencies' and 'person-days for COVID-19 emergency' provided by the ItRC (respectively variables 3 and 4 in Table 1) represent the total number of workdays employed by ItRC emergency operators. We considered variables 2, 3, and 4 to describe the emergency response phase. In particular, we considered variables 3 and 4 as a proxy for the number of response resources deployed for other emergencies and COVID-19 respectively.

Data on 'Operators receiving training' (variable 5 in Table 1) provide information on the number of staff members and volunteers participating in specialist courses related to: (i) training of trainers; (ii) Chemical, Biological, Radiological, and Nuclear (CBRN) disasters; (iii) water rescue operators; (iv) public health department; (v) unmanned aerial vehicle training; (vi) special rescue techniques and means; (vii) information and communication technologies; (viii) canine units; (ix) for mountain rescue - snow response units (Croce Rossa [10]). We considered the number of operators receiving training (variables 5 in Table 1) as representative of the preparedness activities.

4. Findings from the analysis of the Italian Red Cross management during COVID-19

Within this section we highlight the main criticalities that emerged from the analysis of Italian Red Cross management data during COVID-19. In particular: the spatial-temporal differences between sudden-onsets and pandemic disaster management (Section 4.1); the high

Table 1
Summary of the input data used in the analyses with information on variable ID and names, their description, reference to the sections and figures in which the data was used, spatial coverage/resolution and temporal time-range/resolution, dataset names with links for open-access data sources, and data provider. [(*) dataset accessible online for 2020, 2021, and 2022. Further data can be provided on request].

Variable ID - name	Description	Analyses using this variable	Spatial coverage / resolution	Temporal time-range / resolution	Dataset name	Provider
1 - Italian ICU occupancy	Number of Intensive Care Units (ICU) occupancy in Italy	Section 4.2 (Fig. 3); Section 4.3 (Fig. 4); Section 4.4 (Fig. 5)	Italy / country level	03.2020–07.2021 / daily resolution	Our world in data	Global Change Data Lab
2 - Emergency intervention data	Number, type, spatial dimension, and duration of Italian Red Cross emergency intervention data	Section 4.1		01.2018–07.2021 / available per each event	'*virtualSON - Eventi Nazionali*' ('virtualSON - National events') (*)	Italian Red Cross
3 - Person-days for other emergencies	Number of person-days covered by Italian Red Cross operators (staff and volunteers) for emergency response activities other than COVID-19	Section 4.2 (Fig. 3)				
4 - Person-days for COVID-19 emergency	Number of person-days covered by Italian Red Cross operators (staff and volunteers) for COVID-19 emergency response activities	Section 4.2 (Fig. 3); Section 4.3 (Fig. 4)		03.2020–07.2021 / weekly resolution	'*virtualSON - Emergenza COVID-19*' ('virtualSON - COVID-19 emergency')	
5 - Operators receiving training	Number of Italian Red Cross operators (staff and volunteers) participating in specialist training courses	Section 4.4 (Fig. 5)		01.1993–07.2021 / monthly resolution	*n.a.*	

demand for emergency response resources during pandemics (Section 4.2); the need for the DRM system to adjust the response to cope with pandemics (Section 4.3) and the unpreparedness negative loop generation (Section 4.4).

4.1. Spatial-temporal differences between sudden-onsets and pandemics disaster management

We analysed the spatial and temporal scales of the ItRC emergency interventions from January 2018 to July 2021 across Italy (Table 1). Each intervention has been classified according to its spatial dimension and duration. The analysed ItRC interventions encompass the management of natural events, such as biological, climatological, geophysical, and hydrometeorological, as well as technological and humanitarian ones. According to our analysis, the majority (94%) of the ItRC interventions over all the reported months occurred at a local level (LAU2 and NUTS3 spatial scales) and spanned a limited time frame (from hours to days). This result highlights how the system, before the emergence of COVID-19, was used to cope with sudden and local events. On the other side, the COVID-19 crisis management has affected the national and yearly scales. This outcome shows how the COVID-19 crisis has been substantially different to manage compared to all the sudden-onset emergencies that the system was usually tackling, due to the spatial-temporal differences between them.

