Effects of ambient temperature and air pollutants on bacillary dysentery from 2014 to 2017 in Lanzhou, China

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Abstract

Background: Previous studies have always focused on the impact of various meteorological factors on bacillary dysentery (BD). However, only few studies have investigated the effects of climate and air pollutants on BD incidence simultaneously. This study aimed to investigate the effects of temperature and air pollutants on BD in Lanzhou.

Methods: Daily data of BD cases and environmental factors from 2014 to 2017 were collected. A generalized additive model (GAM) was conducted to explore the relationship between environmental factors and BD. Then a distributed lag non-linear model (DLNM) was developed to assess the lag and cumulative effect. Furthermore, this study explored the variability across gender and age groups.

Results: A total of 7102 cases of BD were notified over the study period. High temperature can significantly increase the risk of BD during the whole lag period, temperature has different exposure effects on different genders and age groups. With 9°C as the reference value, each 1°C rise in temperature result in a 4.8% (RR=1.048, 95%CI: 0.996, 1.103) increase in the number of cases BD at lag 0 day. With 50μg/m3 as the reference value, each 5μg/m3 rise in PM2.5 caused a 11.3% (RR=1.113, 95%CI: 1.066, 1.162) increase in the number of BD cases at lag 0. Low concentration of PM10 in the lag of 10-14 days can significantly increase the risk of BD, while high concentration PM10 in the lag of 6-14 days can significantly increase the risk of BD.

Conclusions:Temperature, PM2.5 and PM10 are closely related to the incidence of bacillary dysentery. Our findings suggest adaptation plans that target vulnerable populations in susceptible communities should be developed to reduce health risks.

Background

Bacillary dysentery, also known as shigellosis, is an acute intestinal infectious disease caused by diarrhea bacillus(Zhou yanli, 2009). The infection is spread from person to person via fecal-oral route, contaminated water and food, flies and direct contacts to a patient or carrier(Liu et al., 2019). Epidemics are frequent in overcrowded populations with poor sanitation and most cases occur in summer and autumn. While most cases of bacillary dysentery are mild and do not require drastic treatment, excessive dehydration can be fatal in a severe attack if treatment is unsuccessful(Zhang et al., 2007). According to the National Report of Notifiable Disease from the Center for Disease Control and Prevention in China, there were approximately 109,368 notified cases of bacillary dysentery in 2017, with an incidence rate of 7.92 per 100,000, which is ranked to be the fifth highest number of statutory infectious diseases in category B. *Shigella* infections remain an important public health problem in China, especially among children and old people(von Seidlein et al., 2006; Xuan-yi Wang et al., 2006). Many studies also showed that bacillary dysentery was one of the major infectious diseases affecting the health and quality of life of residents in China(SUN et al., 2008; Li et al., 2018; Liu et al., 2016; Ma et al., 2015).

In recent years, more and more scholars have applied various kinds of statistic methods to interpret the association between meteorological factors and the incidence of bacillary dysentery and it showed that meteorological factors are closely related to the incidence of bacillary dysentery. Chen analyzed the epidemic characteristics of bacillary dysentery and meteorological factors in Henan province in 2010 by using single factor correlation analysis and multivariate linear regression, and found that the incidence of bacillary dysentery was related to precipitation and temperature.(CHEN Wei, 2012). The principal component analysis and time series analysis were used to analyze the meteorological factors and the number of bacillary dysentery in Chengguan district, Lanzhou city from 2005 to 2010, suggested that the incidence of bacillary dysentery in this area was related to high temperature(QIANG Li, 2013). Zhang used BP artificial neural network model to analyze the relationship between bacillary dysentery and meteorological factors in Beijing area, and found that the risk of bacillary dysentery was not only related to the relative humidity and wind speed of the current year, but also related to the previous one to three years(Juan, 2015). Gao used multivariate stationary time series ARIMAX model to quantitatively evaluate the correlation between the meteorological elements and the incidence of bacillary dysentery in Changsha city, and found that the meteorological factors with great influence on the incidence of bacillary dysentery were temperature, air pressure and precipitation (Gao et al., 2014). The relationship between meteorological factors and the incidence of bacillary dysentery in Jinan were discussed by using generalized additive model, and it was concluded that temperature was an important meteorological factor affecting the incidence of bacillary dysentery(Liu et al., 2019). The relationship between bacillary dysentery and meteorological factors in Binyang, Guangxi, was discussed by using principal component analysis and classification regression tree, and found that temperature, rainfall and humidity played an important role in the propagation of bacillary dysentery (Liu et al., 2017).

Through consulting the literature, it was found that most of the studies only focused on the relationship between meteorological factors such as temperature and relative humidity and bacillary dysentery, and there are few studies on the relationship between air pollutants and gastrointestinal diseases such as bacillary dysentery. However, there are studies that have identified a new biological mechanism to explain adverse health effects from air pollution: epigenetics (Bollati and Baccarelli, 2010; Hou et al., 2012). A study suggested that DNA methylation is a mechanism that cells use to control gene expression in a switch-like manner(Zhang et al., 2009). Complement component C3,an important factor in the human defense system, turned out to be a sensitive indicator of immunological reactions to common air pollutants(Renate Stiller- Winkler and Gahiele Leng, 1996). One hand, high temperature can directly affect the body's cardiovascular system and respiratory system, leading to a reduction in the body's immune power in the epidemic and makes the exposed population vulnerable to a variety of infectious pathogens(Bai et al., 2014; Kim et al., 2014), on the other hand, air pollution may amplify people's vulnerability to the adverse effects of temperature(Gordon, 2003) and could act as an effect modifier in the short-term effects of air temperature on disease (Breitner et al., 2014; Ren et al., 2006). Therefore, it is of great significance to explore the effects of air pollutants on incidence of bacillary dysentery.

Although there are many studies on the relationship between the incidence of dysentery and environmental factors, few studies have been studied in semi-arid areas. Lanzhou is located in the intersection of the three highlands like the Tibet Plateau, the Loess Plateau and the Inner Mongolian Plateau, and belongs to the semi-arid region and temperate continental climate. In addition, the elevation of Lanzhou is more than 1,500 meters.So it is of great significance to explore the relationship between the incidence of dysentery and environmental factors in semi-arid areas.

Many studies have used principal component analysis, single-factor correlation analysis and multivariate linear model to analyze the relationship between bacillary dysentery and meteorological factors, but these studies did not consider the nonlinear relationship between meteorological factors and the incidence of bacillary dysentery.In addition, traditional single models (such as generalized linear models, generalized additive models, sliding averaging methods et c) only take into account the effects of a particular time period, and simply introduce the exposure level for several consecutive days in the model, regardless of the characteristics of hysteresis distribution, which is bound to produce a high col-linearity, and not to accurately reveal the relationship between meteorological factors and disease(YANG Jun, 2012).

