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ABSTRACT

The European Union is currently immersed in policy development to address the effects of climate change around the world. Key plans and processes for facilitating adaptation to high temperatures and for reducing the adverse effects on health are among the most urgent measures. Therefore, it is necessary to understand those factors that influence adaptation. The aim of this study was to provide knowledge related to the social, climate and economic factors that are related to the evolution of minimum mortality temperatures (MMT) in Spain in the rural and urban contexts, during the 1983–2018 time period. For this purpose, local factors were studied regarding their relationship to levels of adaptation to heat.

MMT is an indicator that allows for establishing a relationship to between mortality and temperature, and is a valid indicator to assess the capacity of adaptation to heat of a certain population. MMT is obtained through the maximum daily temperature and daily mortality of the study period. The evolution of MMT values for Spain was established in a previous paper.

An ecological, longitudinal and retrospective study was carried out. Generalized linear models (GLM) were performed to identify the variables that appeared to be related to adaptation. The **adaptation** was calculated as the difference in variation in MMT based on the average increase in maximum daily temperatures.

In terms of adaptation to heat, urban populations have adapted more than non-urban populations. Seventy-nine percent (n = 11) of urban provinces have adapted to heat, compared to twenty-one percent (n = 3) of rural provinces that have not adapted. In terms of urban zones, income level and habituation to heat (values over the 95th percentile) were variables shown to be related to adaptation. In contrast, among non-urban provinces, a greater number of housing rehabilitation licenses and a greater number of health professionals were variables associated with higher increases in MMT, and therefore, with adaptation.

These results highlight the need to carry out studies that allow for identifying the local factors that are most relevant and influential in population adaptation. More studies carried out at a small scale are needed.

1. Introduction

In 2015 the General Assembly of the United Nations approved the 2030 Agenda for Sustainable Development, which included 17 Sustainable Development Objectives (SDG). SDG 13 was related to adopting urgent measures to combat climate change and its effects. Currently, the European Union finds itself immersed in climate and environment-related challenges requiring resilience, reduction in vulnerability and improvements in adaptation to climate change. The different effects of climate change include an increase in the average temperature and an increase in the intensity and frequency of heat waves (WHO Regional Office for Europe, 2021). Heat waves represent one of the most direct impacts of climate change on health (European Commission, 2020). However, this impact varies across the European continent, with differences between cities that include factors related to latitude (Kazmierczak et al., 2020).

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This does not mean, however, that the consequences in warm zones are more mild compared to colder zones. For example, the Mediterranean region is one of the most vulnerable regions in Europe in terms of climate. Furthermore, it has been predicted to be one of the most affected by climate change (Linares et al., 2017), in addition to the western part of the European region (WHO Regional Office for Europe, 2021). Among the different consequences, worth noting is the greater impact on the health of the population (Cramer et al., 2020).

In Spain, according to predicted estimates in a climate scenario with more emissions RCP8.5 (Amblar Francés et al., 2017), annual variations in the increase in temperature could range from 4.2 °C to 6.4 °C. This supposes more marked summers and longer heat waves, whose effects will be especially important in urban areas and in terms of human health (Sanz and Galán, 2021). Along with the rest of Europe, in Spain there will be different effects among cities. For example, in terms of the increase in heat waves, consequences will be more marked in communities in the regions of Murcia, Islas Baleares and Canary Islands and less so in Galicia and La Rioja (Gobierno de España, 2020).

Prior studies on mortality have demonstrated that the temperature and its effects differ at the local level (Choi et al., 2021; Hu et al., 2019; Hu et al., 2019b; López-Bueno et al., 2019; López-Bueno et al., 2021; Wang et al., 2018). Differences in mortality between regions due to the effects of heat can be determined by differences in climatological conditions as well as individual characteristics (such as age and socioeconomic level based on income, education and employment), adaptation factors, improvements in infrastructure and services (de' Donato et al., 2015; Gasparrini et al., 2015; Son et al., 2014).

Older adults are more vulnerable to the effects of heat than younger people (Díaz et al., 2015). Education level also has an impact and is related to income level. Those with higher levels of education have an average income that is higher than people with lower levels of education (Muller, 2002). This determines, at least in part, people's living conditions, both in terms of access of medical services and access to acclimatization equipment (Yang et al., 2021).

The implementation of adaptation measures, in particular Heat Health Action Plans (HHAPs), has been shown to be effective in reducing cases of mortality associated with heat(Martinez et al., 2019). These plans include a series of key elements. Of great importance is the inclusion of communications campaigns, printed media, social media and digital media that inform about the risks related to heat and how to prevent them (de'Donato et al., 2018).

