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The association between ambient temperature and mortality in South Africa: A time-series analysis

Noah Scovronick[a,*], Francesco Sera[b], Fiorella Acquaotta[c], Diego Garzena[c], Simona Fratianni[c], Caradee Y. Wright[d], Antonio Gasparrini[b]

[a] *Woodrow Wilson School, Princeton University, Princeton, NJ 08544, USA*
[b] *Department of Social and Environmental Health Research, London School of Hygiene and Tropical Medicine, London WC1H 9SH, UK*
[c] *Department of Earth Sciences, University of Turin, Turin 10124, Italy*
[d] *Environment and Health Research Unit, South African Medical Research Council and Department of Geography, Geoinformatics and Meteorology, University of Pretoria, Pretoria 0001, South Africa*

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ABSTRACT

Background: There is an extensive literature describing temperature-mortality associations in developed regions, but research from developing countries, and Africa in particular, is limited.
Methods: We conducted a time-series analysis using daily temperature data and a national dataset of all 8.8 million recorded deaths in South Africa between 1997 and 2013. Mortality and temperature data were linked at the district municipality level and relationships were estimated with a distributed lag non-linear model with 21 days of lag, and pooled in a multivariate meta-analysis.
Results: We found an association between daily maximum temperature and mortality. The relative risk for all-age all-cause mortality on very cold and hot days (1st and 99th percentile of the temperature distribution) was 1.14 (1.10,1.17) and 1.06 (1.03,1.09), respectively, when compared to the minimum mortality temperature. This “U” shaped relationship was evident for every age and cause group investigated, except among 25–44 year olds. The strongest associations were in the youngest (< 5) and oldest (> 64) age groups and for cardiorespiratory causes. Heat effects occurred immediately after exposure but diminished quickly whereas cold effects were delayed but persistent. Overall, 3.4% of deaths (~ 290,000) in South Africa were attributable to non-optimum temperatures over the study period. We also present results for the 52 district municipalities individually.
Conclusions: An assessment of the largest-ever dataset for analyzing temperature-mortality associations in (South) Africa indicates mortality burdens associated with cold and heat, and identifies the young and elderly as particularly vulnerable.

1. Introduction

There is an extensive literature describing temperature-mortality associations in developed regions, but research from developing countries, and Africa in particular, is limited (Basu, 2009; Benmarhnia et al., 2015; Gasparrini et al., 2015b; Ryti et al., 2016). Furthermore, the few studies from Africa report results for only one or a few cities and over relatively short time periods (Azongo et al., 2012; Diboulo et al., 2012; Egondi et al., 2012; McMichael et al., 2008; Wichmann, 2017).

There are several reasons that the relationship between ambient temperature and mortality in Africa may differ when compared to wealthier regions. Populations often have distinct mortality profiles (cause/age of death) and age distributions, while climatic factors may also differ. Additionally, large segments of the population live in dwellings that do not adequately protect against heat and cold (Makaka and Meyer, 2006; Scovronick and Armstrong, 2012; United Nations Human Settlements Programme, 2011). All of these factors are known or putative modifiers of the effect of temperature on mortality (Basu, 2009; Benmarhnia et al., 2015; Ryti et al., 2016; Scovronick and Armstrong, 2012).

The urgency to better understand temperature-health relationships in developing regions is heightened when considering the near-term opportunities for intervention; rapid rates of economic development and demographic change, combined with explicit government programs aimed at infrastructure upgrading and poverty alleviation may all affect vulnerability to ambient temperature. Examples in South

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* Correspondence to: Princeton University, 411a Robertson Hall, Princeton, NJ 08544, USA.
E-mail address: Noah.Scovronick@princeton.edu (N. Scovronick).

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Africa include government programs to help provide ~ 1.5 million homes to low-income households over the coming years as well as household energy and water supply projects (Department of Energy (Republic of South Africa), 2015; Department of Human Settlements (Republic of South Africa), 2016; Department of Water and Sanitation (Republic of South Africa), 2014).

The shortage of information on how temperature affects health in South Africa is of extra concern in the context of climate change. Mean warming has increased at least 50% faster in South Africa compared to the global average and (like for much of the continent) this trend is expected to continue (Niang et al., 2014; Ziervogel et al., 2014). As a result, there is strong consensus that adaptation will be key to protect populations in Africa from future climate impacts and that early action is needed (Niang et al., 2014; Schaeffer et al., 2013). However, the Intergovernmental Panel on Climate Change, along with independent researchers and the South African government have all pointed to a lack of research on climate- and weather-health relationships as a barrier to climate-informed decision-making (Government of the Republic of South Africa, 2011; Niang et al., 2014; Smith et al., 2014; Wright et al., 2014; Ziervogel et al., 2014).

Accordingly, in this study we analyze the association of temperature and mortality in South Africa using a national dataset that includes all 8.8 million recorded deaths between 1997 and 2013. This is the first study to employ such a large-scale dataset from anywhere in Africa, and to our knowledge no comparable study exists from any country at a similar level of economic development.

