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Multidimensional hazards, vulnerabilities, and perceived risks regarding climate change and Covid-19 at the city level: An empirical study from Haifa, Israel

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ABSTRACT

Climate hazards and vulnerabilities in cities are multidimensional. Natural features determine heat, floods and wildfires. Social features determine vulnerability and resilience. This study examined multidimensional hazards, vulnerabilities, and resilience in Haifa, a socially diverse Mediterranean city. Spatial indices of heatwaves, floods, wildfires and social vulnerability were developed by Geographic Information Systems geoprocessing functions using Digital Elevation Model, land use and welfare data. An online survey assessing risk perceptions, sense of danger and community resilience was distributed to residents (N = 549), and geocoded using street identification. The results show that climate hazards and vulnerabilities vary within the city and reflect its geographical and social characteristics: lower regions are prone to heat and floods and elevated neighborhoods to wildfires. All zones and segments of the population are in certain danger, but climate hazards and vulnerabilities are heterogeneous and unequally distributed, with certain neighborhoods more exposed. The downtown area is most vulnerable in social features, yet its residents have higher resilience perceptions compared to uptown, where the main hazard is wildfires and the main vulnerability is aging. Implications for urban climate policy: local stressors should be mitigated at the neighborhood level by investing in suitable infrastructure and fostering community resilience.

1. Background

The climate of the Mediterranean basin is determined by the interaction between mid-latitude and sub-tropical circulation regimes and a complex morphology of mountain chains and land–sea contrasts. These unique conditions make this region one of the world's main climate change hotspots (Giorgi and Lionello, 2008; Negev et al., 2015; Linares et al., 2020). The main characteristic of the Mediterranean basin as a climate change "hotspot" is the predicted reduction of precipitation, which is in contrast to the general increase of the hydrological cycle. In addition, the rapid warming of the basin, faster than the global annual mean surface temperature, also determines the Mediterranean as a hotspot (Lionello and Scarascia, 2018). Currently, the mean temperature increase of the basin is 20% higher than the mean global warming, and it is undergoing a warming trend with longer and hotter summers, an increase in the frequency and the severity of heat waves, changes in precipitation patterns and a reduction in rainfall amounts (Cramer et al., 2018).

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These conditions increase water demand (Bucak et al., 2017), ecosystems degradation and wildfires risk (Vilà-Cabrera et al., 2018). Furthermore, recent predictions for the coming decades in the Mediterranean show that heatwaves, drought and floods are expected to become more common phenomena (Zittis et al., 2016; Cramer et al., 2018). A recent study indicated that in the business-as-usual pathway, in the second half of this century, unprecedented extreme heatwave conditions will emerge in the Middle East and North Africa (Zittis et al., 2021). Such climate-related stressors will increase health and welfare impacts in the Mediterranean Basin, especially among vulnerable communities (Linares et al., 2020).

According to the United Nations (2018), 55% of the world's population lives in urban areas, a proportion that is expected to increase rapidly to 68% by 2050. Economically deprived populations, older people and those with pre-existing conditions are more vulnerable to extreme climate events such as heatwaves and floods, and have a lower adaptive capacity (Paavola, 2017). Since cities concentrate populations including vulnerable groups (such as poor people, young children, elderly and migrants), as well as major economic activities, societies' assets and infrastructure in high-risk locations, they are particularly susceptible to significant risks resulting from climate change (Revi et al., 2014; Paz et al., 2016). For example, heat is exacerbated in cities by the 'urban heat island' effect that increases with population density, extensive economic activities and city expansion (Milojevic et al., 2016). In addition, many cities are in coastal areas, and therefore are exposed to projected rises in sea level, storm activity, and associated flooding (Hallegatte et al., 2013). In densely populated urban areas, the changing climate affects the health and welfare of a much larger number of people in various ways.

For example, heatwaves contribute directly to morbidity and mortality from cardiovascular and respiratory illnesses, particularly among elderly people and those with chronic diseases (Loughnan et al., 2010). Urban populations are particularly vulnerable to the health risks of heat (Ellena et al., 2020). Additionally, heat conditions increase the risk of wildfires (Vilà-Cabrera et al., 2018); extreme weather events can cause direct physical injuries and deaths from intense storms, rainfall, winds and floods; changes in rainfall patterns (drought, floods) have impacts on supplies of fresh water which affects sanitation and increases the risk of water-borne diseases (Paz et al., 2016); changes in temperature can worsen air quality which may cause respiratory illnesses (Fiore et al., 2015); temperature increase and changes in precipitation patterns contribute to the transmission and outbreaks of vector-borne diseases (Linares et al., 2020), and extreme weather events disrupt urban lifelines (such as water, food, and energy sources) which may cause serious consequences for the city residents (McBean and Henstra, 2003).

In Mediterranean cities, people have to deal with high temperatures in summer, usually with high humidity which increases the heat stress since in the heat and humid conditions the efficiency of evaporative cooling is slower and the body may become unable to maintain a stable core temperature (Coffel et al., 2017). In the transitional seasons, over short periods of time, the climatic conditions can change from one extreme to another. Dealing with such variability may be more complicated than in other regions with different climates (Hamza and Paz, 2016). Although the use of air conditioners is common, poor populations are less likely to use them and are therefore more exposed to extreme heat (Teschner et al., 2020). All the characteristics above make the residents of the Mediterranean cities particularly vulnerable to the impacts of climate change (Paz et al., 2016).

The Intergovernmental Panel on Climate Change (IPCC) (Lavell et al., 2012; Oppenheimer et al., 2014) refers to the characteristics of climate change and its effects on geophysical systems, such as floods, droughts, deglaciation, rising sea levels, increasing temperatures, and frequency of heat waves as *hazards*. In contrast, the term *vulnerability* refers primarily to characteristics of human or social-ecological systems exposed to hazardous events and trends (increasing temperatures, droughts, floods, rising sea levels). Vulnerability is dynamic and context specific, determined by human behavior and societal organization, which influences for example the susceptibility of people and their coping and adaptive capacities to hazards. The term *exposure* refers to the presence (location) of people, livelihoods, environmental services and resources, infrastructure, economic, social, or cultural assets in places that could be adversely affected by physical events and which, thereby, are subject to potential future harm, loss, or damage. *Resilience* is defined by the (IPCC) Lavell et al., 2012 as "the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions". Similarly, community resilience, has been defined as "the community's ability to deal with crises or disruptions" (Leykin et al., 2013).