The study aimed to quantify the relationship between environmental factors and bacillary dysentery in Lanzhou, with consideration of lagged and cumulative effects. It will contribute to a better understanding of the health impacts of environmental factors and provide evidence to support decision-making for prevention and control of BD.

Methods

1. Data collection

Notified data of daily number of BD cases between January 2014 and December 2017in Lanzhou were obtained from Center for Disease Control and Prevention of Lanzhou city. In this study, all bacillary dysentery cases were defined based on the diagnostic criteria and principles of management for dysentery (GB 16002-1995), issued be the Ministry of Health of the People's Republic of China.

Daily meteorological data for Lanzhou were extracted from the publicly accessible China National Weather Data Sharing System. The meteorological variables included daily mean temperature, relative humidity, air pressure, wind speed and sunshine duration. Data of air pollutants were obtained from the local environmental protection station and included PM2.5, PM10, CO, NO_2 and O_3.

2. Statistical methods

Firstly, a descriptive analysis was performed to describe the distribution of BD cases and environmental factors during the study period. Then the correlation between the environmental factors and the number of daily incidence of bacillary dysentery in Lanzhou was analyzed by adopting *Spearman* grade correlation, and the meteorological factors and air pollutants related to the incidence of bacillary dysentery were included in the model. A generalized additive model(GAM) was developed to examine the exposure-response relationship between environmental factors and the BD cases, with consideration of different lag period of environmental factors. As an initial exploratory analysis, the result of GAM were used for the following models. A distributed lag non-linear model (DLNM) was applied to estimate the cumulative and delayed effects of the environmental factors on BD.

The cross-base matrix was established for the daily cases of bacillary dysentery and environmental factors, respectively. The number of daily bacillary dysentery as the dependent variable was fitted by quasi-Poisson connection function. Based on the control of seasonal, long-term trends and weekly effects, distributed lag non-linear model (DLNM) was used to fit the correlation between environmental factors and the cases of bacillary dysentery. The influence of daily temperature, daily PM2.5 and PM10 on the incidence of bacterial dysentery was analyzed, while the confound effects of relative humidity, sunshine time, wind speed, C0, NO_2 and O_3 were controlled. Finally, a two-dimensional matrix of temperature, PM2.5, PM10 and lag time was established to study the lag effect of temperature, PM2.5 and PM10 on the BD. The basic model is following.

$$\log[E(Y_t)] = \alpha + \beta TEM_{(t,l)} + \gamma PM2.5_{(t,l)} + \lambda PM10_{(t,l)} + ns(CO, df = 3) + ns(NO_2, df = 3)$$
$$+ ns(O_3, df = 3) + ns(rhu, df = 3) + ns(ssd, df = 3) + ns(time, df = 7/year) + \varphi DOW_t$$

Where is the expected daily count of BD on day t, α is the intercept. β, γ and λ were the effect estimate of temperature, PM2.5 and PM10. *Ns ( )* represented the thin plate splines function, which were used to adjust for other environmental factors and long-term and seasonal trends. According to the relevant investigation, we selected 14 days as the maximum lag period(WANG Jin-yu1, 2018). Using the median daily temperature, PM2.5 and PM10 (P_{50}) as reference values, the relative risk (RR) values of different temperatures, PM2.5 and PM10 and different lag time were calculated. In this study, R3.5.0 software was used for statistical analysis and DLNM program package was used to fit regression model, the test level is 0.05.

Results

1. Descriptive analysis of BD and environment factors

A total of 7,102 cases of bacillary dysentery were notified in the study area over the study period. There were more male cases with a male-to-female sex ratio of 1.17:1 (3,822:3,280). As showed in table 1, the average number of daily BD cases was 4.84. The average values of daily mean temperature, PM2.5 and PM10 were 7.73℃, 53.44μg/m^3 and 124.47μg/m^3, respectively.

2. Correlation analysis between BD and environment factors

The correlation between the incidence of bacillary dysentery and PM2.5, PM10, CO, NO_2 and O3 was statistically significant ($p<0.05$), respectively. The incidence of bacillary dysentery was negatively correlated with PM2.5, PM10, CO, NO_2 and positively correlated with O_3.The effects of temperature (r=0.58), PM2.5 (r=-0.39) and PM10 (r=-0.33) on the incidence of bacillary dysentery were more significant.

3. Exploratory analysis of the relationship between temperature and BD

As shown in Fig 1, there is a nonlinear relationship between the temperature of different lag days and the number of daily BD. The correlation strength between different average temperature and bacillary dysentery changed with the change of different lag days, while low temperature and high temperature could significantly increase the risk of bacillary dysentery and the effect of the high temperature lasted longer. When the temperature were -16°C and 19°C, the RR values were the largest and were 1.23 (95%CI: 1.08, 1.39) and 1.05 (95%CI: 1.02, 1.09), respectively. When the temperature was lower than -5°C, the effect of temperature on BD was the strongest at lag 0 day. Besides, with the prolongation of lag time, the effect of low temperature decreased gradually, however, the low temperature could not increase the risk of BD within 7 to 14 days of lag. High temperature could significantly increase the risk of BD in the whole lag period, and the cumulative effect of temperature on BD in lag 14 days was shown in Fig 2, the type of cumulative effect curve of daily average temperature was roughly "J".

Fig.2 depicted the cumulative effect of different lag temperatures on people of different ages and genders. The exposure response relationship of average daily temperature on the male and 7-40 years old people both were J-shaped curves, while they were U-shaped curves on the women and 0-6 years old people. Although the average daily temperature had different exposure effects on different sex and age groups, the minimum risk temperature of bacillary dysentery was around 9 °C. As shown in table 2, with 9°C as the reference value, the lag effects were strongest at lag 0 days for every 1°C increase in temperature, and the risk of BD increases for men, women and 0-6 years old people were 0.8% (RR=1.008, 95%CI: 1.004, 1.013), 1.0% (RR=1.010, 95%CI: 1.003, 1.017) and 2.0% (RR=1.020, 95%CI: 1.013, 1.028), respectively.

4. Exploratory analysis of the relationship between PM2.5 and BD

Fig.3 illustrates the effect of PM2.5 on BD. The plot showed a very strong immediate positive effect the high PM2.5 concentration above around 100μg/m^3 at lag 0-2 days, indicating that a high number of BD cases would occurred with the first 0-2 days of any hot spell crossing the PM2.5 of 100μg/m^3. Higher concentration of PM2.5 also seemed to have a moderate effect on BD at around 8-14 days lag period. Lower concentration of PM2.5 seemed to have a moderate positive effect on BD at 0-6 days lag period. The plots indicated that both lower and higher concentration of PM2.5 could increase the risk of BD when lag 0-8 days.