2. Methods

We conducted a time-series regression analysis of the temperature-mortality relationship in South Africa using a national mortality dataset and two independent sources of temperature data.

2.1. Mortality dataset

We obtained a dataset of all recorded deaths ($n = 8,814,625$) in South Africa from 1997 to 2013, inclusive (17 years). The information is from the country's civil registration system, the only national source of mortality statistics. The dataset was provided by Statistics South Africa, which estimates that death registration for adults is ~ 89% complete early in the study period, rising to ~ 94% by the end (completeness of child records has not been reported) (Statistics South Africa, 2014a, 2014b). Anonymized individual data reported where each death occurred at the level of the district municipality (there are 52 in South Africa and we refer to them hereafter as “districts”). District sizes range from relatively small urban areas to much larger areas located in the more unpopulated regions of the country (Fig. 1). In addition to death district, individual data included cause and age of death. Data on district of residence was not available.

After dropping records for stillbirths ($n = 226,593$), deaths with incomplete district information ($n = 82,154$) and with an incorrect (nonsensical) date of death ($n = 49$), the final all-cause, all-age dataset consisted of 8,509,130 records. The number of all-age all-cause deaths for each district can be found in Table S1 of the Supplementary material.

2.2. Temperature dataset

We obtained daily minimum and maximum temperature data from two sources: the National Oceanographic and Atmospheric Association (NOAA) of the United States and South Africa's Agricultural Research Council. The NOAA dataset included 63 daily series covering a subset of 30 districts, while the Agricultural Research Council dataset included 50 series, one for each district except the City of Johannesburg and Nelson Mandela Bay. There was no overlap in measurement points (stations) between the two sources.

We carried out a three-step quality control procedure on all temperature series from both sources to exclude values resulting from either erroneous transcription or instrument malfunction (Aguilar et al., 2003; Alexander and Herold, 2016; Perkins et al., 2012; Zhang et al., 2011). First, we removed records where the maximum temperature was lower than the minimum. Second, we compared every series with corresponding data from two or more nearby weather stations, selected for proximity and data correlation with the reference series (Milewska and Vincent, 2016; Venema et al., 2012). If the reference series recorded an outlier (values above/below the 90th/10th percentiles), that outlier was removed if the difference with the comparison series was ± two root root-mean-square errors. The root-mean-square error between the reference and comparison series was calculated daily. Additionally, we removed all duplicate sets – defined as periods with at least five consecutive days recording the same temperature. And third, for series exhibiting a break in recording or where metadata indicated a change or relocation of the instrument, the series was tested for homogeneity and corrected if necessary (Fortin et al., 2016; Wang and Feng, 2010; Wang, 2008a, 2008b; Wang et al., 2010, 2007). Only one district (Buffalo City) required an adjustment.

After the quality control procedure, we assembled a final composite dataset consisting of one representative station for each district (Fig. 1), selected for the length of the series and fewest missing data points. In the first year of the study period, there was temperature data available for 29 districts, rising to cover all 52 by 2007 (Fig. S1). For each series in the final dataset, we reconstructed missing data if the data gap was less than or equal to six days in length, using information from the nearby comparison stations (Acquaotta et al., 2009, 2016; Eischeid et al., 2000).

Overall, seven percent of values were reconstructed for the daily maximum and 12% for the daily minimum temperature. Due to the higher number of missing values and because improper instrument management generally has a greater impact on minimum temperature recordings (Acquaotta et al., 2015; Caussinus and Mestre, 2004; Nigrelli et al., 2015; Rangwala and Miller, 2012; Trewin, 2010; Vincent et al., 2009), all subsequent analyses in this paper use the daily maximum temperature.

2.3. Statistical approach

We applied a two-stage time-series modeling strategy, described in several recent methodological papers and previously applied in both multi-city and multi-country contexts, thus allowing for consistency and comparability between studies (Gasparrini, 2011; Gasparrini et al., 2012, 2015a, 2016, 2015b). We briefly describe the modeling stages below and also refer readers to these prior publications for more details (Gasparrini, 2011; Gasparrini et al., 2012, 2015a, 2016, 2015b).

In the first stage, we applied standard time-series quasi-Poisson regression models separately for each district to derive estimates of location-specific temperature-mortality associations. For this step, we modeled the exposure-response association with a natural cubic spline with three internal knots at the 10th, 75th and 90th percentiles of location-specific temperature and the lag-response association using a natural cubic spline with an intercept and three knots equally spaced on the log scale. We controlled for season and trend with a natural cubic spline with eight degrees of freedom per year and also for day of the week.

In the second stage, we reduced the association in two dimensions: first to the overall temperature-mortality association, cumulating the risk over a 21-day lag period to account for the delayed effects of cold and for potential short-term mortality displacement; then to the lag-response associations corresponding to the 99th and 1st percentiles using the district-specific minimum mortality temperature (MMT) as a reference. We pooled the estimated location-specific estimates using a multivariate meta-analytical model, controlling for location-specific average (maximum) temperature and temperature range. The fitted