Adaptation to high temperatures is a key to reducing the adverse effects of heat on the health of residents, and MMT is a valid indicator to measure the adaptive trends of a population or territory (Folkerts et al., 2020; Follos et al., 2020, 2021; López-Bueno et al., 2021a,b,c; Yin et al., 2019). When MMT increases more quickly than average maximum daily temperatures of exposure, it indicates an adaptive population process, thanks to the combination of acclimatization and adaptation of individual factors, both physical and socioeconomic. However, in practice, our understanding of the influence of these factors on the adaptation of the population to heat is limited. Therefore, knowledge of the factors that influence adaptation is needed (Bakhsh et al., 2018) to inform policy development in local governments to protect the population from the consequences of climate change, specifically the effects related to heat (Sánchez Martinez et al., 2011).

The aim of this study was to provide knowledge related to the social, climate and economic factors (rural or urban context) that were related to the evolution of minimum mortality temperatures (MMT) in Spain during the 1983–2018 time period.

2. Materials and methods

2.1. Study area

Spain is located in southwestern Europe. It is the second largest country in the European Union. (505,944 Km^2) and the sixth largest in terms of population (47,322,614 inhabitants). It is characterized by great climate variability, due to its orography and geographical situation, with 3 types and 11 subtypes of climate regions (Eurostat, 2021a, 2021b; Moreno Rodríguez et al., 2005). Administratively, Spain is divided into 50 provinces, all of which were included in this study.

Spain's territory has been classified at the geographical level (NUTS 3) according to Regulation (EC) Number 1059/2003 on the Establishment of a Common Classification of Territorial Units for Statistics (NUTS, 2003). In Spain's case this corresponds to the administrative division of provinces.

2.2. Study variables

Population behavior in terms of the risks of extreme temperatures differs based on the rural-urban typology of the areas where people live (Gutierrez and LePrevost, 2016). Thus, as in prior studies, the differentiation in typology was used in this study (López-Bueno et al., 2021; López-Bueno et al., 2021).

The urban-rural classification in this study used the criteria established by Eurostat (2015), which is based on the rural population as a percentage of the total; this was 20 percent for predominantly rural populations, between 20 and 50 percent for the intermediate regions and 50 percent or more for regions that are predominantly rural. For the purposes of this study, provinces were grouped into two categories: urban, which corresponds to predominantly urban regions, and non-urban, which corresponds to intermediate and predominantly rural regions (Fig. 1).

Variables of reference from other studies carried out in the context of mortality (Follos et al., 2020) were used, as well as those relating to climate, demographics, socioeconomic level and level of services and infrastructure (Barreca et al., 2016; Chung et al., 2018; López-Bueno et al., 2021). The variables used were classified into three categories: dependent, explanatory and control variables (Table 1).

2.2.1. Dependent variable

MMT was used as the principal dependent variable, according to the methodology and results obtained previously by Follos et al. (2020) (Fig. 2). MMT is an indicator that allows mortality to be linked to temperature, in addition to being a valid indicator to assess a population's capacity for adaptation to heat (Folkerts et al., 2020; Follos et al., 2020, 2021; López-Bueno et al., 2021a,b,c; Yin et al., 2019). MMT has been obtained through a deterministic method, using the maximum daily temperature and daily mortality of the study period. For each year and province, the MMT is determined using a quadratic or cubic adjustment (curvilinear regression). From the annual MMT values, a linear adjustment is made to determine the temporal evolution of the MMT. In the case that it does not fit significantly or with a polynomial of order 2 or 3, the MMT for that year are discarded (Follos et al., 2020, 2021).

These data were determined using mortality data and retrospectively predicted temperatures by the National Statistics Institute (INE) and the State Meteorological Agency (AEMET) for the 1983–2018 period.

2.2.2. Explanatory variables

Explanatory variables were preselected in a prior phase and were made up of demographic, economic, housing and health-related variables (Table 1). Each of the variables was calculated by province (equivalent to NUTS 3), accounting for the time period within which each took place during the overall period of the study. The variables used are described here.

The average of the population over 65 years of age and the total population were calculated. The data for both variables were extracted from the principal series of population data since 1971 (Instituto Nacional de Estadística, n.d.-c) and were calculated for each province for the years 1983–2018, using January 1 of each year as a reference.

