Study on the Current Situation and Source Apportionment of $PM_{2.5}$ Pollution in China

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Abstract In this paper, using concentration data of $PM_{2.5}$ in 2013 in China and referring to a lot of literature, we preliminary studied the pollution of fine particulate matter and summarized $PM_{2.5}$ source apportionment in the key cities in China. Our results showed that $PM_{2.5}$ showed significant spatial and temporal distribution; high surface concentrations of $PM_{2.5}$ concentrated mainly in the North China Plain, the Sichuan Basin, Yangtze River Delta and other regions; the average annual concentration of $PM_{2.5}$ was about 80 μg/m^3 in North China Plain; Seasonal changes in the concentration of $PM_{2.5}$ was winter > spring > autumn > summer; fired sources, industrial sources, vehicle exhaust were the major sources of $PM_{2.5}$; motor vehicle exhaust mostly contributed 10% – 30% to $PM_{2.5}$. This review provides a fundamental understanding of $PM_{2.5}$ source apportionment and serves as an important reference for future source apportionment studies to be widely conducted in China.

Key words China, $PM_{2.5}$, Source apportionment, Pollution characteristics

1 Introduction

With China's rapid economic development, accelerated process of urbanization and expansion of industrial scale, the regional air pollution is worsening[1]. The recent haze with fine particulate matter as characteristic pollutants occurring in many areas of China, has posed a huge threat to visibility, public health and urban landscape[2–3]. The fine particulate matter is a dominant factor causing the haze phenomenon, which consists of primary particles and secondary particles directly discharged into the air. The primary particles are mainly composed of dust particles and carbon black particles arising from the combustion of plant and fossil fuel; the secondary particles are mainly composed of sulfate, nitrate and ammonium, often causing greater pollution than conventional air pollutants[4]. The newly revised *Ambient Air Quality Standards* (GB3095 – 2012) in 2012[5] included $PM_{2.5}$ in the conventional air quality assessment, and it was the first time for China to develop $PM_{2.5}$ standards. Monitoring shows that the average annual concentration of $PM_{2.5}$ in many cities of China exceeds the national standard, and the study of pollution levels and characteristics of $PM_{2.5}$ in atmosphere can provide a theoretical basis for further researching its source and prevention measures. Using the scientific source apportionment method to determine the source of $PM_{2.5}$ is the key to control and governance, and the source apportionment of atmospheric particulate matter is mainly to carry out qualitative or quantitative identification of sources of atmospheric particles. China's source apportionment studies started late, and it did not perform the source apportionment studies until the late 1980s[6]. At present, the source apportionment methods mainly include source checklist method, source model method, receptor model method and the method of combining source model with receptor model. China now mainly uses the receptor model as the analytical instrument. In *Technical Guide for Source Apportionment of Atmospheric Particulate Matter* (Trial) developed in 2013[7], it proposed requirements on the source apportionment work of cities, urban agglomeration and regions by stages. Based on a lot of technical literature, this paper uses the fine particulate matter concentration data of key environmental protection cities in 2013 to summarize the pollution situation of fine particulate matter in China and source apportionment of fine particulate matter in the key cities, in order to provide a reference for other staff, and thus provide comprehensive effective information for management departments to minimize the adverse effects of $PM_{2.5}$ pollution.

2 Data sources

The $PM_{2.5}$ concentration data of 74 cities in 2013 are from Greenpeace[8] which collects full-year daily hourly $PM_{2.5}$ data about all stations in 2013 from public information platform of the Ministry of Environmental Protection and local environmental protection departments. On this basis, using the arithmetic average method, we calculate the annual average value of $PM_{2.5}$ in different cities, respectively. The 74 cities are the first batch of cities implementing *Ambient Air Quality Standards* (GB3095 – 2012), and they have more complete and continuous $PM_{2.5}$ monitoring data than other cities. The fine particulate matter concentration and source apportionment results of some other cities are from literature and related research reports.

3 $PM_{2.5}$ concentration distribution in China

3.1 Spatial distribution of $PM_{2.5}$ in China According to new Ambient Air Quality Standards, the average annual concentration of $PM_{2.5}$ at 35 μg/m^3 reaches the standard. In accordance with the air quality ranking of 74 cities released in 2013, the average annu-

Received: August 3, 2014 Accepted: October 15, 2014
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al concentration is highest in Xingtai City, up to 155 μg/m^3; the average annual concentration is lowest in Haikou City, up to 25.6 μg/m^3. The average annual concentration of $PM_{2.5}$ in nearly 92% of cities does not meet the national standards. The average annual concentration in the northern city of China is calculated at 89.9 μg/m^3; the average annual concentration in the southern city of China is calculated at 59.4 μg/m^3; the average annual concentration in the eastern city of China is calculated at 70.6 μg/m^3; the average annual concentration in the central city of China is calculated at 76.6 μg/m^3; the average annual concentration in the western city of China is calculated at 59.9 μg/m^3. The average annual concentration is highest in the northern cities while the average annual concentration of fine particulate matter is lowest in the southern cities. There are also air pollution problems in the central provinces, and the average annual concentration of $PM_{2.5}$ in Xi'an, Zhengzhou, Wuhan, Chengdu, Hefei, Taiyuan and other cities reaches more than twice the national standard.

