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Relationship between Non-Optimal Air Temperature and Mortality Risk in Italy using High-Resolution Data: A Case Time Series Analysis

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INTRODUCTION

Non-optimal air temperature has been associated with an increased mortality [1]. The relationship is usually inverse J-shaped, with higher risk at more extreme temperatures [2]. Nonetheless, estimates of excess mortality due to non-optimal temperature exhibit marked geographical heterogeneity [3]. This variability depends on a range of individual- and area-level determinants, including socioeconomic, demographic, and environmental factors [4]. Characterizing such variability is crucial to trace differences in health impacts and identify hotspot areas [5]. Limitations in this research area include the availability of relevant data and their spatial and temporal resolution as well as study design and statistical methods [6]. Previous studies investigating the association between air temperature and mortality risk have mainly relied on aggregated data at a broad spatial scale [7-9]. The growing availability of environmental high-resolution data (i.e., small-area level) together with advancements in record linkage procedures and computation capability enables the investigation of health risks at a finer spatial level [10].

The case time series (CTS) design, originally developed for spatial analysis, has been recently adapted to handle spatio-temporal data collected longitudinally [11, 12]. The CTS method allows the analysis of high-resolution data to identify small-scale risk patterns across the whole geographical domain [13].

OBJECTIVES

We investigated the association between non-optimal air temperature and all-cause mortality across Italian municipalities, using high-resolution satellite data.

METHODS

We conducted a CTS analysis using an adaptation of the two-stage design to model country-wide small-area data. We collected time series daily data on all-cause mortality and temperature for 7895 Italian municipalities between Jan 1, 2011, and Aug 31, 2024. Deaths were provided by the Italian National Institute of Statistics. Daily mean temperatures on a 1x1 km grid across Italy were extracted from Copernicus Satellite Data. We derived the corresponding municipal-specific daily temperature series by computing the area-weighted average of the temperatures of all grid cells intersecting the municipal boundaries, with weights proportional to the intersection areas. We also collected several municipal-area variables that are potentially linked with differential vulnerability to extreme temperatures. These variables comprised demographic (e.g., proportion of population aged 65+ years and population density), socioeconomic (e.g., income, employment, education, motorization and recycling), landscape (altitude, surface imperviousness degree, normalized difference vegetation index, land cover), and climatological (average annual range of temperature) characteristics. We aggregated municipal-area variables at the province level using population-weighted averages. A principal component (PC) analysis was conducted, and the extracted PCs were used as composite indicators of temperature vulnerability to assess geographical risk differences.

We estimated the association between non-optimal air temperature and all-cause mortality across municipal areas using a two-stage analysis followed by a downscaling procedure. In the first stage, we applied the CTS design, modeling municipal-specific series within each province through a conditional Poisson regression. Four distinct models were fitted for the following age groups: 0-64, 65-75, 75-84, and 85+

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years. First-stage models included terms to flexibly control for long-term and seasonal trends at both municipal and province levels, and indicators for day of week. Temperature-mortality associations were modelled through a distributed lag non-linear model (lag window: 0-21 days), a technique to estimate complex non-linear and lagged dependencies [14]. In the second stage, we cumulated the risk over the lag dimension to obtain the overall temperature-mortality association. Then, we pooled the estimated coefficients for each age group and each province using a multivariate repeated-measure meta-regression. The second-stage model included age and the PCs as meta-predictors to explain variations across provinces.

As a final step, we used the meta-analytical model to downscale risks at municipal-area level. We derived the minimum mortality temperature (MMT) and the MMT-related percentile (MMP) from municipal-specific temperature-mortality curves. We summarized the risk for heat and cold by computing relative risks (RR) and related 95% confidence intervals (CI) at, respectively, the 99th and 1st temperature percentile versus the MMP. We derived a measure of effect of heat and cold by estimating the age-specific excess mortality attributable to non-optimal temperature as well as the standardized rate of excess all-cause mortality and related 95% CI using Monte Carlo simulations.