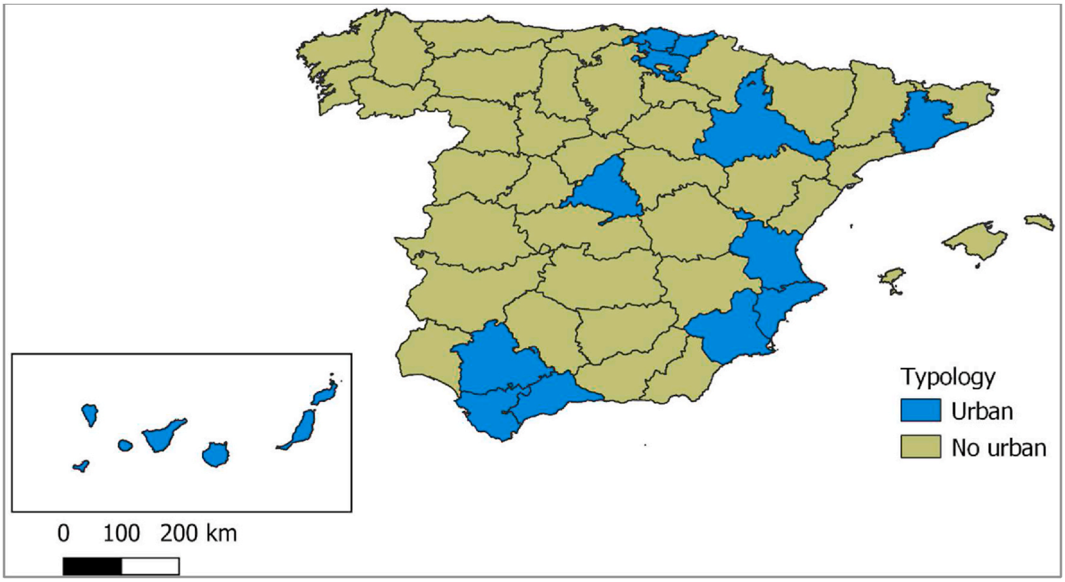

Fig. 1. Map of urban and non-urban provinces in Spain, 2015).

Table 1
Relationship of the variables by category and type.

Type	Category	Variables
Dependent	Mortality	Variation in the minimum mortality temperature by degree and decade (MMT_VAR)
Explanatory	Demographic	Proportion of over age 65 (POP_65) and average of inhabitants (POPULATION).
	Economic	Income per capita (INCOME), deprivation of privileged and underprivileged groups (ECONOMIC RESOURCES).
	Housing	Proportion of dwellings in good conditions (GOOD_HOUSE), proportion of dwellings built in the last 50 years (HOUSE_LESS_50), rehabilitation licenses (REHABILITATION_LICENSES).
	Health	Health expenditure per inhabitant (HEALTH_EXPENDITURE), proportion of health professionals (HEALTH_PROFESSIONALS), proportion of ambulances (AMBULANCES), ratio of health centers (HEALTH_FACILITIES) consultation facilities (MEDICAL_FACILITIES) per inhabitant.
Control	Climatological	Heat wave threshold temperatures based on the 95th percentile (T_95).

The average income per capita for each province of the 2000–2018 series was calculated. The data were extracted from the statistical data of the Spanish regional accounting system (Instituto Nacional de Estadística, n.d.-b).

The population's economic situation, grouped into privileged populations and underprivileged populations, was calculated (Fig. 3). The economic situation can be conditioned by the type of worker or the age of the unemployed population, in addition to education level and the access to the Internet at home. For this variable, an adapted version of the deprivation index IP2011 was used (Duque et al., 2021), which was grouped by provinces and took a dichotomous value: 1 for the most privileged populations (the grouped index value is less than zero) and 0 for the underprivileged populations (the grouped index value is greater than zero).

The proportion of dwellings in good conditions and the average number of dwellings constructed within 50 years prior were obtained. The state of housing and the date of construction were obtained from the Census of Population and Housing of 2011 (Instituto Nacional de Estadística, n.d.-a).

The number of licenses granted to buildings for rehabilitation per 10,000 inhabitants was calculated during the years 2007–2017. The data were obtained from the construction catalog of buildings with municipal licenses for construction from the Ministry of Transport, Mobility and Urban Agenda (Gobierno de España, n.d.-c).

The average municipal health expenditure was obtained for the years 2002–2018. Local entity data were obtained using statistical data related to the general budgets of local entities and their liquidation from telematic services of the General Secretariat of Autonomonic and Local Financing (Gobierno de España, n.d.-a).

The proportion of health professionals was calculated using the average of the ratio of the number of physician or nurses during the 2004–2018 period. The average number of ambulances per 100,000 inhabitants in the 2012–2018 series was obtained. The number of health and primary care centers and the consultation facilities (which are not considered health centers per se, but which provide health care in the area of primary care) were calculated. The average numbers of health centers and consultation facilities were calculated using the average population per 10,000 inhabitants. Data were obtained from the Statistical Portal of the Area of Intelligence Management (Gobierno de España, n.d.-b) and the Primary Care Information System (SIAP) for each province.

2.2.3. *Control variable*

The variables used as a control variable for ambient exposure were temperatures at the 95th percentile for each Spanish province during the 1980–2003 period, considering that vulnerability to heat depends on the population's exposure to heat at the maximum daily temperature (Linares et al., 2017).

2.2.4. *Adaptation variable*

In order to determine whether the provinces showed (or did not show) an adaptive trend during the study period, the **adaptation** was calculated, which corresponds to the difference in variation in MMT with the average increase in maximum daily temperatures, according to the methodology and results (Follos et al., 2020). A value of 1 was assigned to the **adaptation** variable for provinces with adaptation (for which the value of the level of adaptation was greater than 0), and a value of 0 was assigned in provinces without adaptation (which had an adaptation value lower than 0).

