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The next big earthquake may inflict a multi-hazard crisis – Insights from COVID-19, extreme weather and resilience in peripheral cities of Israel

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ABSTRACT

The occurrence of a natural disaster in an area already coping with an epidemic, constitutes a multi-hazard event. Such events are more likely than ever during the ongoing COVID-19 pandemic. In regions that seasonally experience extreme-weather disasters, such multi-hazard crises are imminent.

People living along the Dead Sea Fault and in the Negev are used to harsh weather conditions and to the hardship of living in isolation. While self-reliance and community-support are often the norm in the daily life of residents in in peripheral communities, in an emergency they may be crucial for survival. Worldwide remote communities with limited response and medical infrastructure and resources may struggle to cope with the aftermath of an earthquake while potentially coping with a concurrent epidemic or extreme weather. In this work we focus on the effect of concurring disasters and seasonal stressors. In particular we discuss how various disasters would affect the Covid-19 infection rate, and we demonstrate that in Israel’s periphery cities, heat-stress is a consistent and significant seasonal stressor that would hamper emergency and recovery operations. We also suggest that transient tourist population in these remote cities is expected to burden local emergency efforts and facilities. A seasonal over burden parameter is proposed to describe how seasonal tourism and weather conditions enhance the hardship and risk in a multi-hazard situation. A case study shows that high-resolution spatial analysis of risk and preparedness together with a temporal analysis of seasonal effects, may be used to detect specific neighborhoods with high or low resilience and capacity to cope with disasters.

Our work demonstrates the need for spatial and temporal, multi-hazard analysis for improving local resilience and emergency plans in periphery cities and communities exposed to seasonal harsh weather.

1. Introduction: concurrent multi-hazards - a direct threat in the age of COVID-19 and climate change

While natural hazards such as earthquakes cannot be controlled or avoided, there are ways to minimize their impact on society. A central component of risk reduction is building communal resilience - the ability of a community to work together to prepare for, cope with and recover from a disaster [1–4]. Active personal preparedness and community involvement in local risk mitigation programs are considered effective ways to improve community and national resilience [5–7]. However, the basis for any risk mitigation program or public engagement or dissemination, is the understanding of hazards and risks and their potential to interact or cascade into a composite crises [8,9].

Even as most countries struggle to cope and mitigate the effects of the COVID-19 pandemic, it has already taught us an important lesson: we need to plan for and be able to respond and adapt our response during a multi-hazard crisis [9–11]. The occurrence of geo-hazards such as a tropical storm, earthquake, or wildfire during a prolonged pandemic will dramatically complicate emergency response efforts and the management of evacuees and medical resources. Obviously, the efforts to limit infections, prevent overwhelming of medical resources and enable safe re-opening of social and economic activities, are greatly hindered by geo-hazards [8,9]. The improvements required in emergency planning and resilience building, in light of the likelihood of cascading, multi-hazard events, includes an analysis of temporal patterns such as flu seasons and various weather patterns (heat waves, bush fires,
A ‘concurrent multi-hazard’ is defined as the occurrence of two or more natural (e.g. geologic, atmospheric, biologic) hazardous events that overlap in time and space (e.g. earthquake, flood, epidemic; [9,11]). This is fundamentally different from a cascading event in which one hazard triggers another (e.g. earthquake triggered tsunami, avalanche or landslides), but the results may be similar in severity or spatial or temporal extent.

Several natural disasters have already occurred during the COVID-19 crisis, and as it is expected to persist, various seasonal natural disasters are expected to inflict concurrent multi-hazard events around the world. On March 22, 2020 an earthquake of magnitude 5.3 occurred near Zagreb, Croatia (felt intensity MMI = VII), followed by many aftershocks [12]. As a result, hundreds of houses were damaged, dozens of people were left homeless and several hospitals were evacuated including 22 COVID-19 patients, 15 of whom were in intensive care unit [12]. The moderate Zagreb earthquake provides a good example of response to a multi-hazard event. In the immediate aftermath of the earthquake, Croatian authorities imposed a stricter local lockdown and managed evacuees and local migration to prevent increase in infection rate [9,12]. Some studies debate whether these measures were partially successful [9] or completely successful [12]. Advance planning, ahead of multi-hazard situations may help enforcing such actions more efficiently and systematically, reducing risks posed by multi-hazard events that occur during an ongoing epidemic like COVID-19 [9].

