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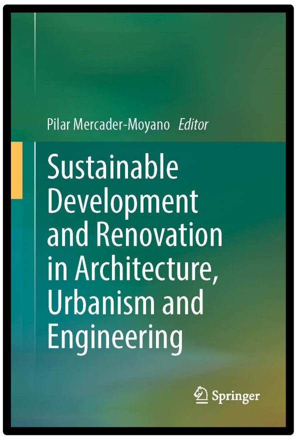

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Urban heat island and vulnerable population. The case of Madrid

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Abstract
The Urban Heat Island effect shows the differences among temperatures in urban areas and the surrounding rural ones. Previous studies have demonstrated that temperature differences could be up to 8ºC during the hottest periods of summer in Madrid, and that it varies according to the urban structure. Associated to this effect, the impact of temperature increase over dwelling indoor thermal comfort seems to double cooling energy demand. In Madrid, fuel poor households already suffering from inadequate indoor temperatures can face important overheating problems and, as a consequence, relevant health problems could become more frequent and stronger. This poses an increment in mortality rates in risk groups that should be evaluated. This research is aimed at establishing the geospatial connection between the urban heat island and the most vulnerable population living in the city of Madrid. Hence, those areas most in need for an urban intervention can be detected and prioritized.

Keywords: Urban Heat Island; Urban Indicators; Vulnerable Population; Heat Wave; Fuel Poverty

1 Introduction

1.1 Relevance of the research

The Urban Heat Island (UHI) is a well recognised effect that rises the ambient air temperature compared to surrounding less urbanized areas (Oke 1982). Recent studies of the UHI of Madrid has shown this temperature difference to be up to 8ºC (Núñez Peiró et al. 2016).

Projections from the Intergovernmental Panel on Climate Change point out that this effect will be exacerbated with temperature increase due to climate change (IPCC 2013). Besides that, estimations for the Iberian peninsula show an important increase in frequency and duration of heatwaves (Fischer & Schär 2010),

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which are expected to be more pronounced in dense urban areas combined with the urban heat island phenomenon.

The combination of all these effects will make population to be exposed to extreme temperatures. High daytime temperatures together along with warm night-time temperatures, for an extended duration of days, will have important impacts over people's health. High temperature health-related consequences have been already studied and some population groups have been identified as being more vulnerable towards this temperature raise. The age of the population has shown to be an important factor, but not only the elder and children are more susceptible to high temperatures; also people already suffering from a chronic disease or people living in high-rise dense areas of the city, are vulnerable towards these effects (Tomlinson et al. 2011; Culqui et al. 2013; Basu 2002; Díaz et al. 2002; Simon et al. 2005). In a recent report for the city of Madrid some districts were already identified as being more vulnerable towards climate change due to their temperatures, social composition and building qualities (Tapia et al. 2015).

Derived from these differences in vulnerability towards extreme temperatures, researchers have started analysing whether social inequalities can be found as a consequence of urban temperature gradient distribution. Results of many of these studies have shown a correlation between urban location of more disadvantaged people and a higher exposure to high temperatures (Harlan et al. 2015). These studies are usually based on heat-related mortality data and point at some socio-demographic indicators as a key element in the measurement of this vulnerability: elderly groups of more than 60-65-70 years, secondary education attainment, people living alone as widowed, divorced and separated, low and middle incomes and poor housing conditions (Wong et al. 2016; Klein Rosenthal et al. 2014). Nowadays heat vulnerability indexes are being developed in different cities based on the correlation of high heat risk and socio-economic conditions (Johnson & Wilson 2009; Johnson et al. 2012; Wolf & McGregor 2013).

In line with these studies, Moreno Jimenez (2003) conducted a study in which urban thermal comfort was correlated to spatial distribution of population's income within the Region of Madrid, and the location of the poorer in less comfortable areas was confirmed. Most recent research has shown how this temperature increase can double cooling demand in dwellings of the centre of Madrid (López Moreno et al. 2015). Taking into account that almost 24% of households of Madrid face problems coping with their cooling and heating energy needs (Sánchez-Guevara et al. 2014) it is urgent to analyse whether these relations between disadvantaged people groups and extreme temperature exposure is taking place in the city of Madrid.

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1.2 Aims and objective of the study

This paper explores the geospatial connection between the urban heat island of Madrid and the location of the most vulnerable population towards high extreme temperatures. The research is aimed at locating which are the neighbourhoods where those most in need live and hence, determining priorities for dwelling energy retrofitting and urban intervention in specific areas of the city.

