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Method Established for Source Apportionment of Human Health Risk in Regional Atmospheric Environment

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Abstract: Previous studies of source apportionment were only focused on contribution rates of pollutants concentration, but have not evaluated contribution rates of influencing degree of pollutants on people's health. To assess the health risk of pollution source to human health in the atmospheric environment, a method of source apportionment of human health risk, which the health risk assessment method combined with the source apportionment receptor model, was established in this research. Based on each pollution source contribution to metallic elements in inhalation particle matter (PM_{10}) at the sampling site of Lanzhou University, the health risks contribution rates to exposed group were estimated according to the established method, and compared with the results of source apportionment. The results were as follows: the concentration contribution rates calculated by chemical mass balance (CMB) model rank from high to low as vehicle exhaust dust (43.4%), urban fugitive dust (29.9%), coal fly ash (21.5%), construction cement dust (1.2%) and metal smelt dust (0.7%); the non-carcinogen hazard index (R^n) contribution rates rank from high to low as urban fugitive dust (87.7%), vehicle exhaust dust (5.9%), coal fly ash (3.0%), metal smelt dust (2.5%) and construction cement dust (0.9%); the cancer risk value of carcinogen (R^c) contribution rates rank from high to low as urban fugitive dust (97.1%), vehicle exhaust dust (1.7%), coal fly ash (0.5%), metal smelt dust (0.5%) and construction cement dust (0.2%). Apparently, the concentration contribution rates were very different from the hazard index of non-carcinogen (R^n) contribution rates and the cancer risk value (R^c) contribution rates. The source with the highest concentration contribution was not the major influence on human health. The influence of source with the contribution rate lowest concentration contribution on human health should not be ignored. This method could also be used in health risk assessment of other pollutants from other sources.

Keywords: Health Risk Assessment Method, Chemical Mass Balance Model, Source Profiles, Contribution Rate, Respiratory Inhalation

1. Introduction

Atmospheric particulate matters have become the major component of urban air pollution currently in China. Inhalable particle matters (PM_{10}) have great damage to human health because PM_{10} is toxic and harmful, and adsorb much toxic and harmful substance due to its large surface area [1-3]. International Agency for Research on Cancer announced that air pollution could result in cancer and the atmospheric pollutants were regarded as carcinogens in 2013 [4]. Moreover, the prevalence [5-7] and death rates [8-10] of respiratory disease and cardiovascular disease can be increased by exposure in high concentrations or a small range increased [11-12] of particulate matter. Source apportionment can offer the pollutant source types and the contribution rates, which are the foundations for taking atmospheric pollution control measures and providing basic data of urban development planning decisions [13]. However, there is an issue that the results of source apportionment are pollutants concentration contribution rates not rates of influencing degree of pollutants on people's health. Philip K Hopke [14] concluded that

National Ambient Air Quality Standards for PM use airborne particle mass as the indicator for making air quality determinations, but it seems highly likely that some types of particles are more toxic than others. And that is, different kinds of toxic species in one pollutant source have different level damage to human health [15]. So in order to provide more rational and scientific data for atmospheric pollution control, the effect of pollutants on human health would be seriously considered in source apportionment. However, there have been very few published efforts to relate apportioned sources to human health effects [14, 16]. The health risk assessment is a method that quantitatively assessed the health risk effect to exposed group caused by environmental pollution measured by risk degree. In this paper, the health risk values to exposed group caused by the pollution sources contributing to metallic elements in PM_{10} at Lanzhou University were calculated according to the health risk assessment combined with receptor model which supplies scientific basis for air pollution control, environment management and decisions.

2. Methods and Data

2.1. Theory

The contribution concentration of pollution sources was calculated by receptor model of source apportionment. According to the above contribution concentration and source profiles of the pollution sources, the contribution concentration of each component in each pollution source was calculated.