While heat waves and earthquakes both have devastating impacts, they are expected to have different interactions and implications with such epidemics and infection mitigation efforts:

- Heat-waves intensify health conditions and may add significant burden on a healthcare system coping with COVID-19. In the aftermath of an earthquake, extreme heat may endanger sheltering evacuees and compromise their provisions and resources (including water, food, medicine and electricity supply). In contrast, earthquakes (like tornadoes and hurricanes) tend to damage infrastructure, supply chains and life-lines, and they often result in many evacuees and crowded shelters which would severely compromise social distancing and infection mitigation efforts (Fig. 1). Suk et al. [8] presents a review of cascading events with epidemic outbreaks after a natural disaster. Epidemiologic conditions at the time of a natural hazard event might also influence the characteristics of emergency and humanitarian responses (e.g. evacuation and sheltering procedures, resource availability, implementation modalities, and assistance types). Quigley et al. [9] demonstrated that the timing of a natural disaster during a pandemic may determine how severely it would impact the infection rate of an epidemic.

The current paper focuses on the importance of multi-hazard analysis for Israel’s peripheral (remote) communities that must be self-sufficient (self-reliant) during national-scale disasters, and where harsh weather may inflict additional hardships. In the following section we discuss seasonal stressors and spatial factors that greatly affect community risk and resilience, and in Section 3 we present a conceptual framework for integrating these in emergency and recovery plans and we present plausible implications that heat waves and earthquake(s) might have on Israel’s COVID-19 scenarios.

2. Risk, preparedness and seasonal stressors along the Dead Sea Fault and the Negev, Israel

2.1. Risk and preparedness in periphery regions of Israel

To prepare for future earthquakes, national emergency scenarios have been developed in Israel to evaluate expected damage intensity. Such scenarios show that a high-magnitude earthquake might cause serious damage to vital infrastructure, roads and communication networks [13]. This is true both for the central metropolitan areas, and for the remote and isolated communities in the periphery of the country (referred to simply as ‘the periphery’). For the latter, earthquakes pose a risk to transportation and life-lines causing insufficient access to water, food, shelter, medical care and information. The Israel National Emergency Management Authority (NEMA) has long realized that in order to improve communal resilience and self-reliance during such harsh post-earthquake conditions, it must promote personal and familial preparedness. This is particularly challenging and important in periphery communities such as those along the Dead Sea Fault (DSF) (Fig. 2).

These communities are physically and, to a large extent, cognitively cut off from the center of the country, making it harder to motivate them to prepare for earthquakes [14]. Ongoing risk reduction efforts struggle to foster innovative community participation programs in such towns [14, 15]. Local communication and leadership collapse might further increase confusion and suffering [16]. While national scale studies of communal resilience are vital for improving national disaster and recovery strategies [e.g. [17], they are not tailored to gauge the ability of specific communities to cope with a disaster in the specific conditions that may prevail. In particular, they do not address the difficulties that isolated desert communities may have in providing and caring for vulnerable locals and tourists, during an epidemic or extreme heat.

2.2. Seasonal stressors related to weather and population fluctuations

The ability to shelter evacuees and provide for those impacted by disaster, is significantly affected by weather conditions (that are often harsh in the desert and along the DSF) and by the total amount of population ‘stranded’ in town (including tourists and evacuees).

Temporal patterns in tourism and in extreme heat conditions were analyzed to demonstrate and highlight the effect these may have on emergency efforts in the days after a disaster. Assuming that national emergency responders, supplies and medical teams will become available after several days, we chose to focus on the potential effect of harsh conditions during this initial emergency response (the probability of a co-occurring multi-hazard event increases significantly in prolonged states of emergency, such as experienced during the COVID-19 pandemic [9]).

Extreme weather was analyzed based on Israel Meteorology Service data (2004–2020 [26]) and threshold definitions that reflect harsh conditions for outdoor activities are used as thresholds for degradation of welfare of evacuees in a state of emergency (Tfelt>24°C for heat stress, and T<4°C for cold stress [26]). Fig. 3 presents the probability of experiencing at least one day of harsh weather within an interval of three days in selected periphery cities and towns (listed in Fig. 2). The three day interval represents a disaster recovery stage in which evacuees are cared for based on local resources. It is important to note that as heat-waves and cold-weather is often several days long, so the probabilities stated in Fig. 3 are more representative of experiencing several days of extreme weather (as opposed to one day).