RESULTS

In Italy, 8938346 deaths occurred in the study period, approximately 653900 per year. Non-optimal temperature was associated with an annual mean excess of deaths of 9502 (95% CI: 7791-10881) and 85535 (95% CI: 75602-94814) each year in Italy attributable to heat and cold, respectively (Table 1). The corresponding standardized excess all-cause mortality rates (deaths per 100,000 person-years) were 12.3 (95% CI: 11.1-13.1) for heat and 110.9 (95% CI: 104.1-117.2) for cold. With regards of Italian regions, we observed slightly higher heat-related standardized excess all-cause mortality rates in the Southern.

CONCLUSIONS

We provide a comprehensive assessment of excess mortality related to non-optimal temperature in Italy, accounting for several determinants of temperature vulnerability. This work also provides a detailed risk map that could be useful for designing effective climate and public health policies at both local and national levels.

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Table 1. Annual excess deaths and standardized excess all-cause mortality rate and corresponding 95% confidence interval attributable to non-optimal temperature by Italian regions in the period Jan 1, 2011 – Aug 31, 2024

Region	**Annual excess deaths (95% CI)**		**Standardized excess all-cause mortality rate (95% CI)**[a]	
	Cold	**Heat**	**Cold**	**Heat**
Piemonte	6790 (6062-7514)	562 (483-636)	107.8 (98.5-116.9)	8.7 (7.8-9.5)
Valle d'Aosta	194 (142-244)	26 (4-44)	115.1 (82.6-145.3)	18.2 (2.6-30.6)
Lombardia	15321 (13204-17084)	971 (636-1110)	121.3 (105.4-133.3)	7.5 (5.4-8.3)
Trentino-Alto Adige	1438 (1252-1614)	76 (41-104)	112.0 (99.0-123.9)	6.1 (3.7-8.0)
Veneto	6644 (6018-7271)	582 (496-662)	105.3 (98.1-112.6)	9.1 (8.0-10.0)
Friuli-Venezia Giulia	1903 (1645-2138)	210 (162-251)	105.1 (92.1-116.0)	11.6 (9.0-13.6)
Liguria	2455 (1938-2941)	353 (247-445)	91.5 (72.4-109.2)	13.3 (9.4-16.6)
Emilia-Romagna	6350 (5635-7062)	555 (458-646)	99.0 (89.3-108.1)	8.3 (7.1-9.4)
Toscana	5299 (4726-5873)	691 (586-781)	95.0 (86.5-102.4)	12.2 (10.5-13.6)
Umbria	1242 (1121-1366)	141 (122-161)	91.4 (85.0-98.8)	10.1 (9.0-11.1)
Marche	2143 (1928-2352)	264 (222-304)	93.0 (85.4-100.1)	11.2 (9.7-12.6)
Lazio	7183 (6314-7960)	978 (852-1096)	102.6 (93.8-109.7)	13.8 (12.6-15.1)
Abruzzo	1935 (1782-2086)	231 (203-257)	106.5 (101.0-111.8)	12.5 (11.5-13.6)
Molise	493 (447-538)	73 (65-82)	109.6 (101.2-117.0)	16.3 (14.8-17.8)
Campania	7581 (6580-8496)	1096 (890-1287)	134.8 (119.6-149.1)	19.4 (16.2-22.4)
Puglia	5093 (4604-5575)	848 (736-942)	106.7 (98.5-115.1)	17.9 (16.2-19.4)
Basilicata	827 (750-904)	132 (117-146)	110.0 (101.4-117.8)	17.5 (16.0-19.0)
Calabria	2762 (2519-3007)	369 (322-413)	119.2 (111.3-127.3)	16.0 (14.5-17.5)
Sicilia	7545 (6873-8186)	1074 (929-1198)	133.4 (124.4-142.7)	19.1 (16.9-20.7)
Sardegna	2337 (2062-2603)	270 (220-316)	112.5 (101.0-123.4)	13.1 (11.1-14.8)
Italy	85535 (75602-94814)	9502 (7791-10881)	110.9 (104.1-117.2)	12.3 (11.1-13.1)

[a] Deaths per 100000 person-years

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