4.2. High demand for emergency response resources

Due to the large spatial extent of the COVID-19 crisis, its management required a significant amount of emergency response resources. In this section, we consider the number of person-days for the COVID-19 response activities as a proxy for the number of resources deployed. Fig. 3 shows how the number of monthly person-days for COVID-19 (light purple bars in panel (a)) was three orders of magnitude higher than those deployed for the management of all other emergencies (light green bars in panel (b)) in Italy from March 2020 to July 2021. This result shows how the pandemic management stressed the overall emergency system reducing the coping capacity for any other hazard.

Moreover, the number of person-days deployed for the COVID-19 emergency response and the number of ICU cases, used as a proxy of the pandemic intensity, showed similar trends. The similarity is statistically confirmed by applying the cross-correlation function [52], which provides a value of 0.57 at lag 0. Therefore, the number of person-days can be considered a representative variable to describe the demand for emergency response resources. In addition, Fig. 3 shows the number of person-days to cope with the second wave at the end of 2020 was significantly lower than those for the first wave albeit a similar number of ICU cases. Indeed, during the first phases of the COVID-19 pandemic, the emergency response system had to urgently adjust to a new crisis. That condition was very different in terms of spatial-temporal scales from sudden-onset emergencies (Section 4.1) and required a great number of resources. Nevertheless, after the first wave, the system learned how to efficiently deploy the available resources.

4.3. The DRM system needs time to adjust the response

In Fig. 4 we show the derivative values of the number of person-days covered by ItRC operators during the COVID-19 crisis and the ICU cases at a monthly time step.

The change in the sign of the first-order derivatives from one month to the next represents an inflection point in the trend of both variables. In five out of six months (May, August, September, and December 2020; April 2021) in which there was an inflection point in the ICU cases trend, there was not a corresponding inflection point in the number of person-days deployed. The emergency system took at least one month to adjust its response through an increase or decrease in the number of person-days deployed to match the increasing or decreasing number of ICU cases. The result shown by the first-order derivatives is further confirmed by applying the cross-correlation function between the number of person-days deployed for COVID-19 emergency response and the number of ICU cases. The highest value of cross-correlation (0.64) is obtained at one month shift (i.e., at lag 1).

4.4. The unpreparedness negative loop

Due to the high demand for emergency response resources required to cope with the COVID-19 pandemic (Section 4.2), the preparedness for