A clear seasonal pattern shows that in Eilat, Jericho, Beite She’an, Qiryat Shemona and Tiberias, any disaster occurring between mid-April and November will constitute a multi-hazard event with extreme heat likely to inflict harm in most days. While the analysis in Fig. 3 shows the

![Fig. 1. Weekly infection rate scenarios with perturbations of infection rate due to a concurring earthquake (all three earthquake scenarios include ten days of high infection rate represented by the fractional growth parameter g ([9]).](image-url)
probability of any heat stress (moderate, heavy or extreme), most of these cities, especially those along the DSF (Fig. 1), experience at least 25 days of extreme heat stress ($T_{\text{felt}} > 30$) during the summer. In Mitzpe Ramon, Arad and Sefad there are on average only 72, 121 and 148 days of harsh conditions every year (respectively; compared to 165–202 days in the other cities). In most of these cities, the probability of experiencing harsh weather during an emergency is above 60% during 6–8 months (in Mitzpe Ramon 60% probability is surpassed only in January, July and August, and in Arad only in May–September).

Seasional fluctuations in the number of tourists that visit and stay at selected periphery cities were analyzed based on national tourism reports 2016–2018 [27]. In order to describe such seasonal fluctuations in Mitzpe Ramon, Finzi et al. [28] defined a parameter for total population (Tpop) that presents the overall number of people as a fraction of the resident population ((tourists + residents)/residents). The calculation is based on monthly occupancy reports without robust indications of how these rates are divided on the different days of the month. Even months of low occupancy might have single days (or multi-day events or holidays) with full occupancy. In the current study, Tpop represents the average weekend occupancy assuming it constitutes half of the monthly occupancy. Table 1 shows the total population at selected periphery cities (those with sufficient tourism data). As seen in Table 1, Eilat serves

![Fig. 2. Israel hazard map showing maximum Peak Ground acceleration (PGA) (Israel building code IS 413, 10% probability of exceedance in 50 yr [18,19]) and location of periphery cities along the Dead Sea fault and in the Negev. Right - details of population and hazard in these cities.](image)

![Fig. 3. Probability of having at least one day of harsh weather during a three day disaster in chosen peripheral cities [26]. Harsh weather defined to be $T_{\text{felt}} > 24^\circ\text{C}$ for heat stress, and $T_{\text{felt}} < 4^\circ\text{C}$ for cold stress [26].](image)
as an example of how important it is to account for total population in emergency planning. The number of people staying in Eilat (residents and visitors), at any given weekend, is between 47% and 102% higher than the permanent resident population. The numbers stated for Eilat and Tiberias are by far a conservative estimate, as our tourism data for these cities is based on hotel occupancy and does not include visitors staying at Airbnb units and campsites. The seasonal fluctuations in Eilat, Tiberias and in the old neighborhood of Mitzpe Ramon are significant, with the estimated ratio between maximum weekend population and minimum weekday population being 1.9, 1.3, 1.4 respectively. Emergency plans in such cities, should account for such population changes, in particular for planning ahead of multi-hazard crises in remote places with seasonal extreme weather. During an ongoing crises such as a lasting pandemic, evaluation of seasonal stressors and potential concurring disasters is especially important [9].

Covid-19 has practically halted tourism activities worldwide [29]. However, efforts to revive internal tourism and economic activity, achieved a partial return of visitors to some of the cities in the current study. Eilat and lately Mitzpe Ramon have come back to high occupancies, and therefore are susceptible to multi-hazard events with interacting effects of extreme weather, high transient population and COVID-19.

### Table 1
Population fluctuations in three tourism-oriented cities in Israel’s periphery. In Mitzpe Ramon the data includes Airbnb and is subdivided to represent population fluctuations in different neighborhoods [28].

|        | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Eilat  | 1.5 | 1.5 | 1.6 | 1.8 | 1.7 | 1.8 | 1.9 | 2.0 | 1.7 | 1.7 | 1.6 | 1.6 |
| Tiberias | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.3 | 1.3 | 1.2 | 1.2 | 1.2 | 1.2 |
| Mitzpe Ramon | 1.0 | 1.0 | 1.1 | 1.1 | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.0 | 1.1 | 1.1 |
| New neighborhoods | 1.2 | 1.3 | 1.4 | 1.3 | 1.3 | 1.2 | 1.2 | 1.3 | 1.1 | 1.1 | 1.2 | 1.3 |
| Old neighborhoods | 1.2 | 1.3 | 1.4 | 1.3 | 1.3 | 1.2 | 1.2 | 1.3 | 1.1 | 1.1 | 1.2 | 1.3 |