According to the health risk assessment method [17-19], the health risk to exposed group caused by each component in pollution sources through respiratory inhalation was assessed. The method is as follows:

$$D = q \times IR \times EF \times ED / (BW \times AT) \quad (1)$$

D is the amount of the average daily intake of pollutants in some exposure way ($mg\cdot(kg\cdot d)^{-1}$), q is the concentration of pollutants in the atmosphere ($mg\cdot m^{-3}$), IR is the inhalation rate ($mg\cdot d^{-1}$), EF is the exposure frequency ($d\cdot a^{-1}$), ED is the exposure duration (a), BW is the body weight (kg), and AT is the average exposure duration (d).

$$R^{n} = D / RfD \quad (2)$$

$$R^{c} = D \times SF \quad (3)$$

R^{n} is the hazard index of non-carcinogen through some exposure way, RfD is the reference dose for non-carcinogen through some exposure way ($mg\cdot(kg\cdot d)^{-1}$), R^{c} is the cancer risk value through some exposure way, and SF is the carcinogenic potency factor through some exposure way, ($[mg\cdot(kg\cdot d)^{-1}]^{-1}$).

The joint toxic effects of each component were considered only additional effects. The health risk values to exposed group caused by PM_{10} from each pollution source were calculated by adding health risk value of each component in each pollution source, at last, health risk contribution rates of each pollution source were calculated by the health risk value of PM_{10} from each pollution source dividing their sum. And last, it is proved that it is necessary to take the health risk influences into account for establishing rational and efficient air pollution control measures by comparing the health risks values contribution rates of each pollution source with concentration contribution rates of each pollution source. The theory roadmap is showed in Figure 1.