2 Means and methods

2.1 Summer Urban Heat Island of Madrid during a heat wave

Along 2015 and 2016 years, a proximity environmental temperature measurement campaign was conducted. Temperatures were registered by the method of urban transects, as shown in Figure 1, already used in the first UHI existing study of Madrid (López Gómez et al. 1988). Results shown in present study were registered in the night of the 15th of July of 2015 under a heat wave event conditions and maximum intensity of the Urban Heat Island. Hence, this research has worked with an urban gradient temperature snapshot wherein the two phenomenon are combined.

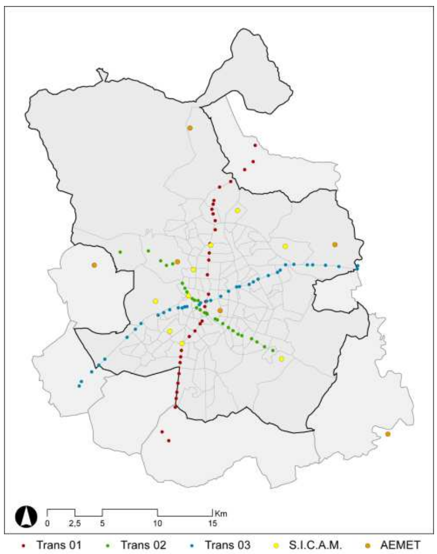

Fig. 1 Map of Madrid with the transects conducted on 2015, the 15th of July.

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2.2 Vulnerable population indicators towards extreme temperatures

Previous research showed socioeconomic indicators as a key element to detect vulnerability to heat-related illnesses and mortality. Social indicators used for this study were selected from available data derived from the European project Urban Audit (Eurostat 2012). This project, started in the late nineties, was aimed at gathering statistical data that enabled the comparison of life quality among main European cities. The project is conducted by Directorate-General for Regional and Urban Policy of the European Commission and Eurostat.

Available statistical data for the city of Madrid is disaggregated by neighborhoods in what the project call *sub-city districts* which are urban areas with a population between 5,000 and 40,000 inhabitants, smaller than districts and formed by the aggregation of census sections.

Four were the indicators selected from the Urban Audit database:

- Mean household annual net income (€): represents household's income and is calculated by National Statistics Institute derived from data of the Spanish Tax Agency.
- Proportion of foreigners over total population: people who do not have the nationality of the country of residence regardless the place of birth.
- Single household (%): proportion of single households over the total.
- Low educational level (%): proportion of the population between 25-65 years old with a maximum level of education ISCED 0, 1 or 2 according to the classification of the United Nations. Level 0 is for early education level, 1 for elementary education level and 2 is for the first stage of secondary education level.

All indicators were selected from 2011 data, except income values that were only available from 2013.

In line with existing literature that points at aged people and children as population at risk towards extreme temperatures, data for these groups was extracted from 2011 municipal census. Hence, another two indicators were incorporated to the study with the same disaggregation level as the sub-city districts:

- Elderly (%): proportion of the population over 70 years old.
- Children (%): proportion of the population under 4 years old.

Values of these indicators were studied for the 142 subcities or neighbourhoods of Madrid and different levels of vulnerability were established according to the range of these values. Hence, vulnerability threshold levels were established as the first or fourth quartile value of an indicator. Severe vulnerability was studied as well, and thresholds used in this case were the first or the ninth decile. Table 1 shows resulting thresholds for each indicator according to this method.

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Table 1 Thresholds for vulnerability indicators

Indicator	Vulnerability threshold	Severe vulnerability threshold
Mean household annual net income (€)	< 27,189.45€ (Q1)	< 23,863.83€ (D1)
Immigrants (%)	> 21.08% (Q4)	> 25.31% (D9)
Low educational level (%)	> 37.66% (Q4)	> 47.69% (D9)
Single household (%)	> 31.82% (Q4)	> 35,71% (D9)
Elderly (%)	> 17.16% (Q4)	> 19.04% (D9)
Children (%)	> 5.43% (Q4)	> 7.15% (D9)

2.3 Geographic Information System Tool

All the information of this research was managed, analyzed and represented through a Geographic Information System (GIS) Tool. The software used was ArcGIS version 10.3.

Urban area disaggregation level was the *sub-city* previously defined, set by the indicators used from the Urban Audit. A reference temperature value was associated to each one of these areas as explained in section 2.1, which is the arithmetic mean value of all contained points within each area. Calculations were made by means of the ArcGIS statistics package.