#### 2.3. Local spatial factors in risk and resilience

##### 2.3.1. Mitzpe Ramon case study

Situated in the heart of the Negev desert, Mitzpe Ramon is the most isolated town in Israel (Fig. 2). Like many other peripheral towns in Israel, the gradual growth of the town resulted in neighborhoods that are very different in age, design and demographic characteristics. The older neighborhoods consist of 3–4 story high apartment buildings which are largely populated by older immigrants and original settlers of the town, and the newer neighborhoods consist of 1 story semi-detached (duplex) houses and single family houses with younger families. Finzi et al. [30] developed an online self-evaluation tool to determine the expected Damage Intensity (DI) for common types of houses in town as a result of the peak ground accelerations stated in the Israel building code [31]. As this estimate accounts for the hazard, exposure and vulnerability of structure in its specific location, it is a good and simple proxy for risk. As the self-evaluation tool is meant for the general public, the DI scale used is a simplification of the Modified Mercalli Intensity (MMI) scale with severity levels MMI \( \leq 3 \) defined as DI = 0 and MMI > 9 as DI = 6 [28,30].

The self-evaluation tool also determines the users Personal Readiness Evaluation (PRE), which is based on 13 questions regarding familial preparedness, action plan, mobility, community involvement and

![Fig. 4. Expected severity of damage intensity (using the Modified Mercalli Intensity – MMI scale) and average neighborhood preparedness (PRE) in Mitzpe Ramon (polygons, color coded based on MMI data, average PRE stated where sufficient data exists). We found higher preparedness and lower expected damage intensity in the newer neighborhoods in town. Modified from Finzi et al. [30].](image-url)
support, awareness and risk perception. The PRE scores range from 0 (completely unprepared) to 10 (prepared). Finzi et al. [30] showed that risk and preparedness in Mitzpe Ramon have clear and alarming spatial patterns (Fig. 4). Specifically, in the two older neighborhoods (where buildings were constructed before the formulation of a modern building code in 1980 [28,30]) we found that the population is very low and resident preparedness is significantly higher (PRE = 5.2).

Finzi et al. [28,30] identified low-resilience neighborhoods in Mitzpe Ramon and suggested that effective local risk mitigation efforts should specifically address them. In relation to multi-hazard events consisting of an earthquake during an epidemic such as Covid-19, age-dependent vulnerability should also be addressed, as the older neighborhoods in Mitzpe Ramon have clear and alarming spatial patterns (Fig. 4) and resident preparedness is significantly higher (PRE = 5.2).

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3. Integrating seasonality and local factors in multi-hazard emergency planning

3.1. Conceptual index for Seasonality over burden (SOB)

The cold winter nights in the high desert, and the extreme heat of summer days in the Negev and all along the DSF, are life threatening in the aftermath of a natural disaster. So much so, that survivors might be forced to find shelter in structurally compromised buildings or even collapsed structures, putting themselves further at risk. In some locations such as Mitzpe Ramon, relatively moderate weather conditions during fall and spring pose no such threat. Hence, between the dramatic difference in weather and the fluctuations and spatial distribution of tourism occupancy - seasonality must be taken into account when assessing preparedness, risk and emergency plans.

A generic, qualitative index for Seasonal Overburden (SOB) due to changing population and harsh weather conditions could be defined as follows [28]:

SOB = W × TPop (1)

where W represents the probability of experiencing harsh weather conditions in any single day or night during the aftermath of a disaster (W = 1 - probability; Probability given in Fig. 3), and TPop is the total population ((tourists + residents)/residents). The harsh weather probability (W) is a function of the number of days considered as the self-reliance stage of emergency response. This duration highly depends on the availability of regional and national resources that can come to the help of a community, and on the connectivity between the local community and the source of help (or the ability to evacuate people to a better facility outside the community).

The SOB evaluations for Israel’s periphery cities are shown in Table 3 (conditional formatting is used to emphasize variations in SOB with red = high and blue = low). While harsh winter and summer conditions are well represented by the seasonal pattern of SOB, the influence of high total population is also apparent (e.g., in Eliat and the old neighborhood of Mitzpe Ramon).