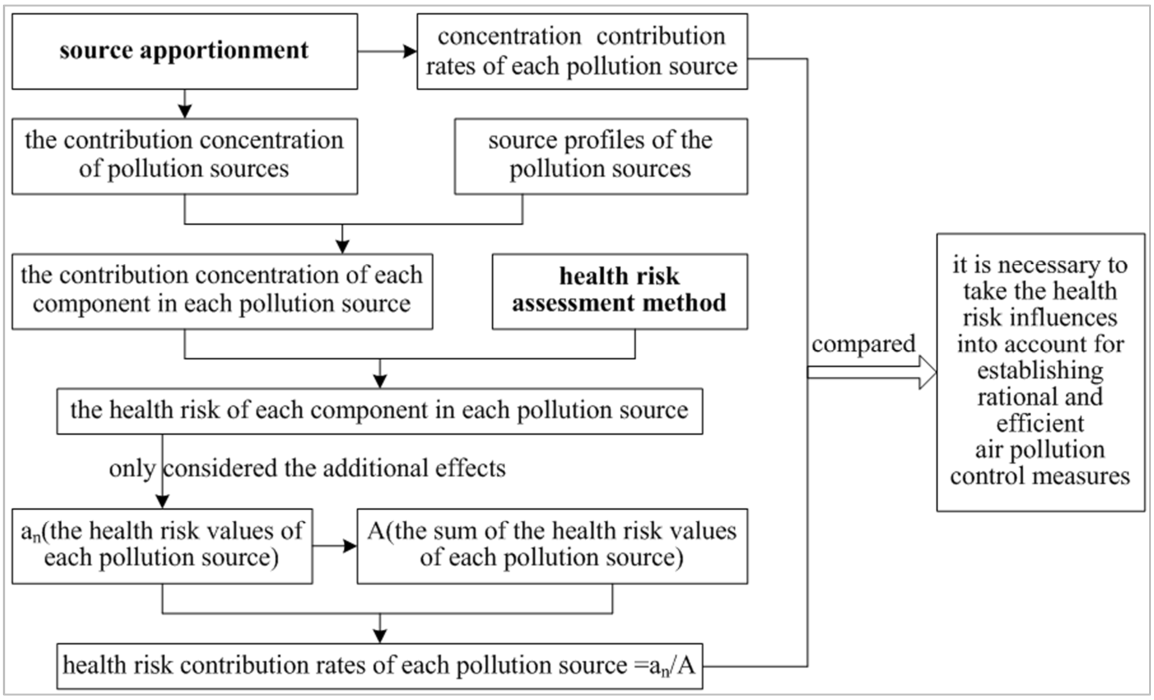

Figure 1. *The theory roadmap.*

2.2. Data

Ambient PM_{10} samples were collected on the roof of the meteorological building at Lanzhou University in 2010. PM_{10} were collected on Teflon membrane filters using medium flow air sampler (KB-120) for analysis of the metallic elements. Samplers were operated for 20 hr at a flow rate of 100L/min. Samples were analyzed by an inductively coupled plasma-atomic emission spectrometry (ICP-AES). Details of instrument settings and analytical parameters (resolutions, calibration, instrument detection limits) can be found elsewhere [20].

The source profiles are showed in Figure 2. The source profiles of construction cement dust, soil dust, urban fugitive dust are measured, while the source profiles of coal fly ash and metal smelt dust are replaceable source profiles suitable for Lanzhou City [20], and the source profiles of vehicle exhaust dust is from USEPA.

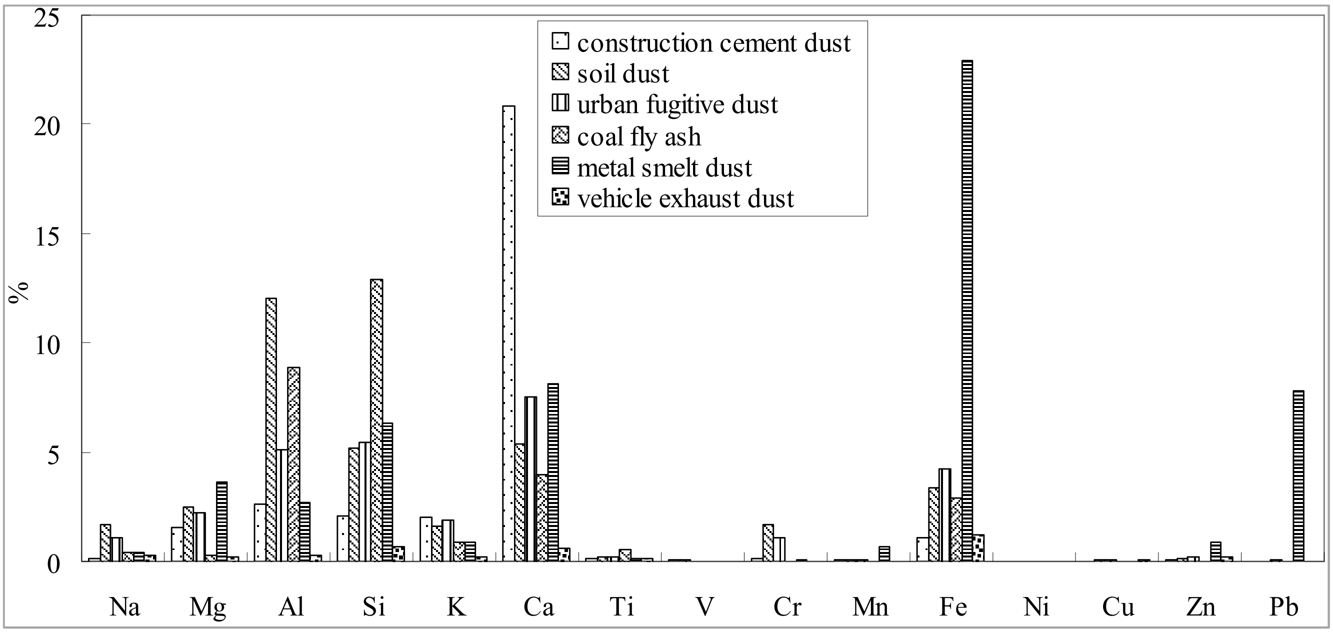

Figure 2. *Source profiles of metallic element in PM_{10} in Lanzhou city.*

2.3. Parameter Selection

It's important to note that all kinds of fractions in PM_{10} have great damage to different ages groups' health, but the health risk values of metallic elements to children and elderly people just be focused on in this paper. The established method also could be used to analyze the health impacts of other fractions to all groups.