As shown in Fig. 4, the cumulative effects of different PM2.5 concentrations on different genders and age groups were nonlinear. The cumulative effect of PM2.5 on the whole population was inverted S-shaped curve, the cumulative effects curves of female and ≥41 years old people were similar to the total population, while male, the cumulative effects curves of male, 0-6 years old and 7-40 years old people were U-shaped. Table 3 shows the relative risk of BD in different genders and age groups for each 5μg/m^3 increase in PM2.5 concentration, when lag 0 day, the risk of BD increases for male, female, 0-6 years old group and ≥41 years old group were 1.1% (RR=1.011, 95%CI: 1.005, 1.016), 1.4% (RR=1.014, 95%CI: 1.008, 1.020), 2.1% (RR=1.021, 95%CI: 1.014, 1.027) and 1.3% (RR=1.013, 95%CI: 1.006, 1.020), respectively. The increased risk of BD for the people aged 7-40 years was not statistically significant during the whole lag period.

5. Exploratory analysis of the relationship between PM10 and BD

Fig. 5 showed the nonlinear relationship and lag effect between PM10 and BD. When the concentration of PM10 was lower than 110μg/m^3, there seemed to have a moderate positive effect on BD at around 10-14 day lag period, which indicated that the lower concentration of PM10 could significantly increase the risk of BD when delayed 10-14 days. On the contrast, when the concentration of PM10 was greater than 110μg/m^3, there seemed to have a strong positive effect on BD at lag 10-14 days. There were also some shorter lag period (0-3 days) but negative effect when the concentration of PM10 was higher than around 110μg/m^3.

Fig. 6 showed the cumulative effect curves of different PM10 concentrations on people of different genders and age groups, showing that the exposure response relationship was different between different genders and age groups. The types of cumulative effect curves of daily PM10 concentration on the population of 0-6 years old group and 7-40 years old group were “L”, and the curve types of male, female and ≥41 years old people were inverted “U”.

As shown in table 4, taking 110μg/m3 as reference value, at lag 14 days, each 10μg/m^3 increase in PM10 corresponded to an increase of 0.3% (RR=1.003, 95%CI: 1.001, 1.006) and 0.1% (RR=1.001, 95%CI: 0.999, 1.005) in cases of BD for male and ≥41 years old people, respectively. At lag 0 day, the increase risk for people aged 7-40 years was 0.1% (RR=1.001, 95%CI: 0.996, 1.003). The risk of BD in women and people aged 0-6 years decreased during the whole lag period, and with the number of lag days increases, the amount of female decline increases gradually, while the reduction in people aged 0-6 years gradually decreased.

Discussion

In this study, the effect of temperature and air pollutants on BD in Lanzhou was examined by using time-series analyses including a distributed lag non-linear model and a generalized additive model. The results showed that both temperature and air pollutants were related to the incidence of bacillary dysentery. The 0-6 year-old people and women were most vulnerable to high temperature and high concentration of PM2.5 while 7-40 years old people were vulnerable to high concentration of PM10. Bacillary dysentery, as a legal infectious disease in China, has been in the top five in the reporting system of statutory infectious diseases in China in recent years, and the incidence of bacillary dysentery varies greatly in different regions. Studies have shown that the incidence rate in Lanzhou city was significantly higher than that in the whole country and other regions (Liu et al., 2016). Therefore, the study on the factors affecting the incidence of bacillary dysentery has important hygienic significance for the prevention and control of diseases, and provides a scientific basis for the relevant institutions to formulate preventive measures.

The study found that high temperature increased the risk of BD, with 9°C as the reference value, each 1°C rise in temperature led to a 4.8% increase in the daily number of BD for total population, which was similar to the findings of previous studies. For example, the study by Li revealed that the incidence of BD would increase by 1.58% for each 1°C rise in daily mean temperature (Li et al., 2016). A study conducted in Jinan also found that for each 5°C increase in daily average temperature, the incidence of BD increased by 61%(Liu et al., 2019). The growth and reproduction of *shigella* were inhibited under the condition of low temperature (Checkley et al., 2000). A study exploring the attributable fraction (AF) under varying temperature found that temperature was positively associated with BD, and morbidity risk linearly increased with temperature increase above 18.4°C in Hefei, China(Cheng et al., 2017). In addition, the results of stratified analysis of different sex and age groups showed that women and those under 6 years old were sensitive to the effects of temperature on bacillary dysentery, and the results were consistent with the relevant studies (Li et al., 2016; WANG Jin-yu1, 2018), which may be related to the relative weakness of gastrointestinal tract function. The lag effect analysis showed that the effect of temperature was highest at lag 0 day. This finding was also in accordance with previous study(Liu et al., 2019). High temperature could increase the risk of bacillary dysentery.The main reasons for this may be the following two aspects, one of which is that the increase of temperature is beneficial to the survival and propagation of pathogens in the external environment(QIAN Ying-jun, 2010). Meanwhile, the rise of temperature directly affects the whole process of food processing, transportation and storage, and increases the likelihood of people being infected with pathogens (Huang et al., 2012). Another mechanism is considered that bacillary dysentery is transmitted in the form of fecal-oral contact transmission, direct or indirect consumption of patients or carriers of fecal contaminants and infection, or indirect transmission of flies or cockroaches. Summer is just the best season for flies and cockroaches to survive, in addition, changes in the living habits and behavior of individuals in high temperature environments include eating habits and the frequency and range of outdoor activities et al (Ma et al., 2015a).

In addition to meteorological factors, air pollutants were also known as an important factor affecting public health, and studies have shown that air pollutants such as PM2.5, PM10 and NO_2 were closely related to the increase in population morbidity and mortality, even at lower levels (Analitis et al., 2018). There was a study indicated that every year more than 13 million deaths worldwide were due to environmental pollutants, and approximately 24% of diseases were caused by environmental exposures that might be averted through preventive measures (Hou et al., 2012). In this study, the effects of PM2.5 and PM10 on the disease were also discussed, and it was found that high concentrations of PM2.5 and PM10 could significantly increase the risk of bacillary dysentery, and that low concentrations of PM2.5 could increase the risk of disease in a shorter lag time, suggesting that PM2.5 had an acute harm to the health of the population, and the sensitivity of women and people aged 0-6 to pollutants was higher than that of other groups. Toxicological studies have revealed that PM2.5 was actually a carrier whose surface could adsorb a variety of substances that would cause a variety of symptoms and diseases, that is to say, the most harmful to the human body is not the particulate matter itself, but the chemical substances adsorbed on the particulate matter. Therefore, when the high concentration of PM2.5 is more conducive to the air bacillary dysentery pathogens attached to the PM2.5, outdoor activists will carry pathogenic bacteria attached to PM2.5 or PM10 and other absorption into the human respiratory system, circulatory system and digestive system et c, leading to the onset of bacillary dysentery(Yan-ping, 2013). On the other hand, population exposure and high concentrations of air pollutants such as PM2.5 and PM10 have had a certain impact on the body's immune mechanisms and metabolic capacity, and studies have found that exposure and air pollutants can alter the body's genes (Bind et al., 2014). When the human body is exposed to PM2.5 and PM10, it may alter the genotype of the body's response to the pathogen of bacillary dysentery, so the resistance to the body decreases when exposed to various pathogens.