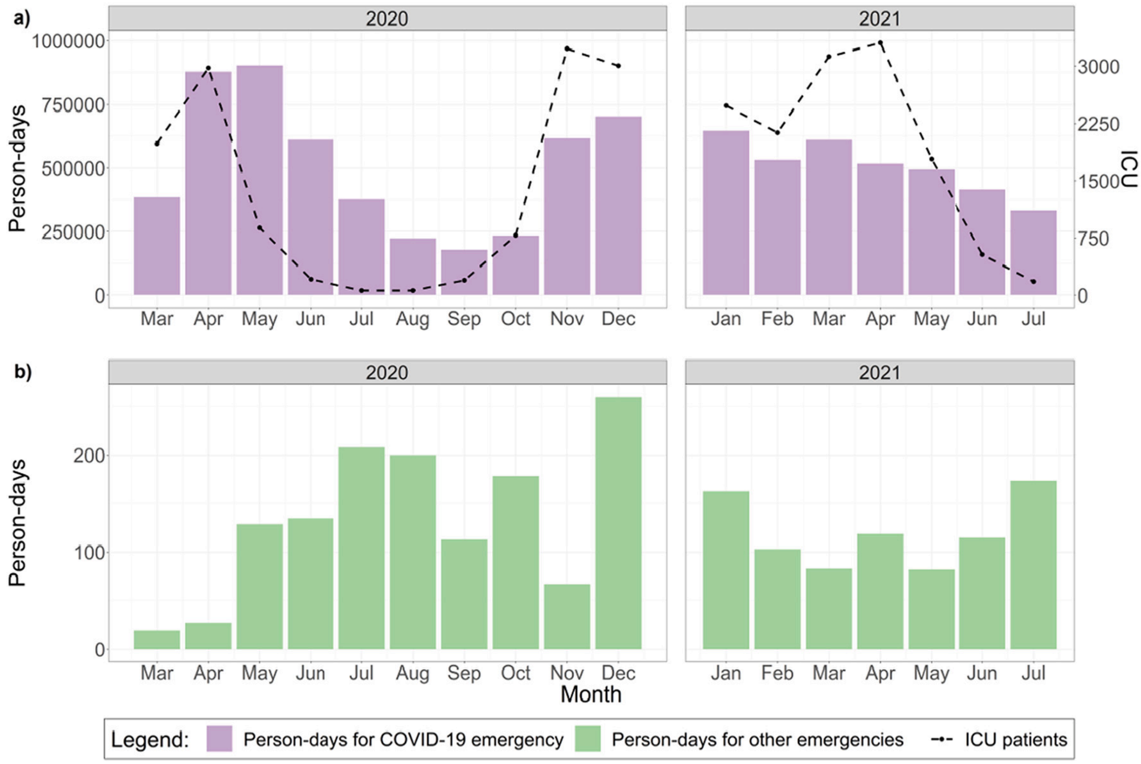

Fig. 3. Number of person-days covered by Italian Red Cross operators for COVID-19 emergency response activities (light purple bars) and the number of person-days covered by Italian Red Cross operators for emergency response activities other than COVID-19 (light green bars). The black dotted line represents the trend in the Italian Intensive Care Unit (ICU) occupancy. Variables' sources and descriptions are reported in Table 1 (For an interpretation of the references to colour in this figure, the reader is referred to the web version of this article).

any other hazard was substantially reduced. Such a condition resulted in an overall weakening of the DRM system capacity. Fig. 5 reports the number of monthly operators receiving training over the 2020–2021 period (orange bars) compared with the historical monthly operators receiving training (light orange boxplots). From the figure, we can see that the number of monthly operators receiving training was lower than the 25th quantile of the historical values for seventeen consecutive months out of eighteen. Moreover, we superimposed the trend in the number of ICU cases (dotted black line in Fig. 5) to visually identify possible critical patterns in the preparedness activities. In 2020, the system did not fully exploit the 'inter-pandemic' phase to carry out training activities (June–August 2020). Only in July 2021, after one and a half years of pandemic crisis, did the system take advantage of the reduced number of ICU cases to increase its level of preparedness. In particular, in July 2021 the number of operators receiving training was higher than the average monthly value considering the historical trend.

