The evaluation of heat vulnerability in Friuli Venezia Giulia

Vulnerabilità alle ondate di calore in Friuli Venezia Giulia

Laura Pagani, Maria Chiara Zanarotti and Anja Habus

Abstract Heat waves are leading cause of weather-related illness and death, in a context where their frequency, intensity and impact are expected to surge due to rising climate change, growing urbanisation and population ageing. This work develops a Heat Vulnerability Index by means of the composite indicator methodology with the aim to depict heat vulnerability in Friuli Venezia Giulia at the census tract level. The results show that heat vulnerability follows a spatial pattern with highest hazard in urban areas, lower risk in rural areas and lowest danger in mountainous areas. The performance interval approach is exploited to validate the Index.
Abstract *Le ondate di calore sono la principale causa di malattie e decessi legati ai cambiamenti climatici. La loro frequenza, intensità ed impatto sono destinati ad aumentare a causa del crescente surriscaldamento globale, urbanizzazione ed invecchiamento della popolazione. Questa analisi sviluppa un indice di vulnerabilità alle ondate di calore mediante la metodologia dell'indicatore composito per rappresentare la vulnerabilità, a livello di sezione censuaria, nella regione Friuli Venezia Giulia. I risultati mostrano che la vulnerabilità al calore è alta nelle aree urbane, media in quelle rurali e bassa nelle zone montane. L'approccio basato sull'intervallo di performance viene utilizzato per convalidare l'indice.*

Key words: Heat vulnerability index, heat waves, composite indicator

1 Introduction

With growing global warming, extreme climate events like heat waves (HWs) will increase in duration, frequency and intensity. Urban and metropolitan areas are particularly affected by HWs due to higher heat-absorbing capacity and reduced night-time cooling capability of these environments with respect to the surrounding rural

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areas; this is the so-called Urban Heat Island (UHI) effect. HWs are becoming a significant public-health concern as the observed warming has raised heat-related morbidity and mortality of certain categories of individuals that suffer an excessive burden from heat-load. Specifically, the thermoregulatory system of elderly, children and ill individuals is impaired by high air temperatures and humidity levels. Nevertheless, targeted economic investments, mitigation and prevention policies can minimise health impacts of climate threats. Thus, there is a growing interest in understanding the determinants of heat vulnerability (HV) and identifying population and geographical areas more susceptible to adverse health impacts associated with HWs.

2 The Concept of Heat Vulnerability

HV is a latent and multifaceted concept, hence a readily available and comprehensive measure of this complex phenomenon does not exist. To carry out a meaningful measurement, a sound theoretical framework is designed and the determinants of HV are first identified. Secondly, a complete set of non-interchangeable indicators, i.e. the system of basic indicators (BIs), is collected for a comprehensive representation of the construct of interest.

2.1 Definition

The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as

> [...] the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity [2].

In addition, it outlines the three dimensions of vulnerability as follows: **Exposure** (E), the nature and degree to which a system is exposed to significant climatic variations; **Sensitivity** (S), the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli; **Adaptive capacity** (AC), the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

The IPCC framework is embraced to assess the subset of vulnerabilities associated with heat stress in the Friuli Venezia Giulia (FVG)[1] and guides the selection of the set of manifest variables that allow to quantify HV.

[1] FVG is Italy's north-easternmost region. Its landscape spans from the Carnic and Julian Alps to the Adriatic Sea, determining the subdivision into four main parts: mountainous-alpine terrain in the north, hilly to the south of the mountains and in the central part of the eastern border with Slovenia, plain from the centre to the coastal area in the south

2.2 The System of Basic Indicators

To reflect both the multifaceted nature of HV as well as the three dimensions identified by the IPCC, climate, environmental, health and socio-demographic data[2] are employed in the analysis. The statistical unit of reference is the census tract, that is the smallest entity of the municipality based on which the data collection of national census surveys is organised.

