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Developing a risk-based air quality health index

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HIGHLIGHTS

- ► We developed an air quality health index based on excess risk of morbidities.
- ► Excess risks were derived from time series analyses of data on hospital admissions.
- ► Risk categories were constructed based on the WHO Air Quality Guidelines.
- ► Advisory messages were developed for the general public including high-risk groups.
- ► This index has a short lag time and reflects health risk from multiple pollutants.

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ABSTRACT

We developed a risk-based, multi-pollutant air quality health index (AQHI) reporting system in Hong Kong, based on the Canadian approach. We performed time series studies to obtain the relative risks of hospital admissions for respiratory and cardiovascular diseases associated with four air pollutants: sulphur dioxide, nitrogen dioxide, ozone, and particulate matter with an aerodynamic diameter less than 10 μm (PM_{10}). We then calculated the sum of excess risks of the hospital admissions associated with these air pollutants. The cut-off points of the summed excess risk, for the issuance of different health warnings, were based on the concentrations of these pollutants recommended as short-term Air Quality Guidelines by the World Health Organization. The excess risks were adjusted downwards for young children and the elderly. Health risk was grouped into five categories and sub-divided into eleven bands, with equal increments in excess risk from band 1 up to band 10 (the 11th band is 'band 10+'). We developed health warning messages for the general public, including at-risk groups: young children, the elderly, and people with pre-existing cardiac or respiratory diseases. The new system addressed two major shortcomings of the current standard-based system; namely, the time lag between a sudden rise in air pollutant concentrations and the issue of a health warning, and the reliance on one dominant pollutant to calculate the index. Hence, the AQHI represents an improvement over Hong Kong's existing air pollution index.

1. Introduction

1.1. Objective

The objective of this study is to develop an air quality health index (AQHI) reporting system for Hong Kong that uses locally derived relative risk estimates of air pollutants on health outcomes. It should provide timely and risk-based information to the public on the short-term health risks of air pollution, and advise them of the appropriate behavioural responses to each situation.

1.2. The air pollution index reporting system

The air pollution index (API) reporting system currently used in Hong Kong is a risk communication tool that informs the public of the local level of ambient air pollution, and the potential health risk it would impose, particularly on vulnerable groups such as children, the elderly, and those with existing cardiovascular and respiratory diseases. People use the API to help them make decisions on

Abbreviations: API, Air Pollution Index; AQG, Air Quality Guideline(s); AQHI, Air Quality Health Index; AQO, Air Quality Objective(s); d.f., Degrees of freedom; ER(s), Excess risk(s); ICD, International Classification of Diseases; PM_{10}, Particulate matter with an aerodynamic diameter less than 10 μm; RR (s), Relative risk(s); US EPA, United States Environmental Protection Agency; WHO, World Health Organization.

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outdoor physical activities. In Hong Kong, schools and sports organisations may check the latest API figures to decide whether physical education lessons or outdoor sporting events should be conducted on a certain day. The API systems in many Asian countries, including China, Taiwan, Singapore, Malaysia, Thailand, South Korea, Macau, and Hong Kong, are based on the model advocated by the United States Environmental Protection Agency (US EPA). In the US system, pollutant concentrations for each pollutant, measured in a network of monitoring stations, are transformed to a normalised numerical scale of 0–500. The key reference point is the index value of 100, which is reported whenever any of the monitored pollutants reaches the level set by its respective primary National Ambient Air Quality Standard (US EPA, 1999, 2006). Hong Kong has adopted the US method, but uses its own Air Quality Objectives (AQO) for four 'criteria' air pollutants – particulate matter with an aerodynamic diameter less than 10 μm (PM_{10}), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and ozone (O_3). These AQO were first established in 1987, for the derivation of the Hong Kong API. The index value of 50 is anchored to Hong Kong's long-term AQO.

A major shortcoming of the US-based system is that the calculation of the index depends on whichever air pollutant deviates the most from its reference standard, without regard to the concentrations of the other pollutants. This implies that the joint effect of air pollutants is not considered. Moreover, even though the API is calculated on an hourly basis, the choice of averaging times used as reference standards will affect the timeliness of the reporting system. In Hong Kong, where the 24-h average concentrations of PM_{10} are used as a reference, there is considerable time lag between a sudden, rapid increase in PM_{10} concentration and a rise in API above the warning level, as the latter is derived from the average PM_{10} concentrations over the past 24 h. To address these shortcomings, several researchers have proposed alternative approaches. The Canadian AQHI adopted a multi-pollutant approach that summed up the health risk posed by individual pollutants (Stieb et al., 2008). In the South African system, Cairncross also used a multi-pollutant approach, but anchored the health risk to the World Health Organization (WHO) guideline concentration for O_3 as a reference level for the other pollutants (Cairncross et al., 2007). A similar approach was adopted by Sicard et al. (2011), using $PM_{2.5}$ as a reference instead. An aggregate index using five air pollutants ($PM_{2.5}$, PM_{10}, NO_2, O_3 and SO_2) was further developed for European cities (Sicard et al., 2012).