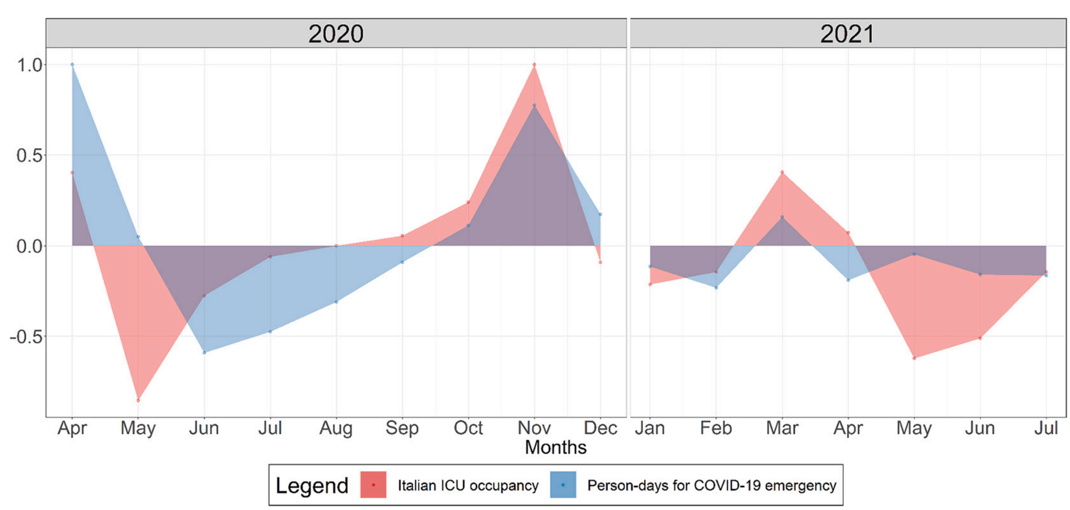

Fig. 4. First-order derivatives of the number of person-days covered by ItRC operators during the COVID-19 crisis (blue dots with underlying area) and the Intensive Care Unit (ICU) occupancy (red dots with underlying area). The dots represent the derivatives' values nondimensionalised using their maximum values. Variables' sources and descriptions are reported in Table 1 (For an interpretation of the references to colour in this figure, the reader is referred to the web version of this article).

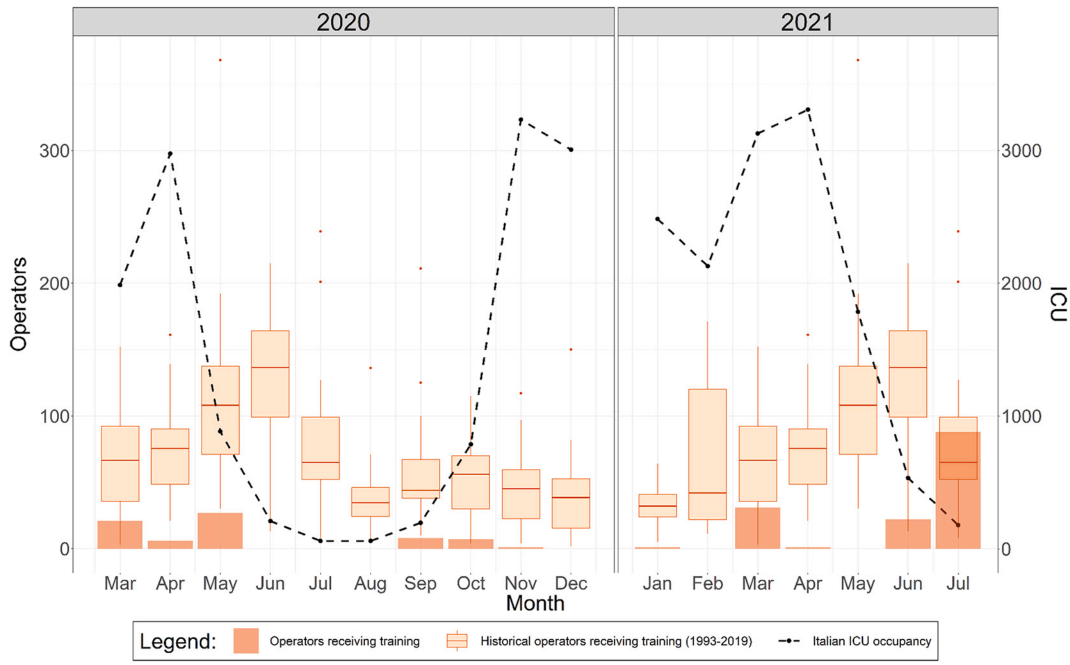

Fig. 5. Number of monthly operators receiving training over the 2020–2021 period (dark orange bars) compared with the historical monthly operators receiving training (light orange boxplots). The black dotted line represents the trend in the number of Intensive Care Units (ICUs). Variables' sources and descriptions are reported in Table 1 (For an interpretation of the references to colour in this figure, the reader is referred to the web version of this article).

5. Advancing multi-hazard DRM

The challenging multi-hazard risk conditions that emerged during the COVID-19 pandemic have boosted the improvement of the DRM paradigm.

In this section we combine the concept of a parallel phases DRM model (Section 2) with the criticalities identified from the management of the COVID-19 pandemic in Italy (Section 4) into three main guidelines for advancing multi-hazard DRM (Sections 5.1 to 5.3).

