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Projecting future summer mortality due to ambient ozone concentration and temperature changes

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HIGHLIGHTS

- Future mortality was predicted considering temperature and ozone level changes.
- Prediction of temperature and ozone level was conducted under four RCP scenarios.
- Exposure and response relationships were modeled by using DLNM method.
- Temperature-related mortality in the future is higher than ozone-related mortality.

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ABSTRACT

Climate change is known to affect the human health both directly by increased heat stress and indirectly by altering environments, particularly by altering the rate of ambient ozone formation in the atmosphere. Thus, the risks of climate change may be underestimated if the effects of both future temperature and ambient ozone concentrations are not considered. This study presents a projection of future summer non-accidental mortality in seven major cities of South Korea during the 2020s (2016–2025) and 2050s (2046–2055) considering changes in temperature and ozone concentration, which were predicted by using the HadGEM3-RA model and Integrated Climate and Air Quality Modeling System, respectively. Four Representative Concentration Pathway (RCP) scenarios (RCP 2.6, 4.5, 6.0, and 8.5) were considered. The result shows that non-accidental summer mortality will increase by 0.5%, 0.0%, 0.4%, and 0.4% in the 2020s, 1.9%, 1.5%, 1.2%, and 4.4% in the 2050s due to temperature change compared to the baseline mortality during 2001–2010, under RCP 2.6, 4.5, 6.0, and 8.5, respectively, whereas the mortality will increase by 0.0%, 0.5%, 0.0%, and 0.5% in the 2020s, and 0.2%, 0.2%, 0.4%, and 0.6% in the 2050s due to ozone concentration change. The projection result shows that the future summer morality in South Korea is increased due to changes in both temperature and ozone, and the magnitude of ozone-related increase is much smaller than that of temperature-related increase, especially in the 2050s.

1. Introduction

Climate change can affect the human health through elevated concentrations of near-surface ozone. Because ozone forms mainly through secondary photochemical reactions in the atmosphere, elevated temperature due to climate change results in faster depletion of the ozone precursors, thereby increasing near-surface ozone concentration (Dawson et al., 2007; Lee et al., 2015). Previous studies have predicted future ozone-related health effects in terms of mortality or number of emergency room visits in Europe and the US (Bell et al., 2007; Chang et al., 2014; Heal et al., 2013; Knowlton et al., 2004; Lei et al., 2012; Madaniyazi et al., 2015; Orru et al., 2013; Post et al., 2012; Tagaris et al., 2009). According to a survey on previous studies, ozone-related mortality and morbidity increase or decrease depending on the location of study. For example, Orru et al. (2013) reported that ozone-related mortality and morbidity are projected to increase for Belgium, France, Spain, and Portugal in the future periods (2021–2050 and 2041–2060) while

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they will decrease for Nordic and Baltic countries.

Furthermore, increased temperature stress is another factor of climate change affecting human health. Many previous studies have investigated the effect of changes in temperature and demonstrated that mortality and morbidity are expected to increase due to increased heat stress (Baccini et al., 2011; Peng et al., 2011; Gosling et al., 2009; Jackson et al., 2010; Li et al., 2015).

Other studies showed that mortality and morbidity will increase in summer but decrease in winter (Ballester et al., 2011; Cheng et al., 2008; Doyon et al., 2008; Guo et al., 2016; Hayashi et al., 2010; Huang et al., 2012; IPCC, 2007; Lee and Kim, 2016; Li et al., 2013; Martin et al., 2012). As a result, the increase in summer typically offsets the decrease in winter, and the net effect of the climate change depends on the location of study. For example, Guo et al. (2016) reported that temperature-related deaths are expected to increase in Brisbane and Sydney, but decrease in Melbourne due to the climate change. Martin et al. (2012) reported that among 15 Canadian cities investigated, temperature-related mortality will increase in 4 cities but decrease in the other 11 cities.

This study estimated future summer mortality in seven major cities of South Korea under four RCP scenarios (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) considering changes in temperature and near-surface ozone concentration. For the estimation of future temperature and surface ozone concentration, we used the HadGEM3-RA model and Integrated Climate and Air Quality Modeling System, respectively.

This study is meaningful in three aspects. First, this is the first study to estimate temperature-related and ozone-related effects of climate change simultaneously under RCP scenarios. In this manner, we can not only estimate future mortality more comprehensively, but also compare the magnitudes of those two effects. Second, it is the first study to estimate ozone-related future mortality among Asian countries at the city level, making it valuable for policy and decision making. Lastly, this study applied recently developed distributed lag nonlinear models (DLNM) (Gasparrini et al., 2010) to extract exposure-mortality relationships. DLNM can accurately model the nonlinear relationship between near-surface ozone and mortality and between temperature and mortality with lagged dependencies. The exposure and response relationships could be modeled more accurately using the DLNM compared to other linear models or nonlinear but single lag models widely used in previous studies.