In order to assess how hazards, vulnerabilities and exposures to climate change are distributed in cities, several studies used various urban (such as road density or vegetation coverage), demographic (population age structure and distribution), climatic (different temperature values, relative humidity, tropical nights) and geographic (topography, elevation) parameters as a basis for mapping the urban environment (e.g. Kim et al., 2017; He et al., 2019a; He et al., 2019b; Zhang et al., 2021). During recent years, such mapping was conducted for heat waves (Kim et al., 2017; He et al., 2019a; He et al., 2019b), rises in sea levels and coastal floods (Kantamaneni et al., 2019; Uddin et al., 2019; Zhang et al., 2021), and wildfires (Miranda et al., 2020). Such spatial visualizations could serve as an important tool for a better preparedness of the city authorities to extreme climatic events.

In recent years, there has been an increasing body of literature on multi-dimensional urban hazards, exposures and vulnerabilities. Birkmann et al. (2013) emphasized the necessity to consider multiple hazard and vulnerability dimensions when designing climate change adaptation. Chow et al. (2012) assessed vulnerability to extreme heat in Phoenix, using an index of hazards (e.g. maximum temperature), vulnerability and capacity (e.g. age and income) as well as a temporal dimension, and showing spatial and temporal variations within the city. Fang et al. (2016) suggested that urban vulnerability assessments should include resource, eco-environmental, economic and social vulnerability, and demonstrated a remarkable overall urban vulnerability across China. In a more recent study that focused on the city of Shanghai, He et al. (2019a), He et al., 2019b) created an index of climate change exposures (such as rising sea levels and land surface temperatures), sensitivity (including unemployment rates, elderly population ratio) and adaptive capacity, and showed that these vary across the city and intensify with rapid urbanization.

Another growing body of literature is the comparison between actual and perceived risk. In a study in Pakistan, Rana and Routray

(2016) showed a positive correlation between actual and perceived flood risk in three cities, although risk perceptions were higher than actual risk. Based on these results, they suggest that in the absence of data regarding actual hazards, perceived risks may serve as an indicator for projecting hazards and taking adaptive measures. Similarly, other studies found a positive association between the risk perceptions of the general public, and the risks assessed by experts. In some cases, however, residents overestimated or underestimated risks (e.g. Kellens et al., 2011; Siegrist and Gutscher, 2006).

While recent studies focused on hazards, exposures and/or vulnerabilities, a limited number of studies included spatial visualizations of multidimensional hazards as well as residents' perceptions regarding hazards and resilience. The innovation of the current study resulted from its aim to spatially present climate hazards (extreme heat, floods and wildfires), vulnerability, residents' perceptions regarding these hazards, and their sense of danger and perceived community resilience.

2. Methods

2.1. Study area

The City of Haifa (Israel) located on a bay in the north-eastern Mediterranean Basin, hosts around 285,300 residents as a part of a large metropolis of 962,5000 people (CBS (Central Bureau of Statistics), 2020a, CBS (Central Bureau of Statistics), 2020b). Haifa is the third largest city in Israel, after Jerusalem and Tel Aviv. Since the early 1930s, Haifa Bay has developed into Israel's primary industrial region. The city is characterized by a complex hilly topography and unique sea-land meteorology and therefore represents a variety of Mediterranean sub-climatic regions (Paz et al., 2009). In addition, the population of the city is heterogeneous from many aspects and includes Jews (76%), Arabs – Muslims and Christians (12%) and others, natives and new immigrants, religious and secular people, of various ages and with different economic status (CBS (Central Bureau of Statistics), 2020a, CBS (Central Bureau of Statistics), 2020b). An increase in the frequency and intensity of extreme weather events has been documented in Israel (Yosef et al., 2016) as a part of the changing climate (Yosef et al., 2019), and in recent years Haifa has suffered from severe heatwaves (e.g. May 2019; September 2020) two large wildfires (2010 and 2016) and winter floods (e.g. December 2019; January 2020).

Fig. 1a presents the four major city regions: North-west, Uptown, Downtown and Kiryat Haim. The city of Haifa is divided into municipal statistical zones, shown in Fig. 1b obtained from the Israeli Central Bureau of Statistics (CBS, https://www.cbs.gov.il/he/pages/default.aspx, edition 2013, acquired February 2020). To examine climatic hazards and population vulnerability, the following spatial indices were developed.

2.2. Wildfire and flood indices

These two indices were developed using the Geographic Information System (GIS) in conjunction with raster and vector datasets geo-processed as spatial layers. The processes used to develop the indices were implemented with the ArcGIS Pro software (version 2.5) of ESRI©. The base surface was a Digital Elevation Model (DEM) raster dataset obtained from the Advanced Land Observation Satellite – Phased Array type L-band Synthetic Aperture Radar (ALOS-PALSAR) (Shimada, 2010) with a resolution of 12.5 m (http://www.eorc.jaxa.jp/ALOS/en/about/palsar.htm), downloaded in April 2018 from https://vertex.daac.asf.alaska.edu/# and clipped to the extent of the study area. The wildfire severity index was developed by reclassifying the values yielded by sloping the DEM into a raster GIS layer of five quintile categories.[1] At the next stage, five GIS vector datasets of built areas, green areas, public institutes, natural forests and water resources (obtained from GISrael (http://www.map.co.il/, Dec 2019) were inserted into a land use vector GIS layer and applied to each of the classes a severity level to wildfire (Oliveira et al., 2014).[2] In order to integrate between the yielded raster and vector layers and create a unified spatial index, the vector layer was converted into a raster layer and both layers were averaged into a single layer.