The age (younger than 6 years old and older than 60 years old) and the sex (female and male) of exposed group were considered as the literature [21]. The RfD and the SF of metallic elements through respiratory inhalation are showed in table 1 [22]. According to US Environmental Protection Agency (USEPA), when the R^n exceeds 1, the toxic species can be harmful to human health. The generally acceptable risk value of R^c is 10^{-6} and the acceptable risk value is 10^{-4} [23-24].

Table 1. *RfD and SF of metallic element.*

Metallic element	V	Cr	Mn	Ni	Cu	Zn	Pb
RfD [mg/(kg·d)]	7.00×10^{-3}	2.86×10^{-5}	1.43×10^{-5}	2.06×10^{-2}	4.02×10^{-2}	3.00×10^{-1}	3.52×10^{-3}
SF [mg/(kg·d)]-1	/	42	/	0.84	/	/	/

3. Result and Discussion

3.1. Comparison Between the Health Risk Contribution Rates and the Concentration Contribution Rates

The source apportionment results were obtained by CMB model based on the data of metallic elements in PM_{10} on the roof of the meteorological building at Lanzhou University in 2010. The results are showed in Figure 3.

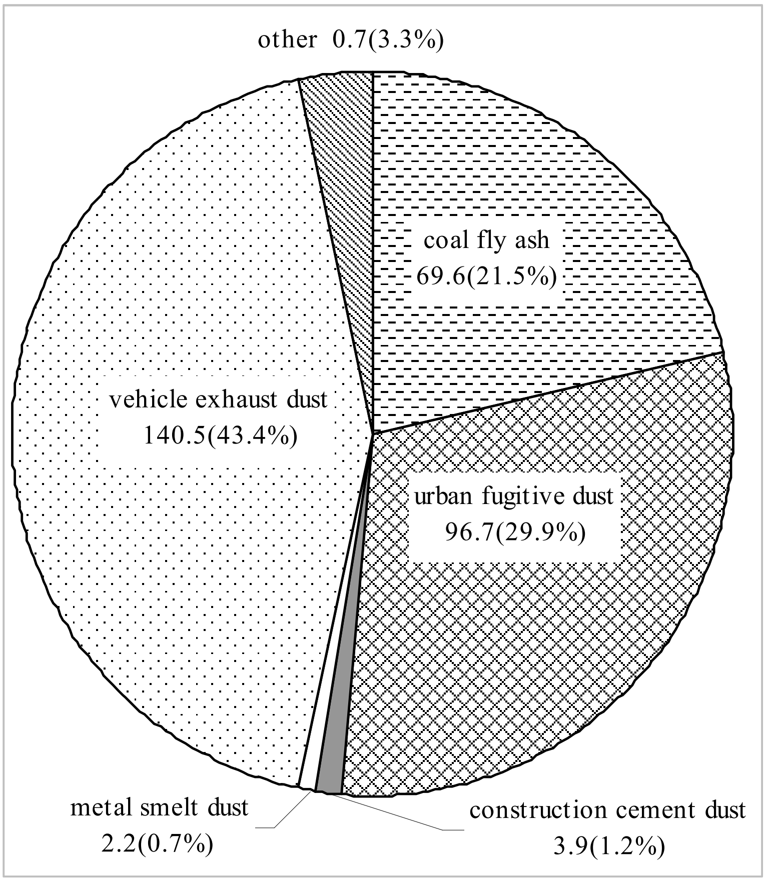

Figure 3. *The source apportionment result of metallic element in PM_{10} in Lanzhou city (The data of outside the parentheses are contribution concentrations (μg/m^3) and the data of inside are contribution rates).*

As shown in figure 3, the pollution sources and concentration contribution rates to metallic elements in PM_{10} at Lanzhou University by CMB model ranked from high to low as vehicle exhaust dust (43.4%), urban fugitive dust (29.9%), coal fly ash (21.5%), construction cement dust (1.2%) and metal smelt dust (0.7%).