Table 1: The system of basic indicators

Class	BI	Description	Dimension	Range
Socio-demographic[a]	Under5	No. of individuals 5 years or less	S	$[0-15992]$
	Over65	No. of individuals aged 65 years or more	S	$[0-25942]$
	NoAC	No. of dwellings without air conditioning	E, AC	$[0-37100]$
Health[a]	Car	No. of individuals with cardiovascular diseases	S	$[0-51956]$
	Res	No. of individuals with respiratory diseases	S	$[0-6582]$
	End	No. of individuals with diabetes	S	$[0-5118]$
	Psy	No. of individuals with psychological disorders	S	$[0-11622]$
	MultiPat	No. of individuals with at least two of the above diseases	S	$[0-25921]$
Environmental	Imp	Degree of soil imperviousness	E, AC	$[1-4]$
	Lcpi	Largest patch of continuously built area	E, AC	$[0-1]$
	Lai	Leaf area index	E, AC	$[1-6]$
Climate	ThomMax	10-years average of daily Thom Index maxima	E	$[21-30]$
	ThomAvg	10-years average of daily Thom Index means	E	$[13-23]$

[a] Normalised by census tract's area (km^2)

As depicted in Table 1, sensitivity to heat is measured by data on population structure and healthiness condition. Climate BIs are indicators of exposure as the Thom Index represents the combined effect of both temperature and humidity on the warming and discomfort level perceived by the human body. Instead, availability of air conditioning and environmental variables do not find a clear-cut classification across literature: they are either proxies of exposure or adaptive capacity, depending on the subjective choice of the analyst. For instance, the number of dwellings without air conditioning can reflect indoor temperatures (E) or the willingness of individuals to seek relief from heat load (AC).

3 A Heat Vulnerability Index for FVG

To obtain a unidimensional measure of heat-risk the system of BIs is summarised into a single variable, called Heat Vulnerability Index (HVI), by means of the Composite Indicator (CI) methodology [3]. CIs construction is a complex task as it entails several steps and choices: BIs selection, functional form assessment, outliers and missing data treatment, normalisation, weights definition and aggregation.

[2] Climate data are provided by *ARPA FVG Osservatorio Meteorologico Regionale*; environmental, health and socio-demographic data are provided by *Regione Autonoma Friuli Venezia Giulia*

After testing several combinations of the aforementioned steps, health and socio-demographic data are log-transformed and BIs are normalised with the the min-max method. These are then aggregated in two stages based on a two-dimensional structure of HV (exposure and sensitivity). At a first stage, a cubic mean with equal weights is applied within HV dimensions. The adoption of a non-linear aggregation function allows the introduction of a partially compensatory approach. This choice is driven by the intention to preserve the impact of those features that make a census tract, and the related inhabitants, vulnerable to HWs either in terms of sensitivity or exposure. In other words, in case of imbalance between BIs, those with a high value do not compensate the ones with a low value. For instance, a census tract characterised by high density of elderly individuals is not fully compensated by a healthy population and thus is still highly sensitive to HWs. As the HVI is an indicator with negative polarity, meaning that an increase in the values of the index corresponds to a worsening of the phenomenon, an upward penalisation must be used. The cubic mean corresponds to a high upward penalisation. At a second stage a linear aggregation with equal weights is applied between HV dimensions. This means that a compensatory approach is instead chosen across dimensions and therefore low values of a dimension, e.g. sensitivity, linearly compensate high values of another dimension, e.g. exposure and vice versa.

4 Heat Vulnerability Patterns in FVG

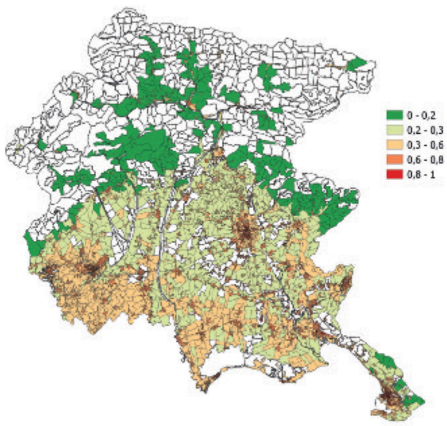

Fig. 1: Heat vulnerability map for FVG

Fig. 1 depicts HV patterns in FVG region (HVI ranges from 0 to 1, min. and max. vulnerability respectively)[3]. The map clearly shows that most urbanised and densely populated areas are the ones that record the highest values of HV: Trieste,

[3] The total number of census tracts is 6,835. Blank areas refer to census tracts having no inhabitants or that never recorded a discomfort from heat as per the Thom Index. The latter are located in the mountainous area, as in line with the orography of the region

Udine, Pordenone, Gorizia, Monfalcone and Sacile. Moreover, HVI increases in the surroundings of SR252, the regional road that connects Palmanova to Codroipo. Also some census tracts in the touristic and coastal cities of Lignano Sabbiadoro and Grado display high levels of HV, whereas other less urbanised census tracts in the same area do not record the same values, e.g. Lignano Riviera. This specific case highlights the impact of invasive tourism and high urbanisation. If furthermore suggests to policy maker to avoid the repetition of such policies in planning new touristic spots. The map points out that mountainous areas (Tolmezzo and Gemona) as well display high levels of HV due to elevated levels of urbanisation. As expected, census tracts located in the north are overall less vulnerable to HWs, whereas the HVI records intermediate levels in the central part of the region.