To sum up, the analysis of different groups of people showed that women and people aged 0-6 were more sensitive to temperature, PM2.5 and PM10 than other populations, which may be less involved in outdoor activities with women, reducing their tolerance to related factors, and the susceptibility of 0-6-year-old people may be related to the imperfections of their developmental mechanisms. Therefore, not only the individual should strengthen the defensive measures on the relevant influencing factors, for example, in the high temperature as far as possible indoor activities, go out with multiple masks, and so on, and the relevant government departments should also strengthen prevention and control measures, including summer can use sprinklers to properly cool the streets and reduce the concentration of inhaled particulate matter in the air.

It should be acknowledged that there are some limitations in our study. One of the limitation is that the effects of many factors, such as social and economic status, health services, and environmental hygiene, could not be analyzed in our study. Moreover, due to lack of detailed laboratory information, we cannot identify the pathogens typing of bacillary dysentery in Lanzhou. Therefore, further studies with detailed laboratory information of bacillary dysentery pathogens, socioeconomic and other possible risk factors should be conducted to examine the association between the specific strains of bacillary dysentery and environmental factors in order to have a better understanding of the health impacts of environmental factors.

Conclusions

Temperature, PM2.5 and PM10 are closely related to the incidence of bacillary dysentery. Our findings suggest adaptation plans that target vulnerable populations in susceptible communities should be developed to reduce health risks.

Abbreviations

BD: Bacillary dysentery

GAM: Generalized additive model

DLNM: Distributed lag non-linear model

RR: Risk ratio

ARIMA: Autoregressive integrated moving average

Declarations

Ethics approval and consent to participate

The study was approved by the Institute Review Board (IRB) of the School of Public Health, Lanzhou University. The study did not involve individual participants, and no individual patient information was collected. As aggregated data with no personal information were involved, this study was exempt from obtaining informed consent.

Consent for publication

Not applicable.

Availability of data and material

Apply to the availability of these data are not publicly available. A person who wants to access the raw data should contact with the corresponding author.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

XWR and XLH conceived and designed the study to conception, study design, data analysis, and interpretation of data and wrote the manuscript. WZ, XDC, HPM and YCL contributed to the data analysis. XYZ, XKZ and SL contributed to the data collection. All authors read and approved the final manuscript.

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References

Analitis A, De' Donato F, Scortichini M, Lanki T, Basagana X, Ballester F, et al (2018) Synergistic Effects of Ambient Temperature and Air Pollution on Health in Europe: Results from the PHASE Project. Int J Environ Res Public Health 15(9):1856-1867

Bai L, Cirendunzhu, Woodward A, Dawa, Zhaxisangmu, Chen B, et al (2014) Temperature, hospital admissions and emergency room visits in Lhasa, Tibet: a time-series analysis. Sci Total Environ 490: 838-48.

Bind MA, Lepeule J, Zanobetti A, Gasparrini A, Baccarelli A, Coull BA, et al (2014) Air pollution and gene-specific methylation in the Normative Aging Study: association, effect modification, and mediation analysis. Epigenetics 9: 448-458.

Bollati V, Baccarelli A (2010) Environmental epigenetics. Heredity (Edinb) 105: 105-112.

Breitner S, Wolf K, Devlin RB, Diaz-Sanchez D, Peters A, Schneider A (2014) Short-term effects of air temperature on mortality and effect modification by air pollution in three cities of Bavaria, Germany: a time-series analysis. Sci Total Environ 485-486: 49-61.

CAO Ruoming CL, JIANG Chao, JING Yiming, ZHOU Lin, ZHANG Lin, LIU Shouqin (2018) Association between ambient ozone and mortality of respiratory diseases in Jinan, China: a time-series analysis. Journal of Shandong University(Health Sciences) 56: 1-7.

Checkley W, Epstein LD, Gilman RH, Figueroa D, Cama RI, Patz JA, et al (2000) Effects of EI Niño and ambient temperature on hospital admissions for diarrhoeal diseases in Peruvian children. The Lancet 355: 442-450.

CHEN Wei LY, CHEN Zheng-li, MA Gui-fang, GUO Xiao-fang, XUAN Shui-li, HE Jing-yang (2012) Analysis on Relativity between epidemic characteristics of bacillary dysentery and Meteorological factors in Henan Province in 2010. Modern Preventive Medicine 39: 5818-5820.

Cheng J, Xie MY, Zhao KF, Wu JJ, Xu ZW, Song J, et al (2017) Impacts of ambient temperature on the burden of bacillary dysentery in urban and rural Hefei, China. Epidemiol Infect 145: 1567-1576.

Gao L, Zhang Y, Ding G, Liu Q, Zhou M, Li X, et al (2014) Meteorological variables and bacillary dysentery cases in Changsha City, China. Am J Trop Med Hyg 90: 697-704.

Gordon CJ (2003) Role of environmental stress in the physiological response to chemical toxicants. Environmental Research 92: 1-7.

Hou L, Zhang X, Wang D, Baccarelli A (2012) Environmental chemical exposures and human epigenetics. Int J Epidemiol 41: 79-105.

Huang C, Barnett AG, Wang X, Tong S (2012) Effects of extreme temperatures on years of life lost for cardiovascular deaths: a time series study in Brisbane, Australia. Circ Cardiovasc Qual Outcomes 5: 609-14.

Juan ZXH (2015) Correlation analysis on gastrointestinal diseases and meteorological variables in Beijing. Journal of Changchun University of Chinese Medicine 31: 105-109.

Kim J, Lim Y, Kim H (2014) Outdoor temperature changes and emergency department visits for asthma in Seoul, Korea: A time-series study. Environ Res 135: 15-20.

Li K, Zhao K, Shi L, Wen L, Yang H, Cheng J, et al (2016) Daily temperature change in relation to the risk of childhood bacillary dysentery among different age groups and sexes in a temperate city in China. Public Health 131: 20-26.

LI Yang WD, ZHOU Ruyi (2018) Relationship between air pollutant and respiratory diseases. Journal of environmental pollution and prevention 40: 508-517.

Liu J, Wu X, Li C, Xu B, Hu L, Chen J, et al (2017) Identification of weather variables sensitive to dysentery in disease-affected county of China. Sci Total Environ 575: 956-962.

Liu Z, Liu Y, Zhang Y, Lao J, Zhang J, Wang H, et al (2019) Effect of ambient temperature and its effect modifiers on bacillary dysentery in Jinan, China. Sci Total Environ 650: 2980-2986.

Liu ZD, Li J, Zhang Y, Ding GY, Xu X, Gao L, et al (2016) Distributed lag effects and vulnerable groups of floods on bacillary dysentery in Huaihua, China. Sci Rep 6: 1-8.

LU Xiao-min CH-y, WU Dong-mei, SUN Zhongg-you (2018) Influence of air pollutants on occurrence risk of hand-foot-mouth disease in Yancheng city. Chinese Journal of

Woman and Child Health Research 29: 276-280.