As the method in the second part, R^n and contribution rates, R^c and contribution rates to exposed group caused by each pollution source are calculated and showed in table 2.

Table 2. *R^n, R^c and those contribution rates to exposed group caused by each pollution source.*

	Younger than 6 years old				**Older than 60 years old**			
	Male		**Female**		**Male**		**Female**	
	R^n	Rates (%)	R^n	Rates (%)	R^n	Rates (%)	R^n	Rates (%)
construction cement dust	1.19×10^{-2}	0.9	1.26×10^{-2}	0.9	4.85×10^{-2}	0.9	5.05×10^{-2}	0.9
urban fugitive dust	1.15	87.7	1.21	87.7	4.68	87.7	4.87	87.7
coal fly ash	3.97×10^{-2}	3.0	4.20×10^{-2}	3.0	1.62×10^{-1}	3.0	1.69×10^{-1}	3.0
metal smelt dust	3.22×10^{-2}	2.5	3.40×10^{-2}	2.5	1.32×10^{-1}	2.5	1.37×10^{-1}	2.5
vehicle exhaust dust	7.66×10^{-2}	5.9	8.10×10^{-2}	5.9	3.13×10^{-1}	5.9	3.26×10^{-1}	5.9
	R^c	Rates (%)	R^c	Rates (%)	R^c	Rates (%)	R^c	Rates (%)
construction cement dust	6.82×10^{-6}	0.5	7.20×10^{-6}	0.5	2.78×10^{-5}	0.5	2.90×10^{-5}	0.5
urban fugitive dust	1.20×10^{-3}	97.1	1.27×10^{-3}	97.1	4.92×10^{-3}	97.1	5.12×10^{-3}	97.1
coal fly ash	6.37×10^{-6}	0.5	6.73×10^{-6}	0.5	2.60×10^{-5}	0.5	2.71×10^{-5}	0.5
metal smelt dust	1.93×10^{-6}	0.2	2.04×10^{-6}	0.2	7.89×10^{-6}	0.2	8.21×10^{-6}	0.2
vehicle exhaust dust	2.11×10^{-5}	1.7	2.23×10^{-5}	1.7	8.61×10^{-5}	1.7	8.96×10^{-5}	1.7

As shown in table 2, the contribution rates of R^n and R^c caused by each pollution source are not associated with sex and age. The R^n caused by urban fugitive dust was greater than 1 and the R^c caused by urban fugitive dust was greater than 10^{-4}. All of them were beyond the corresponding acceptable values. The R^n and the R^c caused by other pollution sources all were within the acceptable range. The R^n contribution rates ranked from high to low as urban fugitive dust (87.7%), vehicle exhaust dust (5.9%), coal fly ash (3.0%), metal smelt dust (2.5%) and construction cement dust (0.9%); the R^c contribution rates ranked from high to low as urban fugitive dust (97.1%), vehicle exhaust dust (1.7%), coal fly ash (0.5%), metal smelt dust (0.5%) and construction cement dust (0.2%).

Comparison on the contribution rates of R^n, R^c and concentration, the results are showed in Figure 4.