5.1. Managing the system with parallel phases

The analysis of the Italian case study has highlighted the large spatial and temporal extensions of the COVID-19 pandemic which the system has never dealt with in recent history (Section 4.1). The entire national emergency management system was initially overwhelmed by the novelty and magnitude of the pandemic. Most of the available resources were understandably directed towards supporting the response as usually required in case of large-scale disasters. The resources deployed in the COVID-19 emergency response were extremely high in number: on average three orders of magnitude higher than those deployed for all the sudden-onsets emergency management (Section 4.2).

The system was overexposed towards the emergency response and hence it reduced the number of resources for preparedness. This unbalanced configuration is unsustainable in case of slow-onset events such as pandemics due to their long emergency response phase that can hamper preparedness activities over years.

If another disaster occurs, the system could face impacts higher than those without the ongoing pandemic crisis. These stronger impacts would lead to higher demand for emergency response resources, which in turn would further reduce the preparedness activities and hence increasingly weaken the DRM system capacity. Such a condition pushes the system into a negative loop of unpreparedness (Section 4.4).

The adoption of the 'parallel phases' DRM model conceptualised in Section 2.3 provides the way to escape from such a vicious loop, accounting for the contemporary management of both response and preparedness. Managing the system with parallel phases is crucial not only from a multi-hazard disaster risk management perspective but also for the management of single slow-onset hazards. Specifically, in the case of pandemics or droughts, the 'parallel phases' support the exploitation of the hazard dynamic to implement preparedness and recovery actions during the low-intensity response periods, helping in 'flattening the curve' yet to come.

5.2. Keeping the DRM system capacity far from depletion

The high number of resources deployed in the pandemic response brought the DRM system capacity very close to depletion. The system's capacity is represented by the number of resources (e.g., means, human resources, and financial support) that a disaster risk management system can put in place. In the graphical depiction of the 'parallel phases' DRM model (Fig. 2, panel (c)) we represent the total system's capacity as a constant value, represented by the width of the overall band. Nonetheless, the system's capacity can vary over time. If the system cannot cope with one or more contemporary disasters due to the depletion of the available resources, two main mechanisms can generate an increase in the total capacity: (i) the deployment of new internal resources; (ii) the arrival of external support, represented by international humanitarian aid. In the specific case of a slow-onset disaster, such as pandemics, both mechanisms become difficult to implement.

(i) the deployment of new internal resources: the deployment of new internal resources requires a significant effort, both in terms of economic investment and time. Furthermore, the increase of resources in terms of new active operators would also require investments in training. As illustrated in Section 4.4, during the first pandemic wave the Italian Red Cross interrupted almost all the training activities, highlighting the significant difficulty faced by the DRM system in carrying out activities other than response.

(ii) the arrival of external support: the COVID-19 pandemic struck wide areas - even larger than a continent - almost concurrently (Section 4.1). At the same time, several surrounding countries were coping with the high demand for emergency response resources (Section 4.2), hampering the allocation of resources from one place to another and hence leading to a reduction in international mutual support [30].

Furthermore, national and international emergency management agencies had to handle very complex logistics since procedures and protocols for the integrated management of pandemics and natural hazards were in many cases underdeveloped or absent [49]. The ‘asynergies’ arising in the multi-hazard management practices led to increasing both the pandemic spread and the impact of other natural hazards [33].

Nevertheless, the DRM system can learn how to efficiently deploy available resources in order to keep its capacity far from total depletion. Our analysis of Italian data showed how the DRM system has been able to learn how to cope with a new crisis. The number of person-days deployed during the second wave at the end of 2020 was significantly lower than those for the first wave, albeit a similar number of ICU cases (Section 4.3). If the DRM system is able to save part of its capacity, it can deploy new internal resources and receive/provide external support to generate an increase in its total capacity. Specifically, the system can continue to increase its internal resources (e.g., through the enrolment and training of new operators) while also making them available for international mutual support in case of multi-hazard risk. Such a condition triggers a positive loop in the overall increase of the DRM system capacity.