Ma W, Zeng W, Zhou M, Wang L, Rutherford S, Lin H, et al (2015a)The short-term effect of heat waves on mortality and its modifiers in China: an analysis from 66 communities. Environ Int 75: 103-109.

Ma Y, Zhang T, Liu L, Lv Q, Yin F(2015b) Spatio-Temporal Pattern and Socio-Economic Factors of Bacillary Dysentery at County Level in Sichuan Province, China. Sci Rep 5: 1-9.

QIAN Ying-jun LS-z, WANG Qiang, YANG Kong, YANG Guo-jing, LV Shan, ZHOU Xiao-nong (2010) Research progress on the impact of climate change on human health. ADVANCES IN CLIMATE CHANGE RESEARCH 6: 241-247.

QIANG Li YJ-p, TAO Yan, LIU Ya-meng (2013) Relationship between daily incidence of bacterial dysentery and meteorological factors in Chengguan District of Lanzhou City. J Environ Health 30: 644-646.

Ren C, Williams GM, Tong S (2006)Does particulate matter modify the association between temperature and cardiorespiratory diseases? Environ Health Perspect 114: 1690-16966.

Renate Stiller- Winkler, Helga Mel, I, Gahiele Leng CS, 2 and Reinhard Dolgner3(1996) Influence of Air Pollution on Humoral Immune Response. J Clin Epidemiol Vol 49: 527-534.

SUN peiyuan，ZHANG deshan Wy, ZHAO na,PU yonglan, GUO qing, SHI rujing, LIyang(2008) Relationship between incidence of bacillary dysentery and meteorological factors. Capit al Journal of Public Health 2: 100-103.

von Seidlein L, Kim DR, Ali M, Lee H, Wang X, Thiem VD, et al (2006) A multicentre study of Shigella diarrhoea in six Asian countries: disease burden, clinical manifestations, and microbiology. PLoS Med 3: 1559-1569.

WANG Jin-yu1 LS, DONG Ji-yuan3, LI Shou-yu1, LI Pu4, JIA Qing2, WANG Ling-qing2, CHANG Xu-hong (2018) Distributed lag effects on the relationship between daily mean temperature and the incidence of bacillary dysentery in Lanzhou city. Journal of Peking University(Health Sciences): 1-13.

Xuan-yi Wang aFT, b Donglou Xiao,c Hyejon Lee,a Jacqueline Deen,a Jian Gong,d Yuliang Zhao,e, Weizhong Zhou fWL, g Bing Shen,h Yang Song,i Jianming Ma,j Zheng-mao Li,c Zijun Wang,c Pu-yu Su,b, Nayoon Chang aJ-hX, i Pei-ying Ouyang,k Lorenz von Seidlein,a Zhi-yi Xu,a & John D Clemensa (2006) Trend and disease burden of bacillary dysentery in China (1991–2000). Bulletin of the World Health Organization 84: 561-568.

Xuewen Li N, Wang, 3 Guoyong, Ding XLa, Xue2 X (2018) The relationship between meteorological factors and the risk of bacillary dysentery in the highest incidence area of Hunan Province, China during 2005–2010. Royal Meteorological Society 99: 1-5.

Yan-ping SZ-hC (2013) An Overview of PM2.5 Impacts on Human Health. Environmental Science and Technology 26: 75-78.

YANG Jun OY-c, DING Yan, CHEN Ping-yan (2012) Distributed lag non-linear model. Chinese Journal of Health Statistics 29: 772-777.

Yu G, Li Y, Cai J, Yu D, Tang J, Zhai W, et al (2019) Short-term effects of meteorological factors and air pollution on childhood hand-foot-mouth disease in Guilin, China. Sci Total Environ 646: 460-470.

Zhang Y, Bi P, Hiller JE, Sun Y, Ryan P (2007) Climate variations and bacillary dysentery in northern and southern cities of China. J Infect 55: 194-200.

Zhang Y, Rohde C, Tierling S, Jurkowski TP, Bock C, Santacruz D, et al (2009) DNA methylation analysis of chromosome 21 gene promoters at single base pair and single allele resolution. PLoS Genet 5: 1-15.

Zhou yanli Xw, Zhang haiyan,Ma lixian,Pan jinghai,Huang hui,Liu qinghua (2009) Time series analysis on bacillary dysentery andme teorological factors in Dongcheng distr ict, Beijing. D isease Surveillance 24: 697-700.

Tables

Table 1

Summary statistic for daily environment variable and daily number of BD cases from 2014 to 2017 in Lanzhou, China.

variables	$\bar{X}\pm SD$	min	P_{25}	P_{50}	P_{75}	max
Case of BD	4.84±4.19	0.00	2.00	4.00	6.00	35.00
Air pollutants variable						
PM2.5/μg/m^3)	53.44±27.01	12.00	36.00	46.00	64.00	327.00
PM10/(μg/m^3)	124.47±82.18	23.00	82.00	108.00	145.00	1393.00
CO/(mg/m^3)	1.35±0.72	0.40	0.80	1.10	1.60	4.80
NO_2/(μg/m^3)	51.44±21.44	12.00	36.00	48.00	62.00	146.00
O_3_8h/μg/m^3)	85.77±36.05	8.00	58.00	80.00	109.00	194.00
Meteorological variable						
Temperature/1℃	7.73±9.66	-16.70	-0.90	8.90	16.20	26.40
Pressure/1hPa	811.6±4.26	797.40	808.60	811.30	814.60	825.10
Relative humidity/%	60.51±16.23	20.00	49.00	60.00	72.00	100.00
Wind speed/(m/s)	1.95±0.50	0.50	1.50	1.80	1.95	6.30
Sunshine duration/1h	7.07± 3.92	0.00	4.65	8.00	9.80	13.70

Table 2

Relative risk (95% confidence interval) of BD in different subgroups associated with 1 unit increase in daily mean temperature, with ref. at 9°C.

Lag (d)	Relative risk (95% confidence interval)				
	male	female	0-6years	7-40years	≥41years
0	1.008(1.004, 1.013)	1.010(1.003, 1.017)	1.020(1.013, 1.028)	1.010(1.002, 1.019)	0.998(0.990, 1.006)
3	1.006(1.002, 1.010)	1.007(1.001, 1.013)	1.017(1.011, 1.023)	1.009(1.002, 1.016)	0.996(0.989, 1.002)
6	1.003(1.000, 1.007)	1.004(0.999, 1.009)	1.013(1.007, 1.018)	1.007(1.001, 1.014)	0.994(0.988, 1.000)
9	1.001(0.998, 1.004)	1.001(0.996, 1.006)	1.009(1.004, 1.014)	1.005(0.999, 1.012)	0.991(0.986, 0.998)
11	0.999(0.996, 1.003)	0.999(0.994, 1.004)	1.006(1.001, 1.012)	1.004(0.998, 1.011)	0.990(0.984, 0.997)
14	0.997(0.993, 1.001)	0.996(0.990, 1.002)	1.002(0.996, 1.009)	1.003(0.995, 1.010)	0.988(0.981, 0.995)

Table 3

Relative risk (95% confidence interval) of BD in different subgroups associated with 5 unit increase in daily mean PM2.5, with ref. at 50μg/m^3.