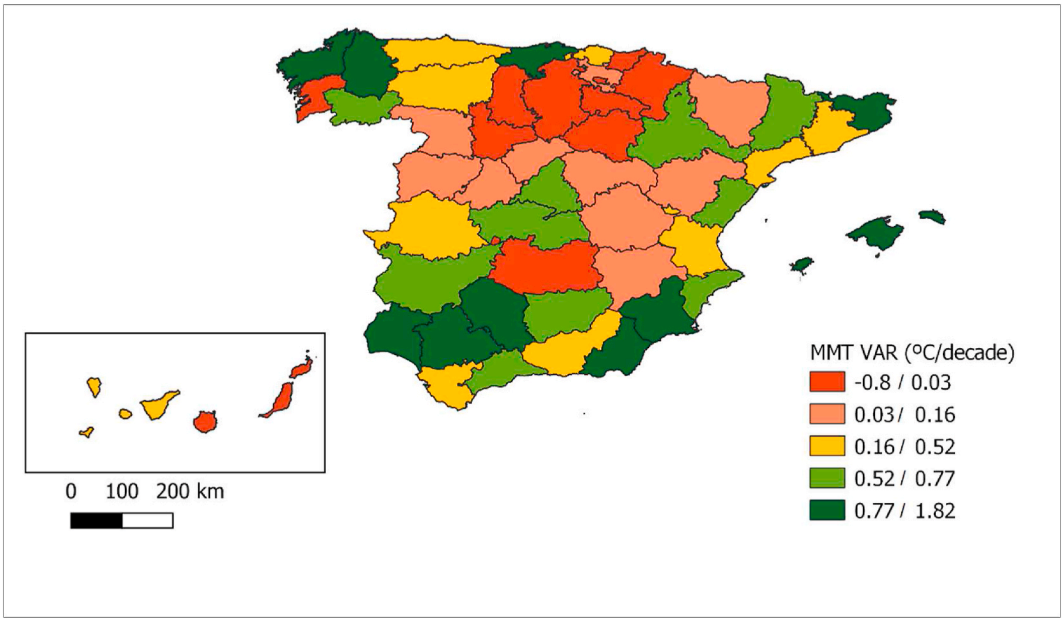

Fig. 2. Variation in the minimum mortality temperature in Spain, 1983–2018.

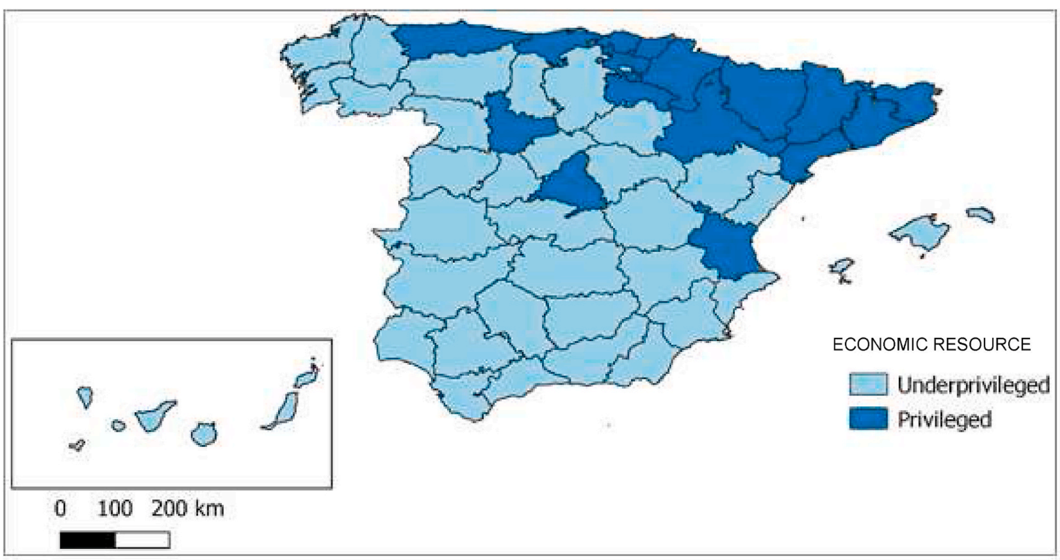

Fig. 3. Map depicting the deprivation of underprivileged and privileged populations in Spain, 2011).

2.3. Data analysis

To carry out the data analysis, we first considered the division between urban provinces (Table 2) and non-urban provinces (Table 3) for each of the variables. They were analyzed using generalized linear models (GLM).

Second, a model was generated using the variables (Table 1) selected, adjusted for each of the groups (urban and non-urban). In these models, the variables were discarded based on the biological sense of their coefficients' direction, negative or positive, and by the backward stepwise methodology, until statistical significance was reached (p-value < 0.05).

The variables INCOME, ECONOMIC RESOURCES, HOUSE_LESS_50 and HEALTH FACILITIES were used for the urban model. For the non-urban model, the variables selected were POP_65, POPULATION, INCOME, ECONOMIC RESOURCES, GOOD_HOUSE, REHABILITATION_LICENSES, HEALTH_PROFESSIONALS and MEDICAL_FACILITIES.