5.3. Impact-based forecasting for multi-hazard disaster risk management

The COVID-19 pandemic has led to high impacts on our society, especially during the first unexpected wave. The number of resources deployed in the emergency response was extremely high, and preparedness activities were substantially reduced (Fig. 5). The DRM system needed time to capture the characteristics of pandemic dynamics, and to continue carrying out preparedness during the low-intensity response periods [54]. In the literature, there are already some examples of modelling approaches and simulation tools developed to forecast the spread of the pandemic, estimate its impacts on people's health and the economy, and evaluate the effects of non-pharmaceutical interventions [4,15,25,44]. Moreover, the wide temporal scale of the COVID-19 pandemic (Section 4.1) led to an increased probability of having multi-hazard risk conditions. Due to the sequence of pandemic and inter-pandemic phases, changes in overlap timing with other hazards could greatly affect the resulting impacts [33]. Such conditions highlighted the need to properly develop impact-based multi-hazard warning systems as well as multi-hazard, inclusive, science-based, and risk-informed decision-making, in line with the Target (g) and Guiding Principle (g) of the Sendai Framework for Disaster Risk Reduction [50].

Combining the prediction of slow-onset waves with the seasonality of sudden-onset hazards (e.g., floods or hurricanes) fosters the planning of appropriate anticipatory actions (AAs) for multi-hazard risks [23,47]. While AA has mostly taken a single-hazard approach, a development accounting for multi-hazards is needed. Indeed, a multi-hazard seasonal impact-based forecast represents a key element in efficiently implementing AAs and forecast-based financing approaches. This need aligns with the recent Guidelines on Multi-hazard Impact-based Forecast and Warning Services [53] and the Early Action Protocols by the Red Cross Red Crescent [20]. These international guidelines call for advancements in coordination at national and global levels to effectively implement AAs and use resources more efficiently.

6. Limitations and future developments

Within this study, some limitations arose in the representation of the ‘parallel phases’ DRM model (Section 2) and in the analysis of the ItRC management data (Section 4).

Concerning the model, the graphical representation depicted in Fig. 2 can only partially capture the complexity of a real multi-hazard management situation. For the sake of clarity, some simplifications were here introduced. In particular, the figure includes a pandemic as a slow-onset event and an earthquake as a sudden one, while the management of all the other hazards is summarised in one band only. Moreover, the disaster management capacity is represented with a constant width for the overall band. In reality, the system's capacity can vary over time according to the deployment of new internal resources and/or the arrival of external support.

The model was supported by the outcomes of the quantitative analysis of operational DRM data. Therefore, the implications coming from the adoption of the ‘parallel phases’ model (Section 5) mainly focus on disaster risk management activities and operations. Nevertheless, the uptake of the ‘parallel phases’ model by the scientific and operational DRM communities can also lead to the re-evaluation of current disaster risk reduction strategies and early warning systems to better capture multi-hazard and slow-onset disaster management dynamics. Such a wider implication can represent a further scientific challenge to investigate.

The analysis on the COVID-19 management is limited to (i) the Italian case, (ii) considering the ItRC data, and (iii) spanning from March 2020 to July 2021.

Regarding (i), the challenges highlighted by the analysis of the COVID-19 management in Italy provided key lessons for multi-hazard DRM that can be transferred to other geographical areas. Nevertheless, future studies could enlarge the analysis to other countries to identify further challenges that did not emerge from the Italian context and provide other lessons to inform the international DRM community. Regarding (ii), while the ItRC is only one of many actors involved in the management of disasters in Italy, it also represents one of the largest and most important operational structures of the Civil Protection System in Italy. Therefore, ItRC data can be considered as representative of the Italian disaster management dynamics. Further developments could include other structures such as the Italian Civil Protection Agency and its resources.

Regarding (iii), the analysis captured the COVID-19 dynamics only until July 2021. Nevertheless, this temporal extent provided information on the most critical periods of the pandemic management and the most urgent needs for advancing multi-hazard DRM. The fast-evolving COVID-19 conditions have introduced new challenges in 2022. In particular, the pandemic has developed new dynamics spreading also during the summer period and hence introducing new timing of the interpandemic phases. This condition further highlights the need of improving monitoring and forecasting to predict sudden changes of the pandemic peaks and hence leading to more effective AAs.