Lag (d)	Relative risk (95% confidence interval)				
	male	female	0-6years	7-40years	≥41years
0	1.011(1.005, 1.016)	1.014(1.008, 1.020)	1.021(1.014, 1.027)	1.001(0.994, 1.008)	1.013(1.006, 1.020)
3	1.007(1.003, 1.012)	1.013(1.008, 1.018)	1.016(1.010, 1.022)	1.002(0.996, 1.007)	1.011(1.005, 1.016)
6	1.004(1.000, 1.008)	1.012(1.007, 1.016)	1.012(1.007, 1.017)	1.003(0.997, 1.007)	1.008(1.003, 1.013)
9	1.001(0.997, 1.004)	1.011(1.006, 1.015)	1.007(1.002, 1.012)	1.004(0.998, 1.008)	1.006(1.001, 1.011)
11	0.998(0.994, 1.002)	1.010(1.005, 1.015)	1.004(0.999, 1.010)	1.004(0.998, 1.009)	1.004(0.998, 1.009)
14	0.995(0.990, 1.000)	1.009(1.003, 1.014)	0.999(0.993, 1.006)	1.005(0.998, 1.011)	1.001(0.995, 1.007)

Table 4

Relative risk (95% confidence interval) of BD in different subgroups associated with 10 unit increase in daily mean PM10, with ref. at 110μg/m^3.

Lag (d)	Relative risk (95% confidence interval)				
	male	female	0-6years	7-40years	≥41years
0	0.991(0.988, 0.995)	0.997(0.993, 0.999)	0.990(0.986, 0.994)	1.001(0.996, 1.003)	0.994(0.991, 0.998)
3	0.994(0.991, 0.996)	0.996(0.993, 0.999)	0.991(0.988, 0.995)	0.999(0.996, 1.002)	0.995(0.993, 0.999)
6	0.996(0.994, 0.998)	0.995(0.993, 0.998)	0.993(0.990, 0.996)	0.998(0.995, 1.001)	0.997(0.995, 1.000)
9	0.999(0.997, 1.001)	0.995(0.992, 0.998)	0.994(0.992, 0.997)	0.998(0.995, 1.001)	0.999(0.997, 1.002)
11	1.001(0.998, 1.003)	0.994(0.992, 0.997)	0.995(0.993, 0.998)	0.998(0.995, 1.001)	1.000(0.998, 1.003)
14	1.003(1.001, 1.006)	0.994(0.991, 0.997)	0.997(0.994, 1.001)	0.997(0.994, 1.002)	1.001(0.999, 1.005)

Figures

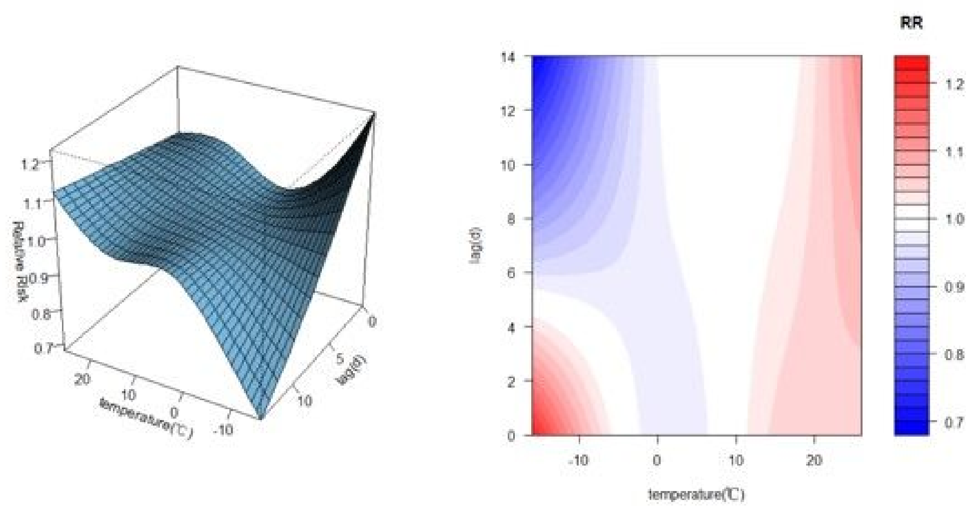

Figure 1

3D & Contour plot of RR along temperature and lags, with ref. at 9°C. (a) A 3D image of the relative risk (RR) of BD along the mean temperature (here 9°C) and lags. Here the legends respectively (from the left) are: relatively risk (RR), daily temperature and lag periods. (b) A contour plot of the relative risk (RR) of BD along mean temperature (here 9°C) and lags. Here the legends respectively (from the left) are: lag periods, daily temperature and levels of relative risk (RR).