Finally, different data was overlap and vulnerability maps were obtained.

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3 Results

3.1 Social indicators and the UHI of Madrid

First part of the study consisted of analyzing the relation between temperature gradient of the UHI and selected socioeconomic indicators. For that purpose temperature gradient was calculated for each neighbourhood in order to set comparable geographical delimitations with the rest of indicators. Each indicator was separately analysed and compared with registered temperatures. Figure 2 shows neighbourhoods with a median income below the first quartile mainly located in the south of the city where higher temperatures were registered. This figure also enables locating some of the neighbourhoods with the highest presence of foreigners settled in hotter areas.

Larger rates of single households can be found in the center of the city where extreme temperatures were recorded. By contrast, population with lower educational levels can be found in the south, as shows Figure 3. Finally, Figure 4 shows the relation of vulnerable population due to its age and the UHI of Madrid. It is possible to detect some of the most aged neighbourhoods in central areas where the highest temperatures are registered, while those with larger presence of children seem to be located in more peripheral areas and hence, with better thermal conditions. However, there can be found some areas in the south side of the city where the overlap between high temperatures and rates of children can be assessed.

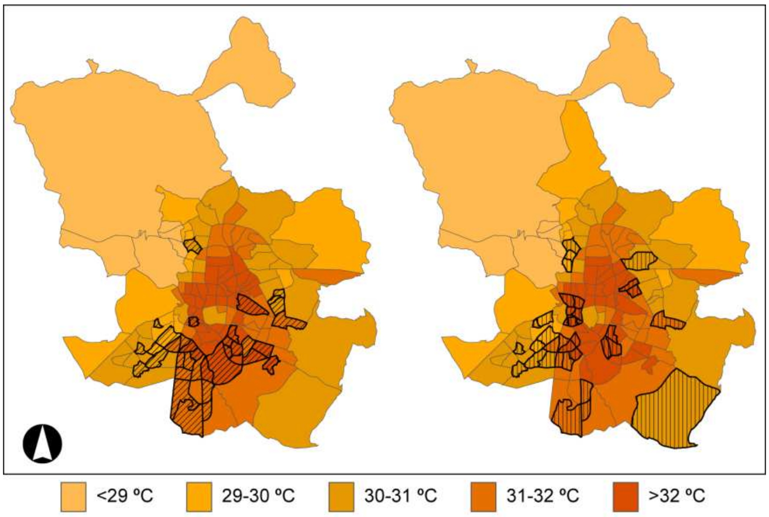

Fig. 2 UHI of Madrid during summer nighttime and neighbourhoods under the first quartile of income (Left) and neighbourhoods with a proportion of foreigners over the fourth quartile (Right).

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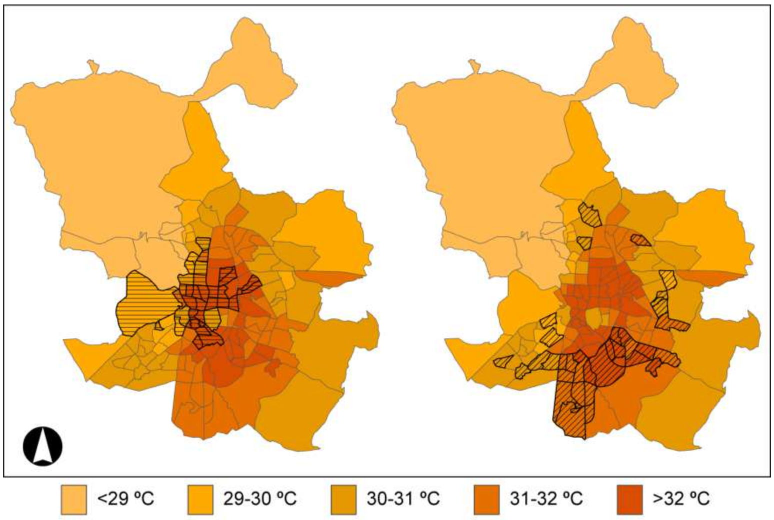

Fig. 3 UHI of Madrid during summer nighttime and neighbourhoods with a proportion of single households over the fourth quartile (Left) and neighbourhoods with a population with low educational level over the fourth quartile (Right).