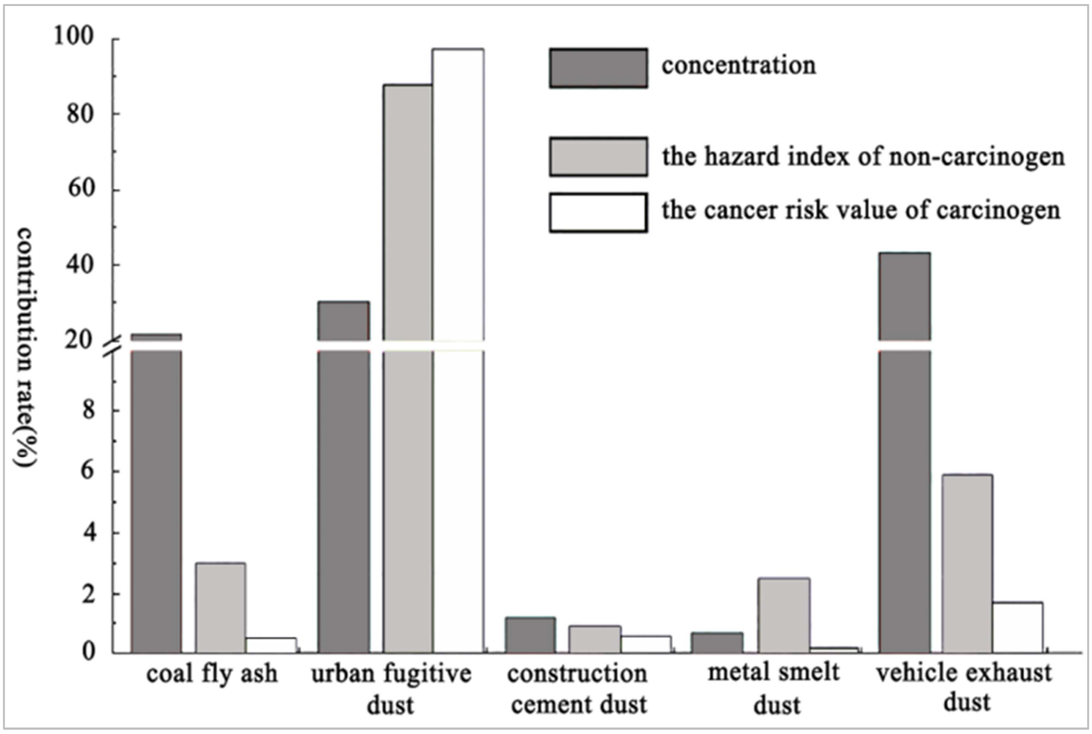

Figure 4. *The contribution rates comparison of the R^n, the R^c and concentration.*

As shown in figure 4, the concentration contribution rates were very different from the R^n contribution rates and the R^c contribution rates. In other words, the source with the highest concentration contribution was not the major influence on human health. The influence of source with the lowest concentration contribution on human health should not be ignored. Therefore, it is necessary to take the health risk influences into account for establishing rational and efficient air pollution control measures.

3.2. R^n and R^c of Metallic Element in Each Pollution Source

The Rn and Rc to exposed group caused by metallic element in each pollution source are calculated and showed in table 3 and table 4.

Table 3. *The R^n to exposed group caused by metallic element in each pollution source.*