3.2. Conceptual index for local hardship during emergency response and recovery

A more complex conceptual ‘hardship index’ can be derived from using SOB as a factor enhancing the overall severity of a disaster or the difficulty to cope with its aftermath [28]. Very few recent studies
Table 4

| Type          | DI, PRE    | SOB, PRE   | DI, PRE    | SOB, PRE   | DI, PRE    | SOB, PRE   |
|---------------|------------|------------|------------|------------|------------|------------|
| One floor, new| 30         | 30         | 30         | 30         | 30         | 30         |
| One floor, old| 25         | 25         | 25         | 25         | 25         | 25         |
| Two floors, new| 40         | 40         | 40         | 40         | 40         | 40         |
| Two floors, old| 35         | 35         | 35         | 35         | 35         | 35         |
| Three floors, new| 50         | 50         | 50         | 50         | 50         | 50         |
| Three floors, old| 45         | 45         | 45         | 45         | 45         | 45         |

Hardship index = N × DI = \frac{\text{SOB}}{\text{PRE}} (2)

The hardship index was calculated for the typical neighborhoods in the studied cities, using DI values presented in Table 2 and SOB values from Table 3. As we only have preparedness estimates from Mitzpe Ramon we use similar PRE values for all cities (PRE = 4 for old neighborhoods and PRE = 6 for new ones). Table 4 presents summer and winter hardship scores of neighborhoods in Eilat, Tiberais, Sefad, Arad, and Mitzpe Ramon, built on hard rock (soil type B) and on soft sediments or soil (type D, which is considered a potential cause for seismic waves amplification). An arbitrary background color scale is set to indicate relatively low severity (blue, hardship = 0–30), moderate (green, 30–50), high (yellow, 50–70) and very high severity (red, 70–100). The results in Table 4 clearly portray the higher risk to neighborhoods with less resistant houses and to cities closer to the DSF (i.e. DI has a dominant effect on hardship and therefore the overall pattern in Table 4 loosely resembles that in Table 2). However, these results also portray the seasonal effects, with summer tourism and heat increasing SOB (and hardship) in all cities, but more so in Eilat (SOB = 4). In winter, the high altitude towns of Sefad and Mitzpe Ramon experience very cold nights (Fig. 3) and significant tourism, increasing their SOB to 2-2.2, and indicating that they may experience relatively severe hardship during a disaster.

While the results in Table 4 are based on speculative values of PRE (based on data from Mitzpe Ramon (28,30)) and incomplete data regarding the number of tourists, the table demonstrates the usefulness of such regional, high-resolution, spatial and temporal analysis of risk, preparedness and various seasonal stressors. While this analysis can only yield a qualitative comparison of the ‘hardship index’ associated with the maximum ground shaking scenarios of the Israeli building code (31), the results can be used to identify low resilience neighborhoods/cities and to illuminate seasonal risk-reduction challenges and required adaptations in emergency response plans. For example, while Sefad and Tiberais are both approximately 10 km from the DSF and (15–18% difference in PGA and Sa values), Sefad is expected to experience higher hardship in winter and Tiberais in summer (Table 4). This is because Sefad experiences harsh cold winter nights and Tiberais experiences extreme heat in summer (Table 3; Fig. 3). Similarly, despite the fact that Mitzpe Ramon is 50 km away from the DSF and Arad is only 10 km away, in winter the SOB in Mitzpe Ramon is 50–80% higher in new neighborhoods and 80–120% higher in older neighborhoods (Tables 1 and 3) resulting in comparable and higher hardship severity compared to Arad (Table 4). During the months of May, June, September and October, Arad experiences significantly more days of extreme heat (Fig. 3) and therefore higher SOB (Table 3; this is not shown in Table 4). In August, due to high tourist occupancy and frequency of very hot days in Mitzpe Ramon, the SOB and hardship severity are again comparable to those in Arad (Table 4). Finally, Eilat and Tiberais experience significantly higher SOB in summer which is well reflected in summer hardship severity that is 48% and 60% higher in summer, respectively (Table 4). Such analyses can and should be used to improve regional and national risk reduction strategies and emergency plans.