The predicted flood severity index was based also on the slope extracted from the DEM. Once sloped, it was manipulated using the 'flow direction' and 'flow accumulation' hydrological functions to evaluate the accumulating contributing flow in each of the generated raster cells. The land use GIS layer developed earlier was used, but this time they were assigned a runoff coefficient (C) to each of the land use classes in accordance with the Rational Method classification (e.g., Young et al., 2009). The resulted layer was converted into a raster layer and merged with the cumulative flow (F) raster layer to result in a peak flow raster as follows:

$$Q = C*i*A \tag{1}$$

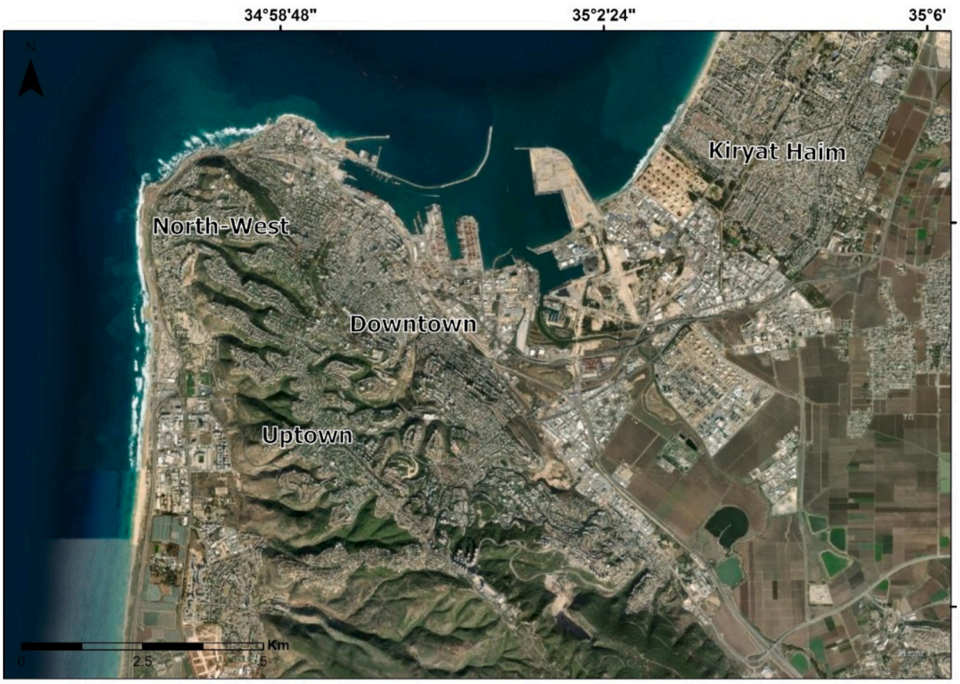
Whereas Q is the peak flow in each cell, C is the runoff coefficient; i is the rain intensity (which was not included since precipitation in the entire study area is almost equally distributed); and A is the accumulating contributing flow.

Finally, the values of the newly created two raster datasets were spatially averaged in accordance with the statistical zones of Haifa (Fig. 1b) to result in a spatial severity index for wildfire and floods ranging between the 1 (low) and 5 (high).

[1] The quintile ranges: Q1 $\leq 3.5^\circ$; Q2 $\leq 8.5^\circ$; Q3 $\leq 14.1^\circ$; Q4 $\leq 21.8^\circ$; Q5 $\leq 31^\circ$ (the highest slope value).

[2] The classifications are (from the least to the most vulnerable to wildfire): 1 (water resources); 2 (groundworks and artificial infrastructure); 3 (green areas within the city); 4 (built up areas); 5 (natural forests).

a.



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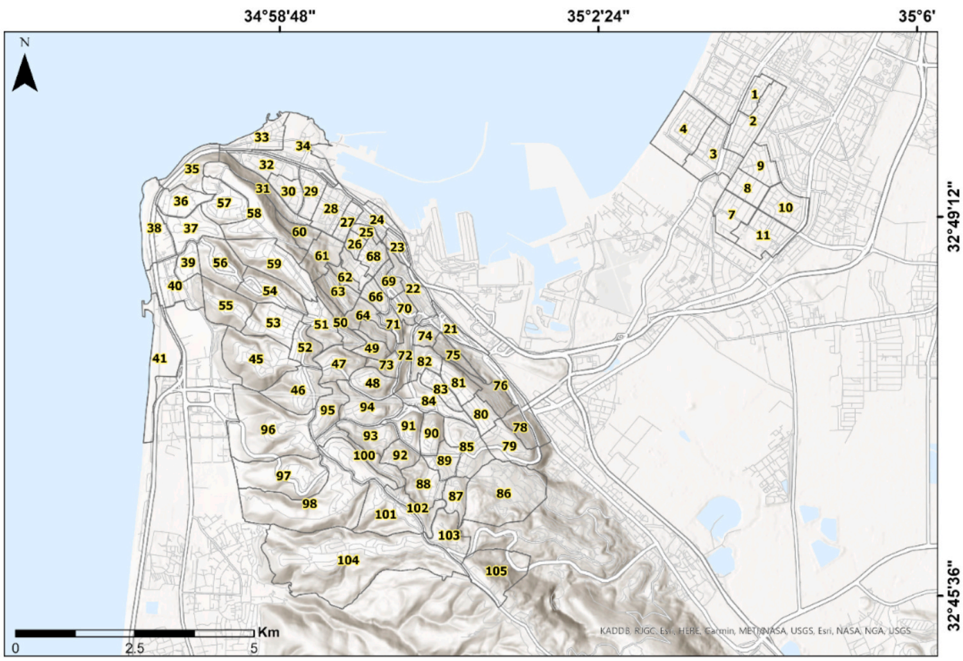

Fig. 1. (a) General overview of the city of Haifa; (b) The statistical zones.

2.3. Extreme heat index

A grid-based dataset covering Haifa and its close surroundings containing the predictions of the maximum daily temperatures between 2010 and 2019 was obtained in March 2020 (Zhou et al., 2020a; Zhou et al., 2020b). Using the R software, the temperatures of selected dates that were characterized by extreme heatwaves during the years 2010–2019 were extracted.[3] Then these maximum values for each of the 1*1 km grid cells were averaged and the dataset bins were sampled to a higher resolution of 100*100 m while cropping to the extent of the study area. Overall, the temperatures in the newly created raster ranged between 28.4°–33.5°. See Fig. 2 for a flowchart describing the stages of developing the floods, wildfires and heat indices.