Exposed group	Pollution source	V	Cr	Mn	Ni	Cu	Zn	Pb
Male of younger than 6 years old	construction cement dust	1.43×10^{-5}	5.67×10^{-3}	6.19×10^{-3}	1.90×10^{-7}	4.87×10^{-7}	1.19×10^{-7}	0.00
	urban fugitive dust	3.71×10^{-5}	1.00	1.43×10^{-1}	1.94×10^{-5}	2.96×10^{-5}	1.53×10^{-5}	2.57×10^{-4}
	coal fly ash	2.40×10^{-5}	5.28×10^{-3}	3.44×10^{-2}	1.28×10^{-6}	3.20×10-6	1.26×10-8	5.42×10-5
	metal smelt dust	6.40×10^{-7}	1.60×10^{-3}	2.93×10^{-2}	7.57×10^{-7}	1.27×10-5	2.19×10-7	1.32×10-3
	vehicle exhaust dust	1.80×10^{-4}	1.73×10^{-2}	5.87×10^{-2}	1.48×10^{-5}	7.59×10^{-5}	1.02×10^{-6}	3.47×10^{-4}
Female of younger than 6 years old	construction cement dust	1.51×10^{-5}	5.99×10^{-3}	6.54×10^{-3}	2.01×10^{-7}	5.15×10^{-7}	1.26×10^{-7}	0.00
	urban fugitive dust	3.92×10^{-5}	1.06	1.51×10^{-1}	2.05×10^{-5}	3.13×10^{-5}	1.61×10^{-5}	2.71×10^{-4}
	coal fly ash	2.54×10^{-5}	5.59×10^{-3}	3.63×10^{-2}	1.36×10^{-6}	3.38×10^{-6}	1.33×10^{-8}	5.73×10^{-5}
	metal smelt dust	6.76×10^{-7}	1.69×10^{-3}	3.09×10^{-2}	8.00×10^{-7}	1.34×10^{-5}	2.31×10^{-7}	1.40×10^{-3}
	vehicle exhaust dust	1.90×10^{-4}	1.83×10^{-2}	6.20×10^{-2}	1.57×10^{-5}	8.02×10^{-5}	1.08×10^{-6}	3.67×10^{-4}
Male of older than 60 years old	construction cement dust	5.85×10^{-5}	2.32×10^{-2}	2.53×10^{-2}	7.77×10^{-7}	1.99×10^{-6}	4.87×10^{-7}	0.00
	urban fugitive dust	1.52×10^{-4}	4.10	5.83×10^{-1}	7.91×10^{-5}	1.21×10^{-4}	6.24×10^{-5}	1.05×10^{-3}
	coal fly ash	9.81×10^{-5}	2.16×10^{-2}	1.40×10^{-1}	5.24×10^{-6}	1.31×10^{-5}	5.14×10^{-8}	2.21×10^{-4}
	metal smelt dust	2.61×10^{-6}	6.52×10^{-3}	1.20×10^{-1}	3.09×10^{-6}	5.19×10^{-5}	8.94×10^{-7}	5.40×10^{-3}
	vehicle exhaust dust	7.34×10^{-4}	7.08×10^{-2}	2.40×10^{-1}	6.05×10^{-5}	3.10×10^{-4}	4.15×10^{-6}	1.42×10^{-3}
Female of older than 60 years old	construction cement dust	6.09×10^{-5}	2.41×10^{-2}	2.63×10^{-2}	8.08×10^{-7}	2.07×10^{-6}	5.07×10^{-7}	0.00
	urban fugitive dust	1.58×10^{-4}	4.26	6.06×10^{-1}	8.23×10^{-5}	1.26×10^{-4}	6.49×10^{-5}	1.09×10^{-3}
	coal fly ash	1.02×10^{-4}	2.25×10^{-2}	1.46×10^{-1}	5.46×10^{-6}	1.36×10^{-5}	5.35×10^{-8}	2.30×10^{-4}
	metal smelt dust	2.72×10^{-6}	6.79×10^{-3}	1.24×10^{-1}	3.22×10^{-6}	5.40×10^{-5}	9.31×10^{-7}	5.62×10^{-3}
	vehicle exhaust dust	7.64×10^{-4}	7.37×10^{-2}	2.49×10^{-1}	6.29×10^{-5}	3.23×10^{-4}	4.32×10^{-6}	1.47×10^{-3}

Table 4. *The cancer risk value to exposed group caused by metallic element in each pollution source.*