3.3. Multi-hazard scenarios for COVID-19 in Israel as an example of seasonal and regional interactions between natural hazards

To illustrate how the occurrence of heat waves and/or an earthquake might enhance infections and deaths during an epidemic (on a national scale), we simulated arbitrary (yet plausible) national epidemiological scenarios based on existing data for Israel. We used the simulator developed at Biozentrum, University of Basel (34), and used epidemiology parameters reported in popular media to get our model to crudely reproduce the existing data from Israel (24/2–24/7/2020 (34)). As stated above, the occurrence of several heat waves in Israel’s summer is very common, and the occurrence of an earthquake is definitely possible. The effect of such events on COVID-19 infection rate is not predictable and is a function of many variables such as the severity and duration of the harsh conditions, the effective management of response, the ability and willingness of the public to adhere to social distancing and hygiene guidelines and on the functionality of medical facilities (especially in case of an earthquake along the DSF). An interesting observation based on the data from Israel, is that during a ten day heat wave (May 22 –June 2), when wearing masks was not recommended in schools and public places and many people looked for refuge at public beaches and pools, the weekly rate of new cases increased by 325% from 117 (May 25th 2021) to 497 (May 31st). Reproducing this rate increase in our simulation suggested that the effective infection rate (Rt) seemingly increased from about Rt < 0.5 to Rt ≥ 2.

In our simulations, to represent a concurring disaster, we simply stop the intervention measures for 5–10 days, allowing Rt to rise to a background seasonal rate which gradually evolves from Rt = 1.9 in July to Rt = 2.8 in January. Fig. 5 presents the rate and total number of deaths and new cases, in an arbitrary, simplistic and somewhat optimistic scenario (Fig. 5, left panel) and in a scenario with three heat waves – 27–31/7/2020 (Rt ~ 1.9), 20–27/8/2020 (Rt ~ 2) and 22–27/5/2021 (Rt ~ 2) and an earthquake with ensuing state of emergency (24–31/12/2020, Rt ~ 2.8). As both the basic scenario and the one with multiple super-imposed natural stressors are arbitrary and do not represent a prediction of any kind, we should only use them to better understand the impact of concurrent events on COVID-19 infection mitigation efforts. In fact, in these scenarios we completely ignore the many potential injuries and deaths resulting directly from the earthquake. However, the apparent attempt to construct such composite indexes and others note the difficulties in doing so at a sub-urban resolution (32,33). For these reasons, we emphasize that the index presented here merely provides a qualitative tool for conducting a comparative, regional analysis.

In the current study, the hardship index is represented by a simple function of the risk of damage (DI which accounts for hazard, exposure and structural fragility) and preparedness (PRE). This ‘overall severity’ or ‘hardship index’ integrates all the stressors and factors above into an index that could be used by emergency planners to better understand the ability of a community to cope with a state of emergency. As this index is conceptual and has not been calibrated due to a lack of data, it is only suggested as a tool to compare severity of impact and hardship to communities within a study area (and as we account for seasonal effects, also a time frame). For this we added a parameter N that is adjusted to normalize the highest hardship score in a region- and time-frame to 100 (Equation (2)).
impact is stark: in mid-August the multi hazard scenario (that included two heat waves) has 40 more deaths and a weekly case rate much higher than the basic scenario (34,500 new cases per week compared to 11,300). By late June 2021 (the end of simulations; Fig. 5), the multi-hazard scenario exhibits a total death toll of 10,920 and 1.75 M recoveries compared to the basic scenario’s 4540 total deaths and 0.7 M recoveries. Comparing these numbers and the estimates of susceptible people in Israel (on June 30, 2021) it seems that the theoretic series of concurrent disasters resulted in the infection of almost one Million more people compared to the basic scenario.

4. Discussion

4.1. Limitations and further work required before operational implementation

The PRE-DI self-evaluation tool [28,30] is an innovative platform for dissemination of national risk and for motivating people to self-evaluate and thereafter improve preparedness. However, further research is needed to determine the effectiveness of online self-evaluation tools as a method to encourage preparations and enhance awareness on risk [35, 36]. Our PRE-DI evaluator is tailored to be user friendly and its simplicity was appreciated by users in our case-study. Simplicity, however, comes at the expense of a thorough account of the complexity of risk and resilience. Due to the reliance on user-provided input, the lack of fragility curves for many structures and the inaccurate correlation

Fig. 5. Epidemiology data (cases and deaths, weekly rate and cumulative) and models based on Israel demography, various estimates of infection rate ($R_t = 0.5–2.8$), 300 intensive care unit beds and 20,000 general hospital beds (horizontal gray lines). Vertical axes are logarithmic. A. A scenario of gradually improving intervention until September 2020 and fixed intervention thereafter (infection rates only change due to epidemiological seasonal effect). B. The same scenario, with a series of unfortunate events that lead to increased infection rates (see text for details). Scenarios performed using online simulator by Noll et al. [34] (https://covid19-scenarios.org/).
between shaking intensity and damage, our qualitative risk (DI) evaluation is mostly suitable for dissemination of knowledge to the public and for comparison between specific neighborhoods in a city. Furthermore, as noted in section 3b, PRE-DI data was only collected in Mitzpe Ramon, and therefore the spatial analysis presented in Fig. 4 was only performed there. In addition, the average PRE preparedness score of a neighborhood would decrease significantly if there are many tourists staying there, suggesting that Tpop could be made a factor in estimating an average PRE score.