2.4. Socio-economic vulnerability

For the socio-economic index, the 2015 socioeconomic status index from the Central Bureau of Statistics of Israel (CBS) available by deciles was acquired (https://www.cbs.gov.il/he/pages/default.aspx#) (Fig. 3a). This CBS index expresses a combination between the demographic composition, education and training, standard of living, employment, and pensions parameters and is suitable for examining the vulnerability of the community to extreme events. For the elderly population (Fig. 3b), data of 2019 for people in the 65+ age group was obtained from the National Insurance Institute of Israel, and calculated the ratio between the number of elderly (aged 65+) and the total population in each of the statistical zones. The National Insurance allowances were used as a proxy for populations that are not fully independent and need assistance in case of emergency. 2019 data was obtained regarding the number of people that are eligible for four types of relevant allowances (disability, nursing, mobility, working injury) from the National Insurance Institute of Israel and calculated the ratio between those who are eligible for any kind of allowance and the total population in each of the statistical zones (Fig. 3c–f). Then the decile degrees were summed up and the four allowances were averaged resulting in the 'National insurance allowances index', for each of the statistical zones (Fig. 3g).

2.5. Perceived hazards, community resilience and sense of danger

In May 2020 an online survey was distributed to 549 residents of Haifa, i.e. to three categories of participants using a quota sampling: (a) Jews, representative of age and gender for the age group 18–70 ($N = 400$); (b) elderly Jews, 65+ ($N = 95$), oversampled due to the higher vulnerability of this age group; and (c) Arabs, who form 11.5% of the city's population, were sampled to represent age and gender for the age group 18–40 ($N = 54$), while Arabs of 40+ were not included as there were not enough Arab members in the survey company who were in the age group of 40+, to represent this age group. The data collection was conducted by the survey company, IPanel, that distributed the survey to its members via e-mail. The Survey was conducted during the first wave of COVID-19, during the first lockdown in Israel, and therefore questions on perceptions regarding COVID were added (see graphical abstract). For the purpose of the current study, three indices were created from the results of the relevant sections of the survey:

(1) *Perceptions regarding hazards and social and health threats:* that is the extent to which a person perceives that a hazard or a threat will impact him or her personally, was calculated based on the following question, taken from (Carmi and Kimhi, 2015): "To what extent do you think that the following threats will impact you personally, on a scale of 1 ("not at all") to 5 ("very much")". This question was used for the following: heatwaves, floods, wildfires, earthquakes, climate change, national security (wars, terrorism), health impact of COVID-19, economic impact of COVID-19, and social impact of COVID-19 (isolation) (see graphical abstract).

(2) *Sense of danger*, that is "the extent to which a person perceives either him- or herself or his or her family as being under threat" (Kimhi et al., 2010), was calculated as an average of four statements on a scale of 1 ("not at all") to 5 ("very much") based on Solomon and Prager, 1992: "To what degree do you feel your life is in danger?", "To what degree do you assess that the country of Israel is in danger?", "To what degree do you assess that the country of Israel is in danger in the long-term?" "To what degree do you think that your family is in danger?"

(3) *Perceived community resilience*, that is "the perceived ability to quickly return to routine after an emergency event… as a community" (Leykin et al., 2013), was calculated as an average of statements 1–10 from Leykin et al. (2013), which are on a scale of 1 ("not at all") to 5 ("very much"). See Table 2 for the statements that present "a sense of danger" and "perceived community resilience".

The participants were asked to provide the name of the street or neighborhood in which they lived, and accordingly their residence was geocoded at the centroid of the adjacent neighborhood. To do so, each surveyor was represented as a spatial feature. Using the Nearest Neighbor function (Cover and Hart, 1967), a continuous density degree of the perceptions was evaluated given throughout the entire study area. The research was approved by the Ethics committee, (blinded institute), #352/19.

3. Results

3.1. Socio-economic vulnerability

A mapping of the social dimensions reveals that the downtown population is characterized by lower socio-economic profiles and higher proportions of disability welfare allowances, making it more vulnerable to extreme events (Fig. 3a and c–g). In the city of Haifa,

[3] The selected dates are: July 12, 2012; July 13, 2012; June 27, 2014; June 28, 2014; August 2, 2015; August 16, 2015; May 17, 2015; May 18, 2015; May 19, 2015; and July 25, 2018.