Furthermore, the dependent variable MMT_VAR included control variable T_95, due to its importance as a variable for climatological control for both groups.

The statistical program STATA version 15 was used to carry out the analysis. Data treatment used software R, version 4.0.2. The geographic information systems program QGIS version 3.16.0 was used for spatial representation.

3. Results

According to the classification criteria in the study, at the province level, Spain is predominantly non-urban, with 72 percent ($n = 36$) non-urban provinces, compared to 28 percent ($n = 14$) urban provinces (Fig. 1). In terms of the adaptation to heat according to the urban-rural typology, 79 percent ($n = 11$) of the urban provinces showed an adaptive trend (Table 2), with 21 percent ($n = 3$) lacking adaptation. In comparison, only 44 percent ($n = 16$) of non-urban provinces showed an adaptive trend (Table 3), with 56 percent ($n = 20$) not adapting. Both differences were statistically significant (p-value < 0.05) according to a

Table 2
Relationships between the dependent, explanatory and control variables in urban provinces.

NAM_MUN	MMT VAR	ADAPT LEVEL	ADAPT.	T_95	POP_65	POPULATION	INCOME	ECONOMIC RESOURCES	GOOD HOUSE	HOUSE LESS_50	REHAB. LICENSES	HEALTH EXPENDITURE	HEALTH PROFESSIONALS	AMBULANCES	HEALTH FACILITIES	MEDICAL FACILITIES
Alicante	0.69	0.50	1	33.3	15.17	1,569,682	17398.21	0	0.94	0.89	7.11	6.64	2784	7.86	4.86	9.29
Álava	0.06	−0.40	0	38	14.41	300,207	32118.95	1	0.96	0.86	12.96	14.70	2789	5.39	6.02	10.46
Barcelona	0.45	0.04	1	30.3	15.00	5,140,403	25885.00	1	0.94	0.75	5.20	15.13	2517	3.89	5.02	3.83
Bizkaia	0.20	0.14	1	32	16.00	1,182,241	26298.32	1	0.96	0.73	7.66	13.35	2527	3.28	6.36	8.54
Cádiz	0.49	0.20	1	32.4	11.44	1,171,259	16015.68	0	0.92	0.85	5.77	5.99	3130	5.10	4.33	6.13
Gipuzkoa	0.03	−0.22	0	33.1	15.72	708,972	28009.00	1	0.97	0.67	4.58	9.37	3102	3.75	7.22	6.51
Madrid	0.58	0.18	1	36.5	13.31	5,736,471	29458.37	1	0.96	0.82	3.20	21.25	3281	1.35	4.08	2.53
Málaga	0.68	0.36	1	36.4	13.16	1,377,593	16361.11	0	0.96	0.91	4.67	8.37	2796	3.02	3.99	7.34
Murcia	1.00	0.83	1	37.5	12.87	1,261,196	18197.11	0	0.93	0.85	3.89	7.41	2671	5.43	5.65	12.91
Las Palmas	0.00	−0.13	0	29.9	10.46	935,091	19029.58	0	0.90	0.84	2.27	6.28	2779	5.48	4.84	6.42
S.C. de Tenerife	0.36	0.14	1	31.5	12.61	864,165	19285.53	0	0.92	0.84	2.44	5.53	2375	5.86	5.60	8.60
Sevilla	1.14	0.83	1	41	12.55	1,791,717	23820.84	0	0.96	0.84	5.62	13.16	2321	4.98	4.42	5.53
Valencia	0.41	0.10	1	33.3	14.78	2,361,208	20494.11	1	0.93	0.77	5.75	6.79	2658	6.63	5.43	12.00
Zaragoza	0.61	0.13	1	37.3	17.35	915,979	23644.26	1	0.96	0.80	9.33	6.28	2471	3.77	6.52	30.39

chi-squared test.

In the selection of the candidate variables (Table 1), there was no statistically significant association found between the independent variables and variation in MMT in urban zones. In contrast, in non-urban zones five variables were found to be statistically significant, in the demographic (**POP_65** y **POPULATION**), economic (INCOME), housing (**REHABILITATION_LICENSES**) and health (**MEDICAL_FACILITIES**) contexts.

With respect to MMT (Fig. 2), it can be observed that both the first and the second quintile correspond to low values of MMT (−0.8 to 0.16), and they are concentrated in provinces that did not show an adaptive trend. In comparison, beginning in the third quartile (0.16–1.82), with the exception of three provinces (Leon, Caceres and Granada, which did not adapt), all of the provinces showed an adaptive trend (Tables 2 and 3).

In terms of economic resources in Spain (Tables 2 and 3), there are more underprivileged provinces (34 or 68%) than privileged provinces (16 or 32%). Privileged zones are found primarily in the northern part of the country (Fig. 3). Although adaptation is not a differentiating factor among underprivileged zones in Spain, 50 percent ($n = 17$) of these areas did not show an adaptive trend, and the other 50 percent ($n = 17$) did (Tables 2 and 3). In comparison, in more privileged provinces 63 percent ($n = 10$) showed adaptation, compared to 37 percent ($n = 6$) that did not.