The ‘hardship index’ discussed above provides a very crude conceptual quantification tailored to amalgamate qualitative evaluations of local hazard, exposure and fragility (DI) together with a self-evaluated resilience score (PRE) and with a simplified factor representing potential seasonal stressors (SOB). Although this index is tailored to inform disaster risk reduction strategies at the highest resolution of community level, it does not systematically and operationally quantify resilience or predict hardship in response to an earthquake. In fact, quantification of risk, resilience and the over-burden by concurrent stressors is very challenging. To date there is no model that offers systematically quantified relative weights and inter dependences between components of resilience [37]. In addition, there is no systematic account of temporal patterns as people and communities transition through different stages of response and recovery [38,39] and no integration of seasonal stressors or quantitative analysis of the impact of multi-hazard on community resilience and recovery. Further theoretical and empirical investigations, as well as regional preparedness surveys are needed to develop such operational and measurable models.

5. Conclusions

The spatial and temporal analysis of risk, preparedness and seasonal effects clearly demonstrate the need for high-resolution, multi-hazard analysis for improving local resilience and emergency plans. During the COVID-19 pandemic, and future epidemics, there is an increased risk of compounding multi-hazard impacts overwhelming health and emergency resources. Emergency response and recovery plans should therefore explicitly consider the probability of and the special adaptation measures required during a pandemic or extreme weather conditions. Similarly, infection mitigation strategies, medical supply and personnel management plans in time of a pandemic, should account for inevitable setbacks and complications inflicted by seasonal stressors. In particular, preparedness and response training should include infection prevention measures, post-disaster hygiene (in shelters and response facilities), and the role that specific natural stressors such as heavy rainfall play in driving outbreaks [8]. Several considerations for multi-hazard preparedness and response strategies are particularly important for periphery, isolated, communities: potential disruption of supply chains [40], limited mobility of national response and humanitarian aid, availability of evacuation centers with capacity for social distancing and coping with harsh weather, and the availability of medical equipment to ensure self-reliance in coping with infectious outbreaks (e.g. personal protective equipment respirators). In many periphery cities in Israel, old neighborhoods are inhabited by older, more vulnerable people, thus exacerbating the heterogeneity of vulnerability and resilience within cities. Periphery cities often have limited health and emergency resources and are required to provide and care for evacuees in an emergency for several days before receiving aid and supplies. Therefore effective emergency management, response and recovery depends on self-reliance and real-time allocation of resources. The ability to analyze spatial and temporal resilience, risk and stressors, at the neighborhood resolution provides a new tool for improving emergency plans, strategies and procedures. Finally, in remote tourist destinations, such as Eilat, risk mitigation efforts must include assessment of tourist and tour-operators’ vulnerability and diligent work with stakeholders and local municipalities to assure that response plans account for the actual total population at risk.

Multi-hazard response plans and adaptation procedures should guide response and recovery operations through complex, high-uncertainty and high-risk decisions, and potentially prevent the worst impacts from occurring. Inclusion of seasonal stressors and high-resolution demographic data in epidemiological models (and in multi-hazard response plans) could provide a basis for worst-case scenarios that should be considered.

On a national scale, temporal and high-resolution spatial analyses of risk during ongoing or recurring epidemics or climatic crises, can improve strategic emergency plans and resource allocation. In the same way that the case study of Mitzpe Ramon illuminated the fact that some neighborhoods will pose a greater challenge and suffer greater hardship in the wake of a strong earthquake, a multi-hazard comparative analysis of risk and community resilience in periphery cities could help guide national emergency policies and long-term investments in infrastructure. In many countries, where peripheral communities are either exposed to extreme weather or to high volumes of tourism, seasonal stressors must be accounted for in risk mitigation strategies, local emergency plans, and in public preparedness dissemination programs.

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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