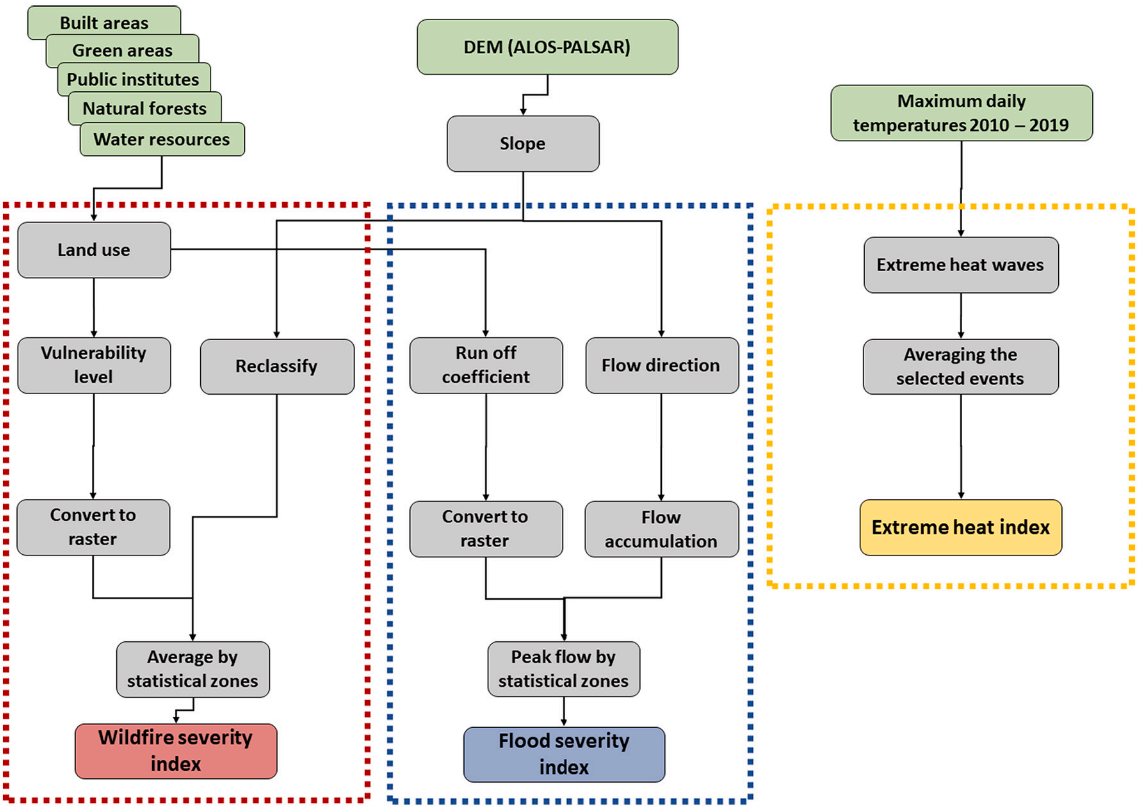

Fig. 2. Flowchart describing the stages for developing the natural indices of wildfire severity, flood severity and extreme heat. The green and gray colors represent the input datasets and the implemented geo-processing stages, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

a clear association exists between the elevation and the socio-economic status of the neighborhoods: while the downtown population belongs to the lowest socio-economic quintile of the CBS, the North-West and midtown (between downtown and uptown) belong to the middle quintiles, and the uptown population is in the highest quintiles (Fig. 3a). However, age-related vulnerability (65+ years) is spread throughout the city (Fig. 3b). Disability, nursing and work injury allowances are found in higher rates in the downtown and midtown regions (Fig. 3c, d, and f), while mobility allowance is distributed more evenly throughout the city. The national insurance allowance index (Fig. 3g) shows that when the four allowances are aggregated, the downtown and the northern neighborhoods have more vulnerable populations (in dimensions) that may affect emergency evacuation, and these are the same neighborhoods with populations that are economically vulnerable. Kiryat Haim, the neighborhood across the industrial zone to the North-East, has a mixed population covering all socioeconomic dimensions.

3.2. Physical and perceived hazards

Climate hazards vary across the city of Haifa. The downtown region is prone to heatwaves (Fig. 4a) and so is Kiryat Haim, while the uptown is prone to wildfires (Fig. 4c). The severity of flooding varies across the city, (with hotspots in the downtown, midtown, uptown and the North) reflecting the topography of Haifa which includes several valleys (Fig. 4e). A mapping of the perceptions regarding climate hazards shows that the views of the residents correspond with the actual risks in the city in general, and in their area of residence in particular (see Table 1 for descriptive statistics of the survey participants). That is, the downtown residents are worried about heatwaves (Fig. 4b) corresponding to their high frequency in the city (Fig. 4a); Uptown residents are relatively more worried about wildfires (Fig. 4d), corresponding to the actual severity of this hazard (4c); and residents are more worried about floods (Fig. 4f) in the North-West which is more prone to floods, but also in the downtown which is not as prone according to our index (Fig. 4e).

3.3. Comparing perceived community resilience and sense of danger

Community resilience was assessed according to statements regarding trust and mutual help among residents, the functioning of the municipality and pride and a sense of belonging regarding the place of residence (see Table 2). The results revealed that, to a certain extent, perceived resilience shows a negative association with the socioeconomic status; namely, downtown residents reported the highest community resilience, while uptown neighborhoods reported lower resilience, and the residents of the mid-north region