As previously mentioned, the CI methodology implies multiple decisions that might influence the resulting Index. To limit the impact of the aggregation methods, the performance interval (PI) approach proposed by Mazziotta and Pareto [1] is employed in this analysis. The researches suggest to compute, for each statistical unit, an interval of possible values rather than a single figure. The range of the PI depends on the level of compensability of BIs and their imbalances, and it generates a lower (LB) and upper (UB) bound for the HVI. Since the HVI has negative polarity, the LB corresponds to the hypothesis of full compensability (arithmetic mean of BIs), whereas the UB corresponds to the hypothesis of non-compensability (maximum across the BIs). The midpoint (MP) of the interval represents the case of a partially compensatory BIs.

Taking into account that the HVI is computed in two steps, the PI is adopted at the second level of aggregation, i.e. investigating different levels of compensability between the dimensions of exposure and sensitivity, whereas within the two HV dimensions the cubic mean is maintained. In addition, data are aggregated at a higher administrative level, i.e. municipality, to allow for a better interpretability of the results.

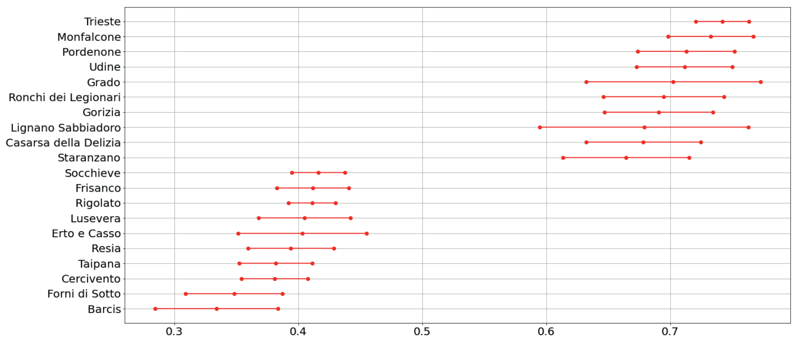

Fig. 2: Performance intervals - Top and bottom 10 municipalities

Fig. 2 displays the PIs of the top and the bottom 10 census tracts when ranked according to the MP[4]. It can be noticed how the ranking changes depending on the

[4] FVG counts 218 municipalities, determining the impossibility to effectively visualise all of them

chosen aggregation function. Grado is ranked 5^{th} based on a MP ranking but it is 1^{st} based on UB ranking. Beyond the impact of the aggregation function, Fig. 2 further confirms that the biggest cities in FVG display the highest values of vulnerability: Trieste, Monfalcone, Pordenone, Udine and Gorizia are all ranked in the first 10 positions, which confirms the validity of the built HVI and the observations resulting from Fig. 1. Conversely, municipalities with the lowest levels of vulnerability are all located in the Alps.

5 Conclusions

Measuring HV is a complex task due to its multidimensional and latent nature. However, the CI technique allows to summarise multifaceted phenomena into a single measure easily accessible to the general public and policy makers.

The resulting HVI for FVG shows that the census tracts recording the highest values are located in urbanised and highly populated areas, specifically in the cities of Trieste, Udine, Pordenone, Gorizia and Monfalcone. Few census tracts at risk are also in the tourist areas of Lignano Sabbiadoro and Grado. These outcomes are in line with expectations, as the synergies of climate and the UHI effect lead to higher daytime temperatures and reduced night-time cooling capacity of cities with respect to rural areas. This behaviour is driven by reduced availability of green areas and higher imperviousness levels of the urban landscape. Furthermore, Trieste, Udine and Pordenone, compared to the surrounding areas, record higher at risk population density, i.e. elderly, children and ill individuals. On the contrary, mountainous and rural areas record the lowest values of HV. These results are validated and confirmed through the PI approach: regardless the use of more or less compensatory techniques in aggregating the HVI, the set of risky areas previously detected remains the same.

Policy makers are suggested to redesign urban plans with the aim to change the way cities develop and grow. The current structure of urban areas should also be reshaped by introducing parks, tree-lined avenues or vegetated rooftops and incentives to steer economic development outside urban areas should be introduced in order to control the urbanisation process.

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