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Air temperature-related human health outcomes: Current impact and estimations of future risks in Central Italy

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HIGHLIGHTS

► We have evidenced contrasting temperature-impact patterns between mortality and hospitalizations.
► We have examined geographical differences in temperature-related human health outcomes.
► Predictions of future city-specific impact of climate change on human health have been provided.
► A slight unexpected increase of short-term cold-related mortality in the very elderly is predicted in several cities.
► General increases of annual temperature-related mortality rates are expected, highest values will be in coastal plain cities.

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ABSTRACT

The association between air temperature and human health is described in detail in a large amount of literature. However, scientific publications estimating how climate change will affect the population's health are much less extensive. In this study current evaluations and future predictions of the impact of temperature on human health in different geographical areas have been carried out. Non-accidental mortality and hospitalizations, and daily average air temperatures have been obtained for the 1999–2008 period for the ten main cities in Tuscany (Central Italy). High-resolution city-specific climatologic A1B scenarios centered on 2020 and 2040 have been assessed. Generalized additive and distributed lag models have been used to identify the relationships between temperature and health outcomes stratified by age: general adults (<65), elderly (aged 65–74) and very elderly (≥75). The cumulative impact (over a lag-period of 30 days) of the effects of cold and especially heat, was mainly significant for mortality in the very elderly, with a higher impact on coastal plain than inland cities: 1 °C decrease/increase in temperature below/above the threshold was associated with a 2.27% (95% CI: 0.17–4.93) and 15.97% (95% CI: 7.43–24.51) change in mortality respectively in the coastal plain cities. A slight unexpected increase in short-term cold-related mortality in the very elderly, with respect to the baseline period, is predicted for the following years in half of the cities considered. Most cities also showed an extensive predicted increase in short-term heat-related mortality and a general increase in the annual temperature-related elderly mortality rate. These findings should encourage efforts to implement adaptation actions conducive to policy-making decisions, especially for planning short- and long-term health intervention strategies and mitigation aimed at preventing and minimizing the consequences of climate change on human health.

1. Introduction

The association between air temperature and human health has been demonstrated in many parts of the world and is described in detail in numerous recent reviews (Conlon et al., 2011; Kovats and Hajat, 2008; Ye et al., 2012; Yu et al., 2011). Commonly, immediate or very

Abbreviations: GAMs, Generalized Additive Models; IPCC, Intergovernmental Panel on Climate Change; HadRM3P, Hadley Centre Regional Model version 3P; ICD, International Classification of Diseases.

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short time scale impact, especially on mortality events, has been observed for high temperatures (Morabito et al., 2012; Muggeo and Hajat, 2009). Conversely, cold weather generally showed a delayed health effect up to several weeks (Analitis et al., 2008; Armstrong, 2006; Muggeo and Hajat, 2009). However, exceptions have recently been described and hospitalizations for specific types of diseases showed an evident immediate cold effect (Morabito et al., 2011).

Several studies showed a greater impact of temperature on mortality than on hospitalizations, especially when extremely high values were reached, with clearly contrasting patterns (Kovats et al., 2004; Linares and Díaz, 2008; Mastrangelo et al., 2006). Generally, U-, V-, or J-shaped relationships have been described (Armstrong, 2006; Iñiguez et al., 2010; McMichael et al., 2008; Ye et al., 2012) and specific temperature thresholds (or optimum temperatures), initially calculated to recognize the minimum mortality level (Kalkstein and Davis, 1989), have been assessed in many cities worldwide. Only a few studies have tried to identify clear temperature thresholds for morbidity events (Kovats et al., 2004; Lin et al., 2009). Starting from these city-specific optimum temperatures, the mortality/morbidity begins to rise with a slope depending on geographical location. The temperature–mortality/morbidity relationship varies greatly depending on latitude, climatic zone and demographic characteristics, showing the worst impact on the elderly population because mostly susceptible to temperature changes (Hajat et al., 2007). Several studies also demonstrated that people living in warmer cities are more affected by lower temperatures and, conversely, people in colder cities suffer from warmer temperatures (Iñiguez et al., 2010; Keatinge et al., 2000a; The Eurowinter Group, 1997). All this information assumes great significance in terms of public health, especially in the light of future climate-change projections provided by climatic scenarios, currently adopted by the community research of climatologists. Since the Intergovernmental Panel on Climate Change (IPCC) indicated that the world average temperature would continue to increase (IPCC, 2007), and because a continuous growth of the elderly population and consequently of the fraction of frail elderly, is expected mainly in industrialized countries (United Nations, Department of Economic and Social Affairs, Population Division, 2011), great attention should be paid to the risk estimation of the potential impact of climate change on human health.