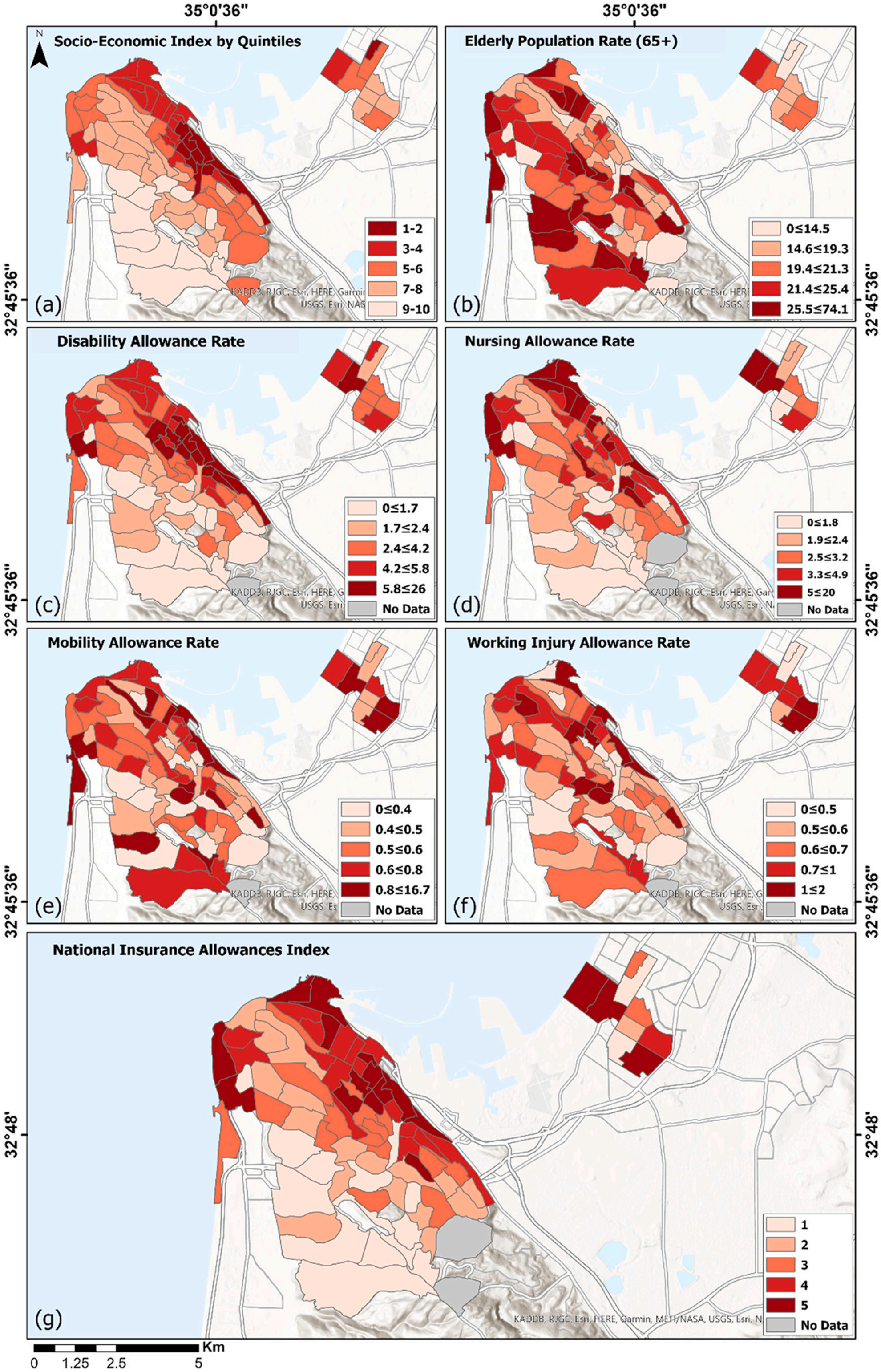

Fig. 3. Socio-economic parameters (in each of the statistical zones): (a) Socio-economic values obtained from the CBS; (b) the ratio between the elderly and the total population; (c) the ratio between those eligible for disability allowance and the total population; (d) the ratio between those eligible for nursing allowance and the total population; (e) the ratio between those eligible for mobility allowance and the total population; (f) the ratio between those eligible for workers' injury allowance and the total population; and (g) the evaluated social security allowance index (average of Fig. 3c–f).

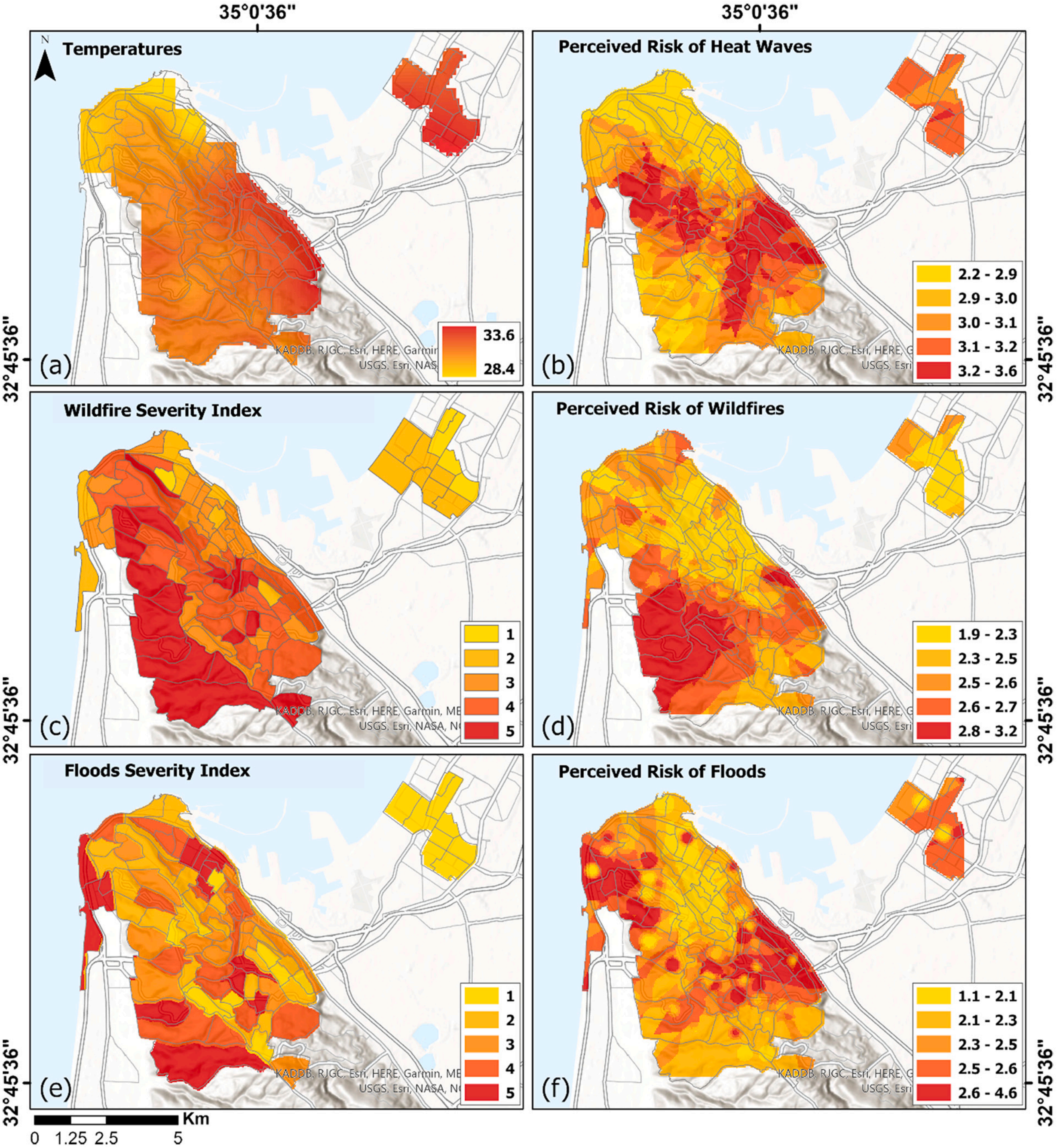

Fig. 4. Climate hazards and perceived risks. (a) Average temperature of excessively hot days in the month of August during the period between 2010 and 2019; (b) Perceived risk of heat waves as evaluated, based on the residents' survey; (c) Severity index presenting the hazard from wildfires throughout Haifa; (d) Adjacent perceived risk from wildfires as evaluated, based on the residents' survey; (e) Severity index presenting the hazard from floods in Haifa; (f) Adjacent perceived risk from floods as evaluated, based on the residents' survey.

reported the lowest resilience (Fig. 5a).