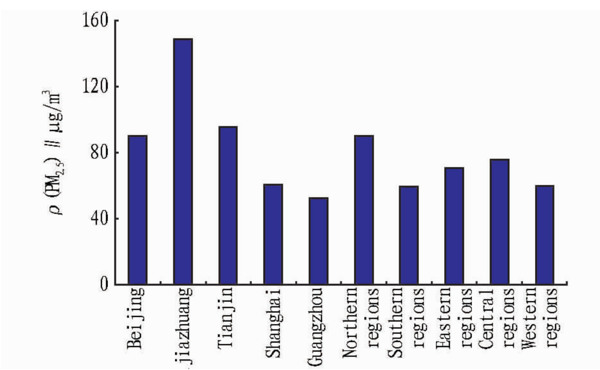
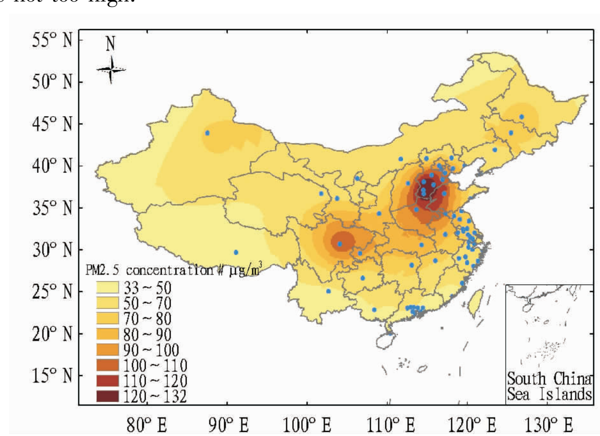


Fig. 1 The average annual value of $PM_{2.5}$ in the key cities and regions in 2013

Using Kriging interpolation method, we perform the spatial interpolation of the average annual concentration of $PM_{2.5}$ in China. Kriging or Gaussian process regression is a method of interpolation for which the interpolated values are modeled by a Gaussian process governed by prior covariances, as opposed to a piecewise-polynomial spline chosen to optimize smoothness of the fitted values[9]. Fig. 2 shows that in terms of spatial distribution, the regions with relatively high $PM_{2.5}$ concentration often have large area coverage, showing obvious regional characteristics. The high-value areas are mainly distributed in the North China Plain, the Sichuan Basin, eastern Hubei, northern Hunan, and the Yangtze River Delta region. These regions are economically developed, where the population is more concentrated and pollutant emission is large. The Sichuan Basin is mainly affected by terrain and weather conditions, and the pollutants are not easy to diffuse. In North China, due to considerable coal burning in winter and frequent temperature inversion, the air pollution is severe, and the dust and sand weather is frequent in spring, so the fine particulate matter concentration is also high. The average concentration of $PM_{2.5}$ throughout the region reaches 80 μg/m^3 or more, which is consistent with the depiction of global air quality map released by the United States National Aeronautics and Space Administration (NASA) (http://www.nasa.gov/topics/earth/features/health-sapping.html). In the southern regions, affected by East Asian monsoon and frequent precipitation, the average concentration of particulate matter is low. In the western regions, the source emission is low, so the average concentration of fine particulate matter is not too high.



Note: Basemap was download from the website of the State Bureau of Surveying and Mapping on September 11, 2012 (http://www.sbsm.gov.cn/article/zxbs/dtfw); the original map name is 100000000 schematic map version 1 (South China Sea coastline illustration); map checkup number is GS(2008)1228.

Fig. 2 The average annual value of $PM_{2.5}$ and distribution of 74 sites in China in 2013

3.2 Seasonal distribution of $PM_{2.5}$ in China To further analyze seasonal variation of $PM_{2.5}$ in various cities, we consult the relevant literature, and produce a summary as shown in Table 1.

Table 1 Seasonal variation of $PM_{2.5}$ in different cities (μg/m^3)

	Monitoring year	Spring	Summer	Fall	Winter	Cited in the literature
Beijing	2013	83	78	82	114.8	[10]
Shanghai	2011-2012	47.8	30.5	39.1	54	[11]
Nanjing	2007	95.5	91.5	79	98	[12]
Harbin	2008-2009	130	60	50	147	[13]
Jinan	2009-2010	108.4	115.9	151	176.8	[14]
Tianjin	2009-2010	71.88	109.86	121.84	118.69	[15]
Chongqing	2004-2005	104.8	61.2	92.1	99.3	[16]
Guangzhou	2002	68.96	57.99	94.06	80.1	[17]

In terms of seasonal distribution, a full year is divided into spring (March to May), summer (June to August), fall (September to November) and winter (December, January and February). From the summarized literature results in Table 1, it is found