Exposed group	Pollution source	Cr	Ni
	construction cement dust	6.81×10^{-6}	3.29×10^{-9}
	urban fugitive dust	1.20×10^{-3}	3.35×10^{-7}
Male of younger than 6 years old	coal fly ash	6.35×10^{-6}	2.22×10^{-8}
	metal smelt dust	1.92×10^{-6}	1.31×10^{-8}
	vehicle exhaust dust	2.08×10^{-5}	2.56×10^{-7}
	construction cement dust	7.20×10^{-6}	3.48×10^{-9}
	urban fugitive dust	1.27×10^{-3}	3.54×10^{-7}
Female of younger than 6 years old	coal fly ash	6.71×10^{-6}	2.35×10^{-8}
	metal smelt dust	2.03×10^{-6}	1.38×10^{-8}
	vehicle exhaust dust	2.20×10^{-5}	2.71×10^{-7}
	construction cement dust	2.78×10^{-5}	1.34×10^{-8}
	urban fugitive dust	4.92×10^{-3}	1.37×10^{-6}
Male of older than 60 years old	coal fly ash	2.59×10^{-5}	9.08×10^{-8}
	metal smelt dust	7.84×10^{-6}	5.35×10^{-8}
	vehicle exhaust dust	8.51×10^{-5}	1.05×10^{-6}
	construction cement dust	2.89×10^{-5}	1.40×10^{-8}
	urban fugitive dust	5.12×10^{-3}	1.42×10^{-6}
Female of older than 60 years old	coal fly ash	2.70×10^{-5}	9.44×10^{-8}
	metal smelt dust	8.15×10^{-6}	5.56×10^{-8}
	vehicle exhaust dust	8.85×10^{-5}	1.09×10^{-6}

As shown in table 3, the R^n caused by each metallic element in each source to male was lower than that to female, and to younger than 6 years old groups was lower than that to older than 60 years old groups. The R^n to exposed group caused by each metallic element in construction cement dust ranked from high to low as Mn, Cr, V, Cu, Ni, Zn and Pb, and all of them exceeded the acceptable value. The R^n to exposed group caused by each metallic element in urban fugitive dust ranked from high to low as Cr, Mn, Pb, V, Cu, Ni and Zn. The R^n caused by Cr ranged from 1.00 to 4.26 and exceeded the acceptable value. The R^n caused by other metallic elements was all within the acceptable range. The R^n to exposed group caused by each metallic element in coal fly ash and vehicle exhaust dust ranked from high to low as Mn, Cr, Pb , V, Cu, Ni and Zn. The R^n caused by each metallic element in metal smelt dust ranked from high to low as Mn, Cr, Pb, Cu, Ni V, and Zn. All of them were within the acceptable range.

As shown in table 4, the R^c caused by each metallic element in each contribution pollution source to male was lower than that to female, and to younger than 6 years old groups was lower than that to older than 60 years old groups. The R^c caused by Cr in each contribution pollution source was higher than that by Ni. The R^n to exposed group caused by Cr in construction cement dust, coal fly ash and metal smelt dust exceeded the generally acceptable value, but were within the acceptable range. The R^n to exposed group caused by Cr in above dust was within the generally acceptable range. The R^n to exposed group caused by Cr in urban fugitive dust was within the acceptable range. The R^n to exposed group caused by Cr in vehicle exhaust dust was beyond the generally acceptable value, but was within the acceptable range. The R^n to older than 60 years old groups caused by Ni in urban fugitive dust and vehicle exhaust dust were beyond the generally acceptable value, but were within the acceptable range. The R^n to other groups was within the generally acceptable range.

4. Conclusion

The health risks contribution rates of the sources contributing to metallic elements in PM_{10} to exposed group were calculated according to the source apportionment results and health risk assessment method. the concentration contribution rates by CMB model ranked from high to low as vehicle exhaust dust, urban fugitive dust, coal fly ash, construction cement dust and metal smelt dust; the non-carcinogen hazard index contribution rates and the carcinogenic risk contribution rates ranked from high to low as urban fugitive dust, vehicle exhaust dust, coal fly ash, metal smelt dust and construction cement dust. Apparently, the concentration contribution rates were very different from non-carcinogen hazard index contribution rates and carcinogenic risk contribution rates. This finding may indicate that source with the highest concentration contribution was not the major influence on human health and the influence of source with the lowest concentration contribution on human health should not be ignored.

The method of source apportionment of human health risk was established in this paper combined health risk assessment with receptor model to analyze source apportionment of human health risk in regional atmospheric environment. The health risks contribution rates to exposed group caused by each pollution sources contributing to metallic elements in PM_{10} at Lanzhou University were calculated according to the established method. The results could supply scientific basis for air pollution control. And this method could also be used in health risk assessment of other pollutants from other sources.

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