7. Conclusions

The long-lasting COVID-19 pandemic crisis has significantly challenged all the national emergency management systems worldwide. The temporal and spatial overlaps of COVID-19 with other natural and anthropogenic hazards have highlighted the need for an integrated multi-hazard DRM model. However, the available DRM paradigms cannot fully capture the complexity of multi-hazard risk scenarios, particularly those involving both sudden- (e.g., earthquakes or flash floods) and slow-onset hazards (e.g., pandemics or droughts).

Starting from this background, our research aimed to identify and provide evidence of the main limitations of the current DRMC when dealing with complex multi-hazard risk conditions involving pandemics. From these limitations, we framed a ‘parallel phases’ DRM model with split bands able to account for multi-hazard risk conditions. We supported the identified limitations analysing ItRC data dealing with past and ongoing emergencies including the COVID-19 pandemic.

The findings from the analysis represent a series of key challenges when dealing with multi-hazard DRM including pandemics: (i) the spatial-temporal differences between sudden-onset events and pandemic disaster management; (ii) the high demand for emergency response resources during pandemics in comparison to other emergencies; (iii) the need for the DRM system to adjust the response to cope with the pandemics seasonality; (iv) the system over-exposure to response activities reducing the number of resources for preparedness and generating the unpreparedness negative loop.

The combination of the key challenges that emerged from the management of the COVID-19 pandemic in Italy brought out three main guidelines for advancing multi-hazard DRM by applying our 'parallel phases' model.

Managing the system with parallel phases. A 'parallel phases' DRM allows the disaster management system to exploit the low emergency intensity of the slow-onset hazards seasonality for preparedness actions while also preparing for any other hazard that can have relevant impacts on the system. Such an approach allows the DRM system to escape from an unpreparedness negative loop acknowledging the need for continuous multi-hazard risk management.

Keeping the DRM system capacity far from depletion. The DRM system can learn how to efficiently deploy the available resources keeping its capacity far from total depletion when dealing with slow-onset events such as pandemics. If the DRM system is able to save part of its capacity it can continue with the increase of internal resources (e.g., through the enrolment and training of new operators) while also making them available for international mutual support in case of multi-hazard risk. Such a condition triggers a positive loop in the overall increase of the DRM system capacity. The development of indicator-based monitoring tools can support DRM authorities in efficiently managing available resources within each DRM phase almost in real-time. Furthermore, these tools should be used to adequately plan DRM strategies for long-lasting crises.

Impact-based forecasting for multi-hazard disaster risk management. The wide temporal scale of the COVID-19 pandemic led to an increased probability of having multi-hazard risk conditions and exacerbating the resulting impacts. The implementation of multi-hazard seasonal impact-based forecasts fosters the planning of appropriate anticipatory actions and forecast-based financing approaches, combining the prediction of slow-onsets waves with the seasonality of sudden-onsets (e.g., floods or hurricanes).

The presented results call for advancements "in long-term, multi-hazard and solution-driven research in disaster risk management", as required by the Sendai Framework for Disaster Risk Reduction 2015–2030 [50]. Our advanced 'parallel phases' model is able to capture the complex management dynamics to deal with the increasingly frequent slow-onset and multi-hazard events. This model introduces a change of perspective from the cyclic, consecutive-phases, and single-hazard DRM approach. For this reason, our 'parallel phases' model can strengthen and boost current and future international policies on multi-hazard DRM towards an effective implementation at national and local level.

Overall, the DRM community should take the opportunity of learning from the dramatic COVID-19 crisis and its impacts to improve regional coordination and collaboration and advance multi-hazard DRM.

CRediT authorship contribution statement

Stefano Terzi: Conceptualization, Methodology, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Silvia De Angeli:** Conceptualization, Methodology, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Davide Miozzo:** Conceptualization, Formal analysis, Writing – review & editing. **Lorenzo Stefano Massucchielli:** Conceptualization, Data curation, Writing – review & editing. **Joerg Szarzynski:** Conceptualization, Writing – review & editing. **Fabio Carturan:** Data curation, Writing – review & editing. **Giorgio Boni:** Conceptualization, Formal analysis, Writing – review & editing.

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Data availability

The authors do not have permission to share data.

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