Fig. 5b presents the sense of danger, based on statements regarding danger at the personal, family and state level. As evident from Fig. 5, there is a reverse association between locations of high perceived resilience and low sense of danger and vice versa, so that residents with low perceived resilience have a high sense of danger, mainly in the North-West of the city and parts of uptown. Kiryat Haim is characterized by mixed perceptions of resilience and danger.

Table 1
Descriptive statistics of survey participants ($N = 549$).

		Percent (%)	Frequency
Age	18–29	28.1	154
	30–40	21.5	118
	41–64	30.2	166
	65+	20.2	111
Gender	Male	49.4	271
	Female	50.6	278
Religion and religiosity	Jewish – secular	67.8	372
	Jewish – traditional	13.1	72
	Jewish – Religious	5.5	30
	Jewish – Haredi	3.8	21
	Arab – Muslim	6	33
	Arab – Christian	2.9	16
	Druze	0.9	5
Family status	In a steady relationship	63.6	349
	Single	25.9	142
	Divorced	6.6	36
	Other	4	22
Number of children	1	13.5	74
	2	22.4	123
	3	18.2	100
	4	4	22
	5	1.3	7
	6	1.3	7
	7+	0.5	3
	None	38.8	213
Country of origin	Israel	83.8	460
	Other	16.2	89
Education	Primary school	0.7	4
	High school	19.1	105
	Vocational Training	24	132
	Academic (BA)	34.8	191
	Academic (MA and above)	21.3	117
Number of people in household	1	11.7	64
	2	29.9	164
	3	20.8	114
	4	18.4	101
	5	11.8	65
	6	4.4	24
	7	2	11
	8+	1.1	6
Income (average income in Israel is 21,063 before taxes)	Much lower than average	26	143
	A little lower than average	20.2	111
	Average	27.3	150
	A little higher than average	19.3	106
	A lot higher than average	6.9	38
Occupation	Management	11.7	64
	Academic profession	27.7	152
	Engineering, Technicians, and similar	6.9	38
	Office work	19.5	107
	Sales and services	10.2	56
	Agriculture	1.1	6
	Industry and building	1.5	8
	Drivers and machinery	1.5	8
	Non-professional workers	16.4	90
	Army	3.3	18

4. Discussion

Climate change will have different health impacts on different populations, and it is important to understand the distribution of hazards and vulnerability at the city level (Ellena et al., 2020). Our findings reveal the diversity and multiplicity of climate hazards and social vulnerabilities in the city of Haifa. The analysis of climate, geography and statistical data shows that the most vulnerable population in terms of socio-economic parameters is the most exposed to the hazard of heatwaves and their severe impacts. Due to climate change, heat is emerging as one of the main risks to health in the Mediterranean area (Zittis et al., 2021). Although the Mediterranean population is basically acclimatized to high temperatures, the poorer neighborhoods in Haifa are more exposed due to a combination of three factors: first, these areas are hotter due to the topography; second, the poorer neighborhoods have a lack of trees

Table 2
Statements (mean, sd) of sense of danger and perceived community resilience.

Sense of danger	Mean	Standard deviation
To what degree do you feel that your life is in danger?	2.17	0.9360
To what degree do you feel that the country of Israel is in danger of being annihilated?	2.72	1.038
To what degree are you worried about the future of Israel in the long-term?	3.15	1.175
To what degree do you think that your family is in danger?	2.54	1.013
Sense of danger (Average of four statements)	2.64	0.821
Cronbach's alpha		0.794
Perceived community resilience		
The municipal authority (regional council) provides its services in fairness	2.78	1.048
There is mutual assistance and concern for others in my town	2.93	1.010
My town is organized for emergency situations	2.81	0.982
I am proud to tell others where I live	3.47	1.123
There is trust among the residents of my town	3.07	0.953
I trust that decision makers in my municipality will help me in an emergency	2.44	1.034
The residents of my town are acquainted with their role in an emergency situation	2.40	1.027
I feel a sense of belonging to my town	3.53	1.088
The relations between the various groups in my town are good	3.28	0.934
I can depend on people in my town to come to my assistance in a crisis	2.90	1.028
Perceived community resilience (Average of ten statements)	2.96	0.756
Cronbach's alpha		0.907

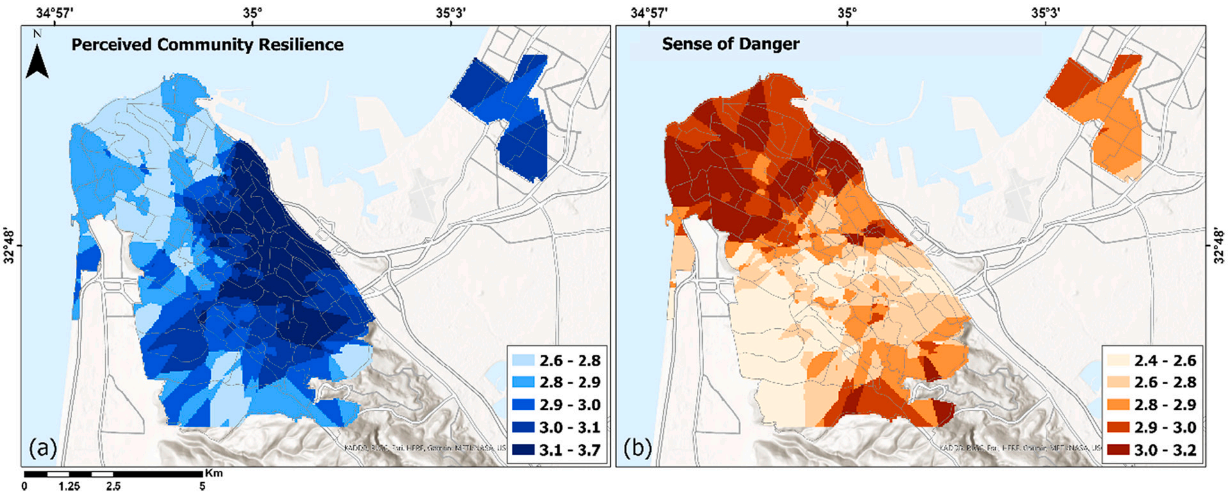

Fig. 5. Perceived community resilience and sense of danger, based on the residents' survey.

and shading and therefore experience a more intense urban heat island, and third, low-income is associated with energy poverty, or "the inability of a household to secure the energy necessary for cooking, heating, cooling or lighting, at a level that meets basic needs" (Teschner et al., 2020). While according to the CBS, 93.5% of the households in Haifa have an air conditioner, in Israel 19% of the two lowest socio-economic deciles do not own an air conditioner (CBS, 2018) (the deciles breakdown is not available for Haifa). In addition, low-income populations may not have the means to pay the electricity bill, fix broken heaters or install energy efficient air conditioners. Additionally, since the age-related vulnerability is spread throughout the city, the vulnerability to a heatwave is high in other parts of town as well, mainly in the uptown neighborhoods which is home to many elderly people.