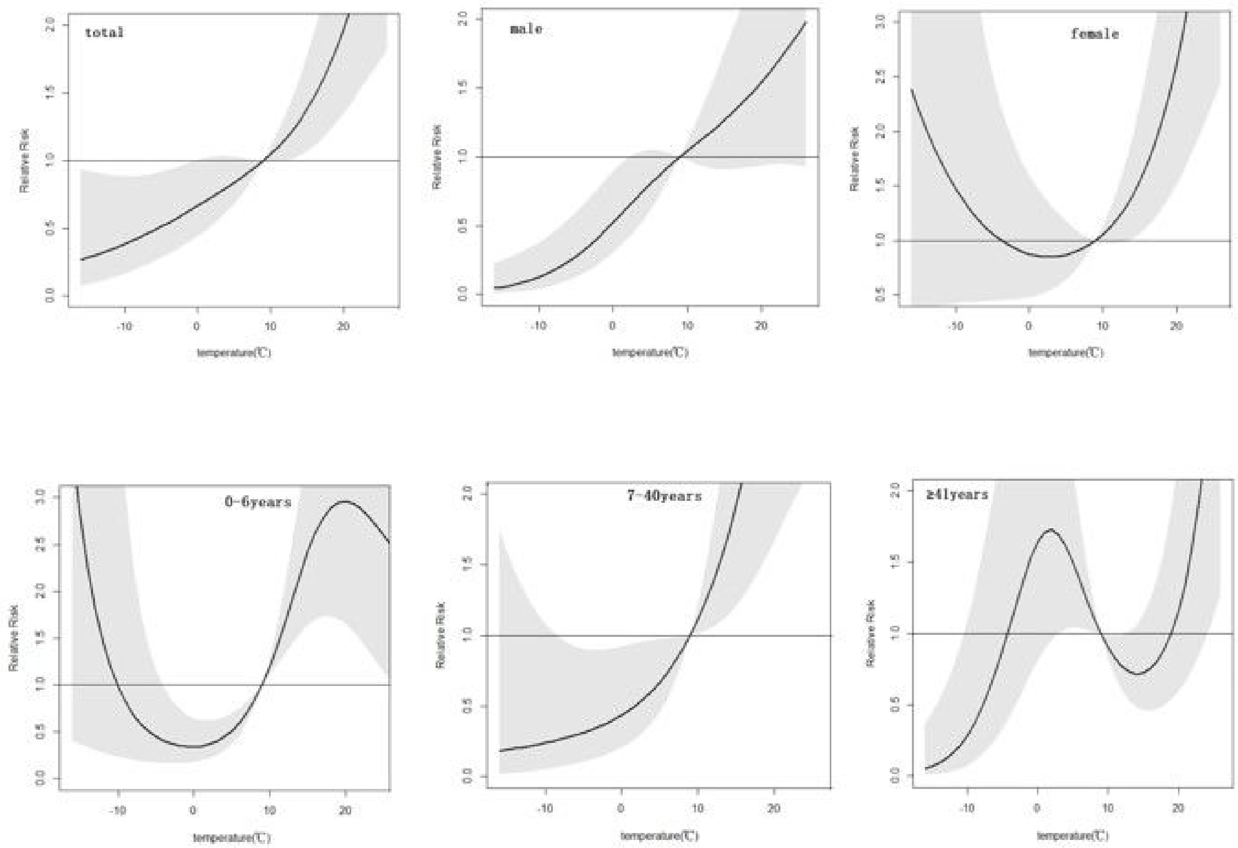

Figure 2

The overall effects of daily mean temperature on BD among different sex and age groups. RR (relative risk), Grey area (95% confidence intervals of overall effects of daily mean temperature).

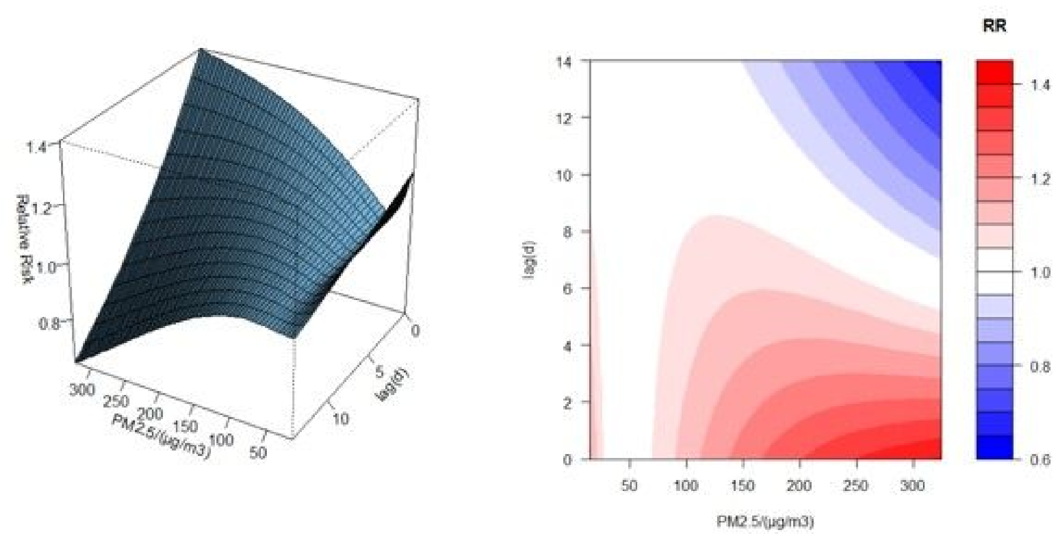

Figure 3

3D & Contour plot of RR along PM2.5 and lags, with ref. At 50μg/m3. (a) A 3D image of the relative risk (RR) of BD along the mean PM2.5 (here 50μg/m3) and lags. Here the legends respectively (from the left) are: relatively risk (RR), daily PM2.5 and lag periods. (b) A contour plot of the relative risk (RR) of BD along mean PM2.5 (here 50μg/m3) and lags. Here the legends respectively (from the left) are: lag periods, daily PM2.5 and levels of relative risk (RR).

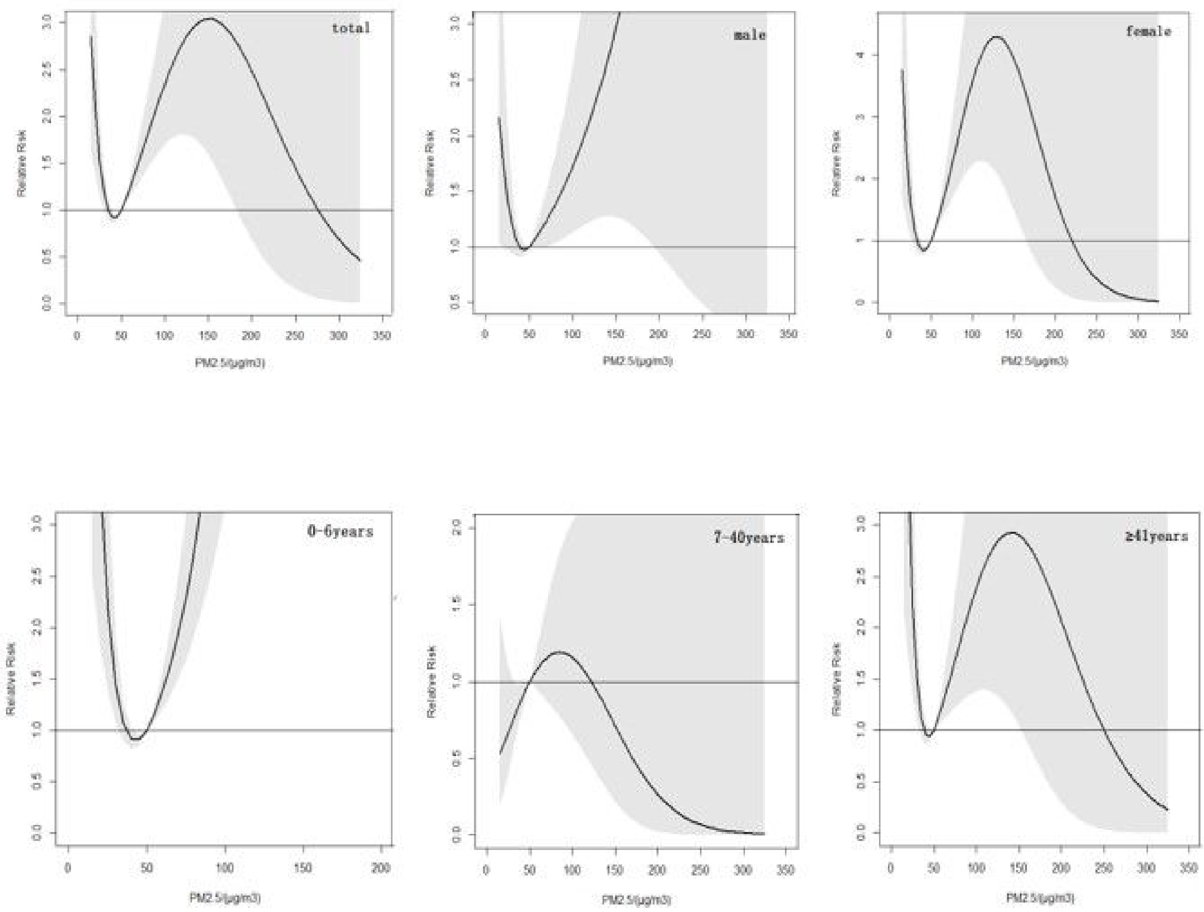

Figure 4

The overall effects of daily mean PM2.5 on BD among different sex and age groups. RR (relative risk), Grey area (95% confidence intervals of overall effects of daily mean PM2.5).