2. Methods

2.1. Summary of procedures

Using time series analyses, we derived relative risks (RRs) of emergency hospital admissions for respiratory and cardiovascular diseases, associated with four major air pollutants routinely monitored in Hong Kong. With these RRs, we calculated the excess risk (ER, which equals RR − 1) of daily hospital admissions associated with each of these air pollutants, expressed as a percentage (%ER), and summed the %ERs of all four pollutants. The reference of the RR (where RR = 1) was set at zero concentrations of all air pollutants. We then grouped them into categories and bands, and developed advisory messages to the public, including specific advice for outdoor workers (included in response to strong community demand) and for susceptible groups (i.e. children, the elderly, and people with existing illnesses).

2.2. Time series analyses

Hospital data from 2001 to 2005 were obtained from all public hospitals under the Hospital Authority that had accident and emergency services. The Hospital Authority is a government-funded organisation which provides over 90% of all hospital beds in Hong Kong, and thus provides us with a sampling frame that has a wide coverage throughout the city. Diagnoses were coded using the International Classification of Diseases (ICD), 9th Revision (WHO, 1977). The following codes were used: 'all diseases of the respiratory system' (ICD 460–519), and 'all diseases of the cardiovascular system' (ICD 390–459). Daily meteorological variables – namely, mean temperature and humidity – were obtained from the Hong Kong Observatory. Hourly air pollutant concentrations were provided by the Environmental Protection Department of Hong Kong.

We performed the Poisson regression on daily emergency hospital admissions for respiratory and cardiovascular diseases combined (the dependent variable), using a generalised additive model. Smoothing for the time variable was done using smoothing splines, with varying degrees of freedom (d.f.). We chose the model with 70 d.f., in which the RRs of the air pollutants were at or near their peak values.[1] The rationale for our model choice was to estimate the highest levels of risk associated with the air pollutants, while maintaining a balanced contribution of %ERs among the four pollutants.[2] The model was adjusted for potential confounders, including daily mean temperature and relative humidity, a 'day of the week' indicator, a holiday indicator, and a season indicator. Over-dispersion was adjusted by the quasi-likelihood method and auto-correlation was adjusted by adding auto-regressive terms into the core model. Residuals plots and partial autocorrelation function (PACF) plots were used to examine the model's goodness of fit.

Following the Canadian methodology, we added the maximum of the 3-hourly moving average concentrations of the pollutants on each day in the model (Stieb et al., 2008). This represented a compromise between the timeliness of air pollutant data and the stability of the air quality health index (AQHI), which would be reported hourly, though based on calculations using the 3-h moving average concentrations of the constituent pollutants. The model was tested for the lag effect of air pollution, using air pollutant concentrations on the same day (lag day 0), the previous day (lag day 1) and two days previously (lag day 2). The 'best lag day' (i.e. one when the RR was statistically most significant) for each air pollutant was chosen according to the maximum *t*-value, calculated using the gam.exact function of S-PLUS (iHAPSS, 2002; Dominici et al., 2004).

The core model (before the air pollutant concentrations were added) is shown as follows:

Log (resp card 0) = resp card 1 to 7 + s (day, d.f. = 70) + s (humidity, d.f. = 15) + s (temperature, d.f. = 15) + day of week indicator + season indicator + holiday indicator.

2.2.1. Explanatory notes

The dependent (outcome) variable, resp card 0, is the daily number of emergency hospital admissions for respiratory diseases and cardiovascular diseases.

[1] In the generalised additive model, the degrees of freedom (d.f.) for the smoothing parameter tested were: 0, 10, 20, … up to 160. RR estimates varied with varying d.f., and peaked at different d.f. The model with 70 degrees of freedom was chosen because the RRs of the air pollutants were near their maximum values.

[2] At d.f. = 70, the relative weights of the RRs of all pollutants in their contribution to the %ER were much more balanced than when using RRs derived from the statistically 'best-fit' model, where the minimum Akaike information criterion (AIC) appeared at d.f. = 147. At d.f. = 70, the ratio of the regression coefficient (β) values for NO_2, O_3, SO_2, and PM_{10} were: 3:4:1:2. At d.f. = 147, where the RR of O_3 was much higher than the others, the corresponding ratios were: 5:10:1:3. This implied that the %ER will be dominated by O_3 concentrations while other pollutants' contributions to the %ER would be much smaller.