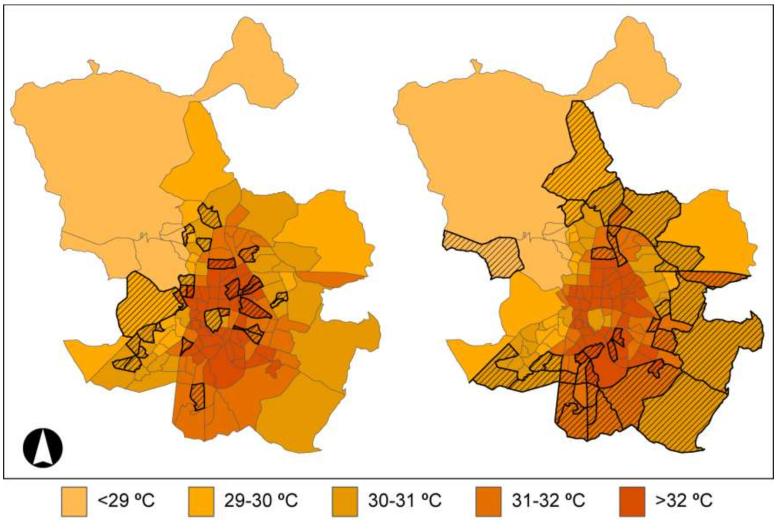

Fig. 4 UHI of Madrid during summer nighttime and neighbourhoods with a proportion of people older than 70 years over the fourth quartile (Left) and neighbourhoods with a proportion of children below 4 years over the fourth quartile (Right).

From this first approach it can be stated the existence of an overlapping between the hottest areas in the city and the presence of neighbourhoods where those most in need live.

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3.2 Vulnerable neighbourhoods and the UHI of Madrid

After analyzing socioeconomic vulnerable indicators separately and comparing them with UHI gradient temperature, some areas of the city were delimitated. Neighbourhoods were defined as vulnerable when three or more of these indicators overlapped so most disadvantaged population could be located. Figure 5 shows these areas and their relation with the temperatures of the city. It can be seen that these neighbouhoods are mainly concentrated in the south of the city.

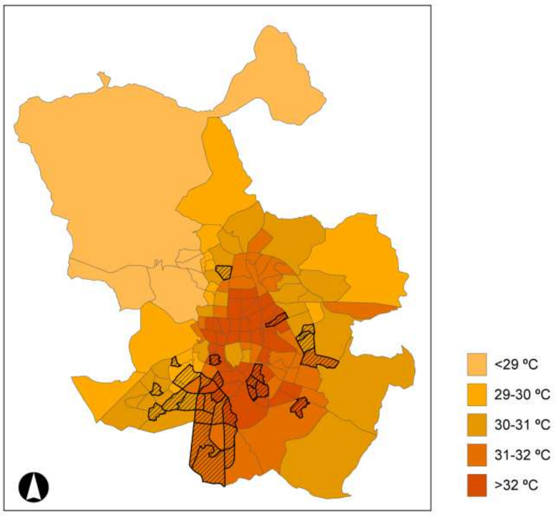

Fig. 5 UHI of Madrid during summer nighttime and vulnerable neighbourhoods according to selected indicators.

Figure 6 plots this data detecting how many and which indicators were overpassed in each neighbourhood and the exact temperature registered. It can be stated that San Cristóbal, San Andrés, Los Rosales, Almendrales, Numancia and San Diego can be considered neighbourhoods that can be facing serious problems to cope with extreme temperatures.

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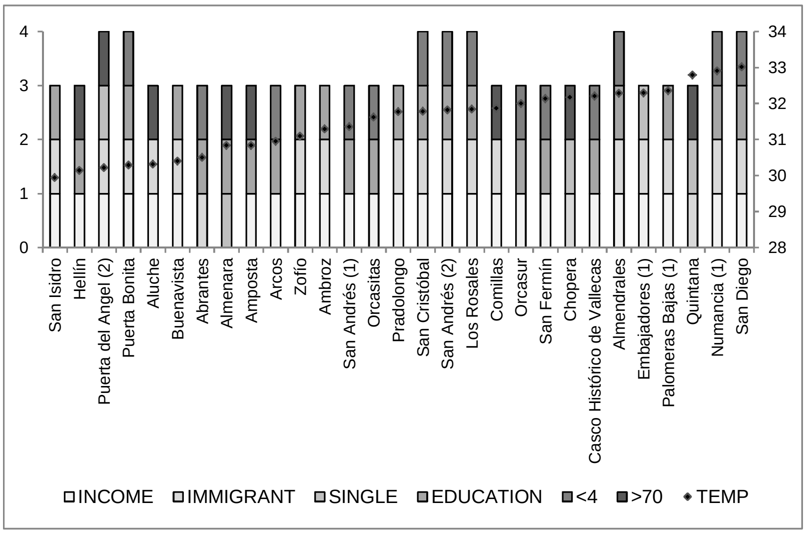

Fig. 6 Neighbourhoods' vulnerability indicators exceeding fixed thresholds and nighttime temperatures registered.