Nowadays, scientific publications estimating how climate change will affect the population's health are much less extensive (McMichael et al., 2006). Since most temperate industrialized countries show a typical seasonal mortality with a winter peak, it has been hypothesized that future winters predicted to be milder should reduce the mortality risk due to cold weather (Langford and Bentham, 1995). On the other hand, as reported in a detailed critical review (Gosling et al., 2009), an increase in heat stress and heat-related mortality, especially among the elderly, is also predicted under different climatologic scenarios. However, at the moment, there is still discrepancy and uncertainty in evaluating the magnitude of these changes and an accurate estimation of the burden of the annual temperature-related mortality will help better understand the potential impact of climate change on human health.

For these reasons, three main issues have been investigated in this study: 1) current quantitative evaluations of the impact of air temperature on two significant health outcomes that were carried out over a 10-year period (1999–2008): non-accidental mortality and hospitalizations; 2) investigations of regional geographical differences of the relationship between temperature and human health; 3) predictions of future city-specific impact of climate change on human health.

For this purpose, generalized additive models (GAMs) and distributed lag models were used to account for the non-linear effect of temperature and to quantify the immediate/delayed health effects of exposure to both cold and heat. Subsequently, high-resolution city-specific climatologic scenarios for two 20-year periods centered on 2020 and 2040, produced by the Hadley Centre Regional Model version 3P (HadRM3P) simulations, were used to predict city-specific short-term changes in temperature-related annual mortality rates for the following near (2011–2030) and distant (2031–2050) 20-year periods.

2. Material and methods

2.1. Health outcome data and study area

The study was carried out over an area of approximately 23 km^2 located in Central Italy (Tuscany) which had approximately 3.7 million inhabitants in 2008. Health outcome data comprised residents of the 10 major cities in Tuscany who died or were hospitalized for non-accidental causes in the cities between 1999 and 2008. Non-accidental mortality and hospital admission data (ICD9 $<$ 800) were provided by the Mortality Registry and the Hospitalization Registry of the Tuscany Region.

The geographical locations of the 10 cities were used to classify them in three city-specific homogeneous areas in climatic and altitudinal terms (See Supplementary material, online Fig. 1): a) Inland plain, which includes the cities of Florence, Prato, Pistoia and Lucca, at an average altitude and distance from the Tyrrhenian Sea of about 50 m a.s.l. and 55 km respectively. The average urban population density for the 10-year period studied was about 1550 inhabitants per km^2. The percentages of elderly (aged 65–74) and very elderly ($\geq$75) population were 11.6% and 11.5% respectively, while the old age index, that is a measure of the relationship between the population over the age of 65 divided by the population under the age of 15 (values higher than 100 indicate more elderly people than the young ones), was 177.0. b) Coastal plain, which comprises the cities of Massa-Carrara, Livorno, Pisa and Grosseto, at an average altitude and distance from the Tyrrhenian Sea of about 20 m a.s.l. and 7 km respectively. The average urban population density was about 910 inhabitants per km^2. The percentages of elderly and very elderly population were 11.4% and 10.7% respectively, while the old age index was 205.0. c) Inland hill, which includes the cities of Siena and Arezzo, at an average altitude and distance from the Tyrrhenian Sea of 310 m a.s.l. and 89 km respectively. The average urban population density was about 349 inhabitants per km^2. The percentages of elderly and very elderly population were 12.2% and 12.7% respectively, while the old age index was 199.2.

Additionally, for the period under study, the average percentage of people older than 64 years accounted for as much as 58% of all people living alone in Tuscany. Furthermore, only 15.2% of families held a domestic air conditioner; on the other hand, 96.2% of families held a heating system (source: the Italian National Institute of Statistics http://sitis.istat.it/sitis/html/).

With regard to the climate features of the areas studied, July and August represent the warmest months in all the geographical areas investigated, while the coldest months are December and January. The inland plains/hills are characterized by the highest/lowest temperatures respectively. Inland cities experienced the highest number of freezing days during winter, especially in rural areas. Furthermore, the daily temperature range is high, especially in the inland hill cities and during the warmest months. Conversely, coastal plain cities are generally characterized by a milder climate due to the influence of the sea, and also show the lowest daily temperature range with rare extreme temperatures.

2.2. Meteorological data

For each of the 10 cities in Tuscany, the daily average air temperature dataset was provided for the 1999–2008 period by means of the Daymet procedure (Thornton et al., 1997). Daymet is a software package that produces daily meteorological data over large regions, taking into account the effects of terrain morphology. Meteorological observations can be included from an arbitrarily large number of stations that are used to fit a locally calibrated relationship of temperature