The analysis of the relationship between MMT and local factors in the models showed that two variables were related in a statistically significant way (p-value < 0.05) in urban zones: ECONOMIC RESOURCES and T_95. In the first case, the rate of variation was lower among more underprivileged populations. In the second, it can be observed that MMT_VAR tended to grow with exposure to extreme heat.

In terms of the non-urban zones, the two variables related to MMT in a statistically significant way (p-value <0.05) were REHABILITATION_LICENSES and HEALTH_PROFESSIONALS. In this case, a greater percentage of rehabilitation licenses for buildings and greater percentage of health professionals showed greater variation with the rate of population adaptation.

4. Discussion

The aim of this study was to gain knowledge about the local social, climate and resource-related factors were related to the evolution of minimum mortality temperatures (MMT) in Spain during the 1983–2018 period. This evolution can be interpreted to represent an adaptive trend among the population. This study provided two main findings. First, our results show that the adaptive trend was different by region. Urban populations adapted more than did non-urban populations. This agrees with other studies that have found differences in the behavior of heat, in which non-urban areas are more vulnerable than urban areas (Chen et al., 2017; Hu et al., 2019). This result contrasts with other studies that have found that urban areas are more vulnerable to heat than rural areas (Gabriel and Endlicher, 2011; Wang et al., 2018). In part, the greater level of adaptation observed in urban zones could be related to a better economic situation.

In this work it has been shown that those provinces whose MMT grows at a rate that is greater than maximum daily temperatures show an adaptive trend. However, this does not imply the disappearance of the health risks associated with extreme heat. Thus, the positive adaptive trend of a vulnerable province does not mean that it will cease to be vulnerable. Instead, it suggests that it will not have greater vulnerability in the future than it does currently. Therefore, this concept of adaptation is not comparable to others found in the literature that are based on risks and percentiles (Azhar et al., 2017; Chen et al., 2016; Follos et al., 2020, 2021; López-Bueno et al., 2021; López-Bueno et al., 2021; Nayak et al., 2018; Reid et al., 2009; Wolf and McGregor, 2013).

With respect to the relationship between local factors and MMT, there were only five preselection variables that were significant (p-value

Table 3
Relationships between the dependent, explanatory and control variables in non-urban provinces.