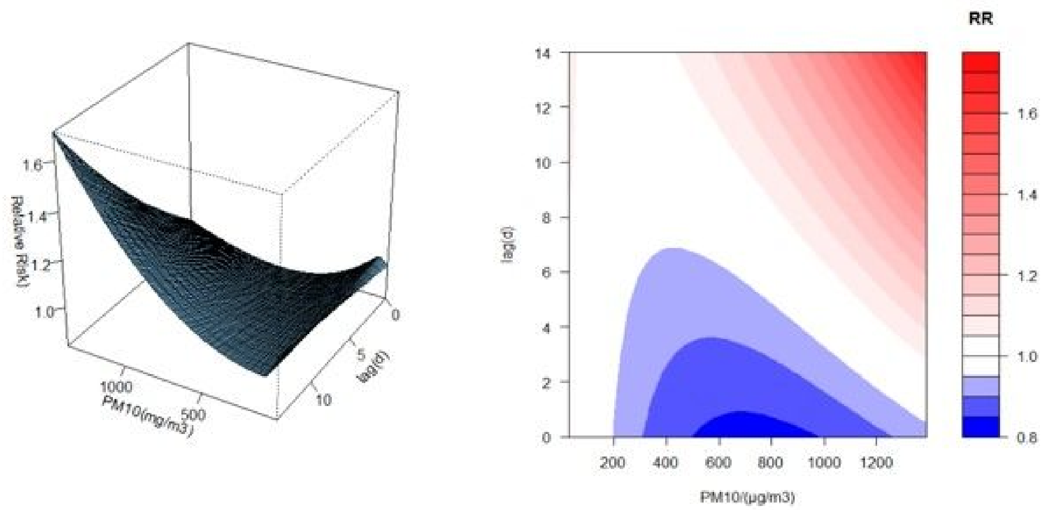

Figure 5

3D & Contour plot of RR along PM10 and lags, with ref. At 110μg/m3. (a) A 3D image of the relative risk (RR) of BD along the mean PM10 (here 110μg/m3) and lags. Here the legends respectively (from the left) are: relatively risk (RR), daily PM10and lag periods. (b) A contour plot of the relative risk (RR) of BD along mean PM10 (here 110μg/m3) and lags. Here the legends respectively (from the left) are: lag periods, daily PM10 and levels of relative risk (RR).

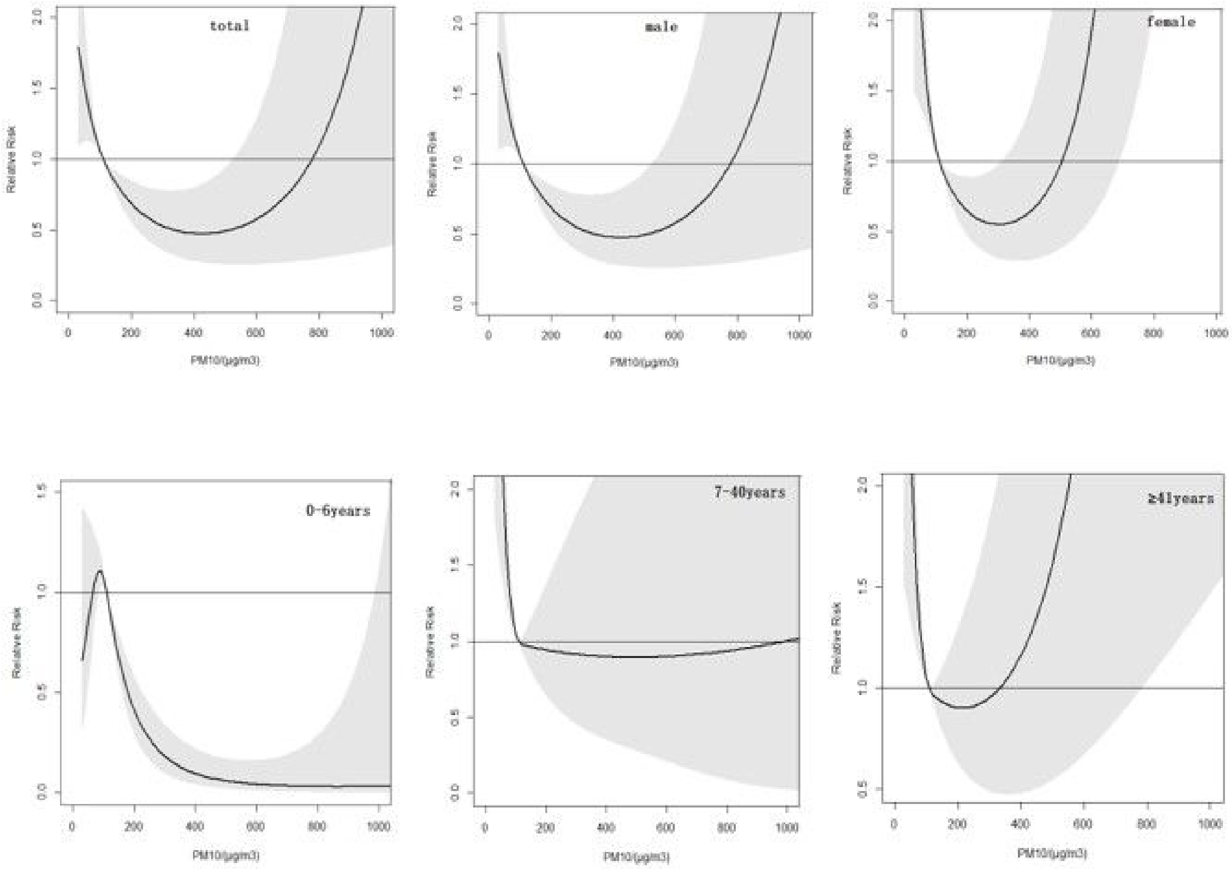

Figure 6

The overall effects of daily mean PM10 on BD among different sex and age groups. RR (relative risk), Grey area (95% confidence intervals of overall effects of daily mean PM10).