Besides that, and in order to better understand neighbourhood vulnerability degree, those wherein at least too indicators exceeded the severe vulnerability thresholds were delimitated. Figure 7 shows the location of these neighbourhoods, mainly placed in the south of the city where also higher temperature levels are registered. Figure 8 gathers all vulnerable neighbourhoods and presents for which indicators severe vulnerability thresholds were exceeded.

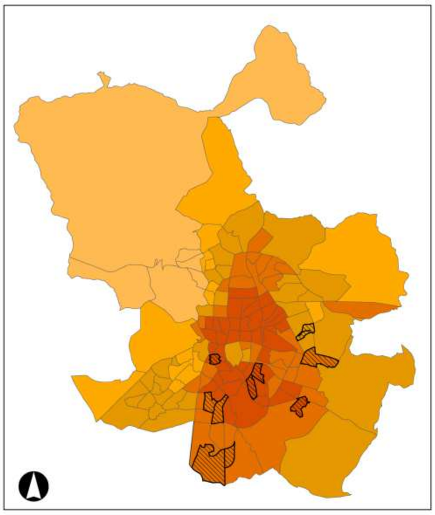

Fig. 7 UHI of Madrid during summer nighttime and severe vulnerable neighbourhoods according to selected indicators.

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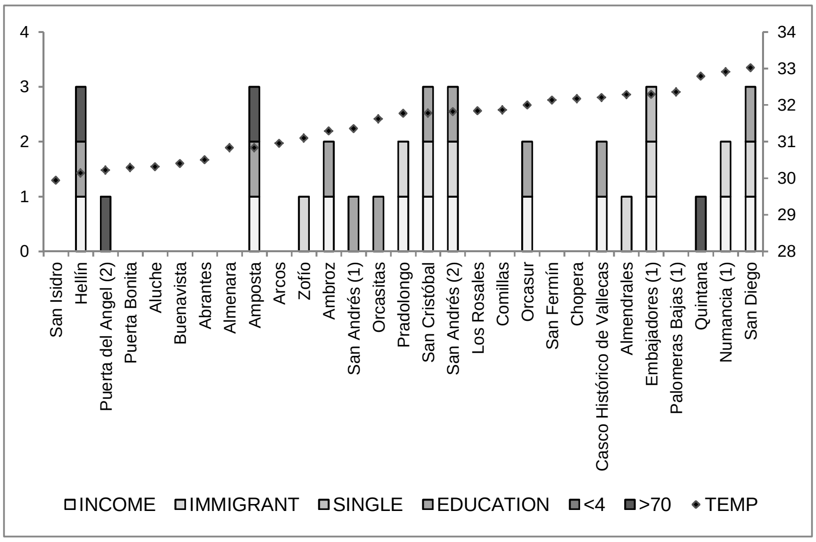

Fig. 8 Neighbourhoods' severe vulnerability indicators exceeding fixed thresholds and nighttime temperatures registered.

4 Conclusions

This research has shown, for the city of Madrid, the existence of several neighbourhoods with an important presence of vulnerable population that are located in some of the hottest areas of the city, which poses important health risks for that population. Methodology developed poses a useful tool in order to establish different degrees of vulnerability and hence, prioritize interventions among urban areas.

Neighbourhoods delimitated as being vulnerable towards high temperatures are, in their majority, included in the 'Map of priority areas for the impulse of urban regeneration'- APIRU by its initials in Spanish- (Área de Gobierno de Desarrollo Urbano Sostenible. Dirección General de Estrategia de Regeneración Urbana 2016). This is mainly because this report is based on studies of deprived areas delimitation that take into account socioeconomic indicators of disadvantage of the population along with some others relative to the poor quality of dwellings.

Households settled in these are likely not to be able to cope with extreme temperature episodes either because of the poor quality of their dwellings or the lack of adequate cooling systems. As a conclusion it can be highlighted the importance of incorporating intercity temperature variations as another indicator that must play an important role in the urban regeneration decision-making process.

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