2. Methods

2.1. Data collection

Daily maximum 8-h (DM8H) near-surface ozone concentration and daily mean temperature data for seven major cities (Seoul, Busan, Daegu, Incheon, Gwangju, Daejeon, and Ulsan) in South Korea during 2001–2010 were obtained from the National Institute of Environmental Research and Korea Meteorological Administration, respectively. Future DM8H ozone concentrations and daily mean temperatures for summer (June–August) during the 2020s (2016–2025) and 2050s (2046–2055) were also obtained from the National Institute of Environmental Research and Korea Meteorological Administration, respectively. City-specific non-accidental daily mortality (ICD-10 codes A00-R99) data were obtained from Statistics Korea.

Future DM8H ozone concentrations were estimated using the Integrated Climate and Air Quality Modeling System (ICAMS) based on historical data for 1996–2005 from the National Institute of Environmental Research (Lee et al., 2015) under four RCP scenarios (RCP 2.6, 4.5, 6.0, and 8.5). ICAMS is based on a nesting structure of global and regional climate and chemical transport models to accurately estimate the surface ozone concentrations over East Asia. A detailed information on ICAMS can be found in Lee et al. (2015). Future daily mean temperatures were estimated using HadGEM3-RA model based on historical data for 2001–2010 from the Korea Meteorological Administration under the same RCP scenarios. We focused on the summer season (June–August) because ozone formation is sensitive to the strength of solar radiation, and elevated ozone concentration events are most likely to occur in summer (Jing et al., 2014).

2.2. Exposure-response relationship

To determine a city-specific exposure-response relationship during the baseline period (2001–2010), a DLNM with an assumption of quasi-Poisson distribution was used (Gasparrini et al., 2010). The model can be expressed as

$$\log(\mathrm{E}[\mathrm{Mortality}]) = \mathrm{CB}(\mathrm{T}) + \mathrm{CB}(\mathrm{O_3}) + \mathrm{DOW} + \mathrm{NS}(\mathrm{time},\ \mathrm{df}) \tag{1}$$

where CB(T) is the cross-basis matrix for daily mean temperature, $\mathrm{CB(O_3)}$ is the cross-basis matrix for DM8H ozone concentration, DOW is day of the week, and NS (time, df) is the natural cubic spline of time with df being 4 degrees of freedom per year. For the cross-basis matrices, the temperature response was modeled applying a quadratic spline with three internal knots, while the ozone and lag responses were both modeled applying a natural cubic spline with tree internal knots. Lags for ozone and temperature were modeled up to 7 days. These modeling choices were made based on previous studies (Gasparrini et al., 2015; Lee and Kim, 2016) and a sensitivity analysis (see Supplementary Information).

In order to determine the exposure-response relationship, we used historical daily data not only for summer but also for all the four seasons. In this manner, we could obtain more accurate relationships for a wider range of exposure, which is necessary for an accurate prediction of future mortality. The extracted relationships were used to predict future summer mortality based on the future daily mean temperature and DM8H ozone concentrations.

2.3. Projection of future mortality due to changes in surface ozone concentration and temperature

Future and baseline total non-accidental summer (June–August) daily mortalities were compared on the basis of mortality ratio (MR), which can be expressed as follows:

$$\mathrm{MR} = \frac{\text{Future Daily Mortality Count}}{\text{Baseline Daily Mortality Count}} = \frac{\frac{(\Sigma_i \mathrm{RR}_{\mathrm{ozone},i})}{n} \cdot \frac{(\Sigma_i \mathrm{RR}_{\mathrm{temperature},i})}{n}}{\frac{(\Sigma_j \mathrm{RR}_{\mathrm{ozone},j})}{m} \cdot \frac{(\Sigma_j \mathrm{RR}_{\mathrm{temperature},j})}{m}} \tag{2}$$

Here, $\mathrm{RR}_{\mathrm{ozone},i}$ and $\mathrm{RR}_{\mathrm{temperature},i}$ are the relative risks due to ozone concentration and temperature, respectively, on a future summer day i, $\mathrm{RR}_{\mathrm{ozone},j}$ and $\mathrm{RR}_{\mathrm{temperature},j}$ are the relative risks due to surface ozone concentration and temperature, respectively, on a baseline summer day j, n is the total number of summer days during the future period, and m is the total number of summer days during the baseline period. Similar methods for calculating future mortality have been used in previous studies (Guo et al., 2016; Lee and Kim, 2016; Li et al., 2013).

3. Results

Fig. 1 shows annual mean summer DM8H surface ozone