NAM_MUN	MMT VAR	ADAPT LEVEL	ADAPT.	T_95	POP_65	POPULATION	INCOME	ECONOMIC RESOURCES	GOOD HOUSE	HOUSE LESS_50	REHAB. LICENSES	HEALTH EXPENDITURE	HEALTH PROFESSIONALS	AMBULANCES	HEALTH FACILITIES	MEDICAL FACILITIES
Albacete	0.04	−0.47	0	37	15.821	378,510	17092.6	0	0.95	0.81	6.60	5.66	2458	7.97	9.39	41.11
Almería	1.28	1.35	1	35.5	12.296	572,008	18254.7	0	0.93	0.89	5.45	22.20	3245	7.70	5.61	28.07
Asturias	0.33	0.15	1	27.6	18.958	1,111,002	19338.9	1	0.94	0.75	7.59	4.01	2056	4.17	6.47	13.97
Ávila	0.05	−0.35	0	33.2	21.441	175,868	17055.9	0	0.96	0.84	4.88	7.95	2115	9.25	13.14	200.68
Badajoz	0.65	0.36	1	39.7	15.861	683,126	14994.5	0	0.97	0.75	14.17	9.99	2705	18.04	8.34	24.87
Balears, Illes	1.07	0.74	1	32.6	13.683	905,868	24144.4	0	0.93	0.77	14.11	8.47	3030	3.27	5.20	9.57
Burgos	−0.06	−0.44	0	34	18.436	369,209	24312.1	0	0.94	0.82	5.69	8.62	2724	6.68	9.82	161.99
Cáceres	0.23	−0.11	0	38.4	18.03	421,494	15206.9	0	0.94	0.77	8.46	12.96	2287	25.55	12.70	60.06
Cantabria	0.79	0.51	1	27.5	16.755	565,552	20348.6	1	0.95	0.77	5.94	4.12	2725	5.32	7.06	20.65
Castellón	0.76	0.39	1	32.6	15.876	520,310	22645.6	0	0.94	0.84	6.57	11.96	2533	9.33	7.05	17.55
Ciudad Real	−0.28	−0.54	0	38.8	16.92	506,388	17864.8	0	0.95	0.79	5.59	5.48	2335	6.55	10.11	17.88
Córdoba	1.82	1.49	1	41.2	15.206	791,212	15432.8	0	0.95	0.80	10.11	4.54	2912	8.03	4.91	12.96
Coruña, A	0.83	0.48	1	26.2	17.762	1,142,966	19621.6	0	0.92	0.80	4.31	3.68	2753	3.43	11.83	3.71
Cuenca	0.13	−0.48	0	35.4	20.814	213,238	18048.6	0	0.94	0.79	5.22	13.19	1648	18.12	16.72	123.24
Girona	1.18	0.53	1	33.6	15.543	621,840	25561.2	1	0.95	0.83	17.66	21.22	2444	6.12	7.10	25.53
Granada	0.29	−0.13	0	38.4	14.337	865,718	15517.7	0	0.94	0.85	10.48	9.58	2555	6.70	5.65	30.81
Guadalajara	0.06	−0.30	0	38.2	16.418	196,456	18052.8	0	0.98	0.91	10.22	10.26	2479	9.10	12.04	170.58
Huelva	1.64	1.32	1	37.6	13.661	486,111	16738.6	0	0.93	0.81	7.48	4.46	2431	11.06	5.49	17.84
Huesca	0.03	−0.46	0	36.1	20.315	220,583	23820.8	1	0.95	0.79	12.01	13.01	2377	10.58	12.58	146.88
Jaén	0.61	0.10	1	37.6	15.437	666,812	15112.7	0	0.95	0.78	15.27	5.09	2594	10.52	6.21	23.49
León	0.18	−0.06	0	32.5	20.534	517,151	18426.1	0	0.94	0.78	3.38	5.22	2081	5.65	7.77	150.09
Lleida	0.57	0.31	1	36.8	17.854	395,467	26056.4	1	0.94	0.76	10.95	10.24	2515	9.49	7.72	62.73
Lugo	1.56	1.37	1	31	23.711	376,658	18616.1	0	0.92	0.75	7.80	5.04	2562	6.73	20.97	3.73
Navarra	−0.07	−0.51	0	35.6	16.092	585,513	26947.3	1	0.99	0.80	9.01	13.06	2485	5.28	8.92	38.54
Ourense	0.66	0.20	1	36.6	23.985	357,842	17316.8	0	0.94	0.77	7.14	7.58	2056	5.21	30.43	3.35
Palencia	−0.07	−0.35	0		19.525	182,273	22070.3	0	0.96	0.80	2.39	1.73	2306	7.13	11.77	182.48
Pontevedra	0.01	−0.09	0	32	15.834	943,735	18442.1	0	0.94	0.81	4.35	4.69	2326	3.87	9.16	2.21
Rioja, La	0.00	−0.41	0	36.4	17.111	294,031	23628.7	1	0.94	0.79	3.39	8.95	2726	5.87	6.35	55.90
Salamanca	0.07	−0.55	0	34.8	20.291	361,774	17754.8	0	0.94	0.88	2.07	13.66	2298	5.49	10.38	119.10
Segovia	0.10	−0.19	0	34.2	19.505	156,989	20500.2	0	0.94	0.79	6.90	13.07	2409	7.78	10.06	179.74
Soria	−0.09	−0.37	0	34	22.545	96,500	21705.8	0	0.95	0.84	5.11	21.96	2130	11.14	15.10	371.13
Tarragona	0.49	0.11	1	35.3	15.613	667,588	26198.5	1	0.88	0.85	13.42	17.12	2155	8.06	6.94	21.70
Teruel	0.06	−0.36	0	35.5	22.168	146,201	22603.5	0	0.95	0.75	13.11	17.69	1940	15.87	19.79	187.33
Toledo	0.61	0.20	1	38.9	16.281	589,771	16656.8	0	0.96	0.87	4.93	6.44	2885	6.66	7.00	28.60
Valladolid	−0.80	−0.98	0	35.9	15.635	521,675	22,126	1	0.97	0.87	2.48	6.84	2889	3.63	7.80	43.57
Zamora	0.05	−0.44	0	35.6	23.908	208,554	16869.2	0	0.95	0.82	4.18	10.36	1639	9.52	11.57	216.10

<0.05) from among all of the candidate variables in the study in the non-urban zones. This suggests that, similar to other studies, demographic factors (Miron et al., 2008), socioeconomic factors (Chung et al., 2018) and infrastructure factors related to public health are related to MMT (Cao et al., 2021), at least in non-urban regions.

On the other hand, in terms of the final model for urban zones, the results were related to economic resources and temperatures situated in the 95th percentile. This suggests that, the greater the number of privileged provinces, and with higher temperatures, the greater the increase in MMT.

People with lower levels of resources may have more difficulties in acclimatizing their housing via air conditioning systems, or they may not even have access to such systems, or have incomes that are insufficient to meet energy consumption needs (Bakhsh et al., 2018). It is also possible that their homes could be more likely to overheat in the absence of air conditioning, due to lower quality construction and insulation (WHO Regional Office for Europe, 2021). The level of deprivation determines vulnerability to heat, which is a further risk in experiencing increases in mortality specifically associated with extreme temperatures (López-Bueno et al., 2021). Along these lines, a prospective study linked changes in vulnerability to heat to different European socioeconomic scenarios. According to the authors, socioeconomic conditions will determine the level of adaptation of each population (Rohat et al., 2019).