A novel point of this study is the spatial comparison between climate hazards (heatwaves, wildfires and floods), and the residents' perceptions of these hazards. The associations found between the modelled hazard index and the perceived risk of heat, floods and wildfires shows that people are aware of the hazards in their area of residence. For example, Downtown residents are aware that heatwaves may affect them. There is also a good fit between the modelled severity of wildfires, and the residents' perceptions. However, there is a lesser fit regarding floods: according to our model, flood severity is higher in North-West Haifa and in the Southern slopes of Uptown, but the perceived threat is higher in Downtown. Interestingly, due to poor infrastructure, in 2019–2020 there were floods mainly in the Downtown area. Modelling climate hazards is complex due to multiple factors. In the cases of flooding, the perceptions of the residents, presumably based on experience, were found as a good proxy for severity. This finding corresponds with previous findings that risk perceptions are associated with actual hazards, especially in communities that have experienced such hazards (Kellens et al., 2011; Rana and Routray, 2016). Therefore, the suggestion that perceptions may serve as an indicator for assessing hazards in the absence of sufficient data (Rana and Routray, 2016) is supported by our study, which lacked data regarding underground sewage infrastructure.

Clare et al. (2017) argue that perceived resilience may contribute to understanding resilience from several perspectives, but recommend that their relationship with measured resilience should be tested. Similarly, Kellens et al. (2011) and Siegrist and Gutscher (2006) show the importance of comparing perceived and actual risks. Along these lines, our study may contribute to a better understanding of the relationship between measured and perceived hazards. Specifically, this study provides a preliminary suggestion that, in the case of Haifa, there is a positive relationship between modelled and perceived extreme climate hazards at the neighborhood level, and that in cases of lack of data, public perceptions may contribute to assessing climate hazards.

Another novel contribution of this study is the spatial presentation of perceived resilience and sense of danger, as well as the comparison between them. The data show that populations with a low socioeconomic status have a lower sense of danger and a stronger perception of community resilience. In Haifa, the lower socioeconomic status neighborhoods are characterized by traditional communities including Arabs and ultraorthodox Jewish religious groups. Our findings correspond to previous studies that showed that among traditional populations, religious and traditional beliefs can promote social cohesion and community resilience to cope with environmental and climatic disasters (Gómez-Baggethun et al., 2012). Therefore, traditional populations with collective action based on networks of relationships, reciprocity, and trust have stronger community resilience (Pelling and High, 2005). This may explain the higher perceptions of resilience among the downtown neighborhoods of Haifa, which are more vulnerable and exposed to extreme climate events.

As for the study limitations, our study developed indices of natural phenomena such as heat, floods, and wildfire. The three indices for floods and wildfires are based on model prediction rather than on the inspection of cumulative true events. Obviously, examining the spatial and temporal patterns of these phenomena over a few decades is likely to yield a more accurate expression of the prevailing hazard. Nevertheless, for the purpose of the study, model prediction should be sufficient even if it is not calibrated with actual historical events since the spatial distribution of the given phenomena is of interest. The limitations of the residents' survey stem from the distribution among members of the survey company. Although this is a large national company, it is limited to members with an email and an Internet connection. Nevertheless, in Haifa, 91.2% of adults use the internet according to the Central Bureau of Statistics socioeconomic survey (CBS (Central Bureau of Statistics), 2020a, CBS (Central Bureau of Statistics), 2020b) and therefore representation may be lower for very traditional (mainly ultraorthodox) communities who are less inclined to use the Internet. The second limitation is that the survey company members do not include a sufficient sample of Arabs over 40 years old in Haifa. However, since this survey was distributed during the first COVID-19 lockdown in Israel, this was a fair means of obtaining a representative sample by age and gender and by including both Jews and Arabs, while observing the lockdown restrictions.

5. Conclusions

Resilience to climate change is a key factor in mitigating the severe impacts of climate change on human beings. International and national policies are crucial but they focus on the large scale. Our study shows the importance of zooming into the city level, and points to the crucial role of municipalities and local agencies in adapting to climate change. Climate hazards vary across neighborhoods, and so do vulnerability and resilience; and resilience should be developed accordingly within cities.

Within cities, studies that focus on one dimension, whether a hazard or a vulnerability, do not provide enough data to prioritize local adaptation. A multidimensional approach may help to identify neighborhoods that suffer from multiple hazards and vulnerabilities, and provides the scientific evidence for prioritizing investment in infrastructure and in the community. Multidimensional studies can support municipalities in tailoring the required adaptation to each neighborhood and community, adapting infrastructure to cool hotspots and mitigating floods and wildfires, as well as building and maintaining resilience, and increasing adaptive capacity. This approach can contribute to engaging wider municipal stakeholders, including health and welfare departments and the public. Evidence-based, multi-sectoral adaptation may assist cities in effective and efficient preparation for the increasing challenges that stem from climate change.

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Contributions

MN conceived the idea of the paper, MN and SP wrote the background, results and discussion, MZ was responsible for the spatial analyses, created the maps and wrote the methods section. All of the authors contributed to shaping and finalizing the manuscript.

Declaration of Competing Interest

The research was approved by the Ethics Committee, University of Haifa, #352/19.

All of the participants gave their consent to participate in the survey.

All of the authors approved the manuscript submission.

The data are available upon request for researchers conducting relevant studies.

We declare no competing interests.

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