The association found for the 95th percentile coincides with what has been reported in the literature. Prior studies have found that greater exposure tends to be associated with lower risks and vulnerability associated with heat waves (Curriero et al., 2002). This is to say that the risks are greater in the cooler zones, which are therefore less habituated to the heat.

Considering that MMT is a measure of adaptation to heat (Folkerts et al., 2020; Follos et al., 2020, 2021; López-Bueno et al., 2021a,b,c; Yin et al., 2019), it should be considered in relation to the increase in environmental temperatures. If the rate of evolution of MMT is greater than the increase in the average maximum daily temperatures in the same time period, the population would be adapting, presumably via a mix of acclimatization, self-adaptation of the population and adaptation dictated by institutions. The zones with a tendency of increasing MMT have more possibilities to adapt. This supposes that the consequences of the impact of heat on health related to extreme heat tend to be lesser (Follos et al., 2021). The group of different elements and factors that explain the process of adaptation to heat of the population in areas with higher temperatures is known as the "culture of heat" (Bobb et al., 2014).

In the final model of non-urban zones, the quality of housing was related to the level of health resources in terms of health personnel. A greater number of rehabilitated dwellings and a greater proportion of health professionals in primary care resulted in better adaptation to heat.

Health professionals in this study were made up of family doctors and nurses in the area of primary care. In the health care context, primary care nurses contribute to reducing mortality among certain groups of patients (Laurant et al., 2018) as well as decreasing social inequalities in health (Poghosyan and Carthon, 2017). Thus, family doctors allow for reductions in the use of hospital services (Fung et al., 2015) and facilitate better health for their patients (Bataineh et al., 2019). In consequence, an increase in the ratio of primary care health professionals is a protective factor.

There are different studies that highlight the importance of housing as a protective element against mortality associated with extreme heat (López-Bueno et al., 2019; López-Bueno et al., 2021; Taylor et al., 2015). Housing characteristics, such as the age of the dwelling (López-Bueno et al., 2019), the lack of insulation, the number of windows and the number of hours with sunshine, among others, determine the capacity for mitigation (Zuo et al., 2015). In Spain more than half of dwellings were built prior to the 1980's, and as such are older and poorly insulated (Cuerdo-Vilches & Navas-Martín, 2021). The design of efficient dwellings and rehabilitation of housing could reduce the effects of heat (Ramakrishnan et al., 2017). Thus, there are numerous recommendations that aim towards improvements in buildings, from changes in roofing to cool roofs (Mahadevia et al., 2020) and painting walls with light colors for solar protection to improvements in the insulation of external walls (Porritt et al., 2011, 2012).

This study presents various limitations. On one hand, as an ecological study, its conclusions are valid only at the population level (Neuman, 2014). Nor have data on air pollution been considered, given the lack of high quality, provincial level data.

Another limitation relates to the concept of rurality used. There is currently no clear consensus or definition. There are different classification criteria based on territory, informed by demographic dimensions, services or infrastructure (López-Bueno et al., 2021).

The data were aggregated and analyzed at an intermediate level (provinces). However, provinces are not homogeneous population groups in terms of socioeconomic status, types of population or lifestyles. Therefore, it is important to consider that the results obtained here could mask the behavior of different subpopulations that live within a province. Further study of specific populations is therefore needed to help designate relatively homogenous zones based on environment, climate and meteorology, as well as in terms of the social, economic, cultural, demographic and urban structure of the population. Population studies based on non-administrative sample units described here would facilitate obtaining results that show greater consistency.

These results provide an interesting, exploratory approximation, however, the development of concrete measures and specific recommendations in public health requires the development of studies at a level smaller than the province level. This would provide more detailed results based on more homogenous population units.

5. Conclusions

This study suggests that urban provinces in Spain have better adapted to heat than non-urban provinces. Furthermore, in urban areas the increase in MMT was conditioned by the population living in more privileged areas with greater economic resources and by temperatures in the 95th percentile. In rural zones, it was related to a greater number of health personnel and rehabilitated housing. Therefore, socioeconomic and climatological factors, together with public health policies, conditioned adaptation; the greater the increase in MMT, the greater the possibilities of adaptation, given that increasing temperatures is generalized in Spain (Aemet, 2020).

Therefore, it is necessary to carry out studies that identify those factors that are the most relevant and influential in the population's adaptation with respect to MMT (Folkerts et al., 2020), considering the heterogeneity of each zone. This would permit an approach to heat prevention plans at the local level, as suggested by various authors (Bakhsh et al., 2018; Follos et al., 2021; Oudin Åström et al., 2020; Rodrigues et al., 2021; Sánchez Martinez et al., 2011).

Disclaimer

The researchers declare that they have no conflict of interest that would compromise the independence of this research work. The views expressed by the authors do not necessarily coincide with those of the institutions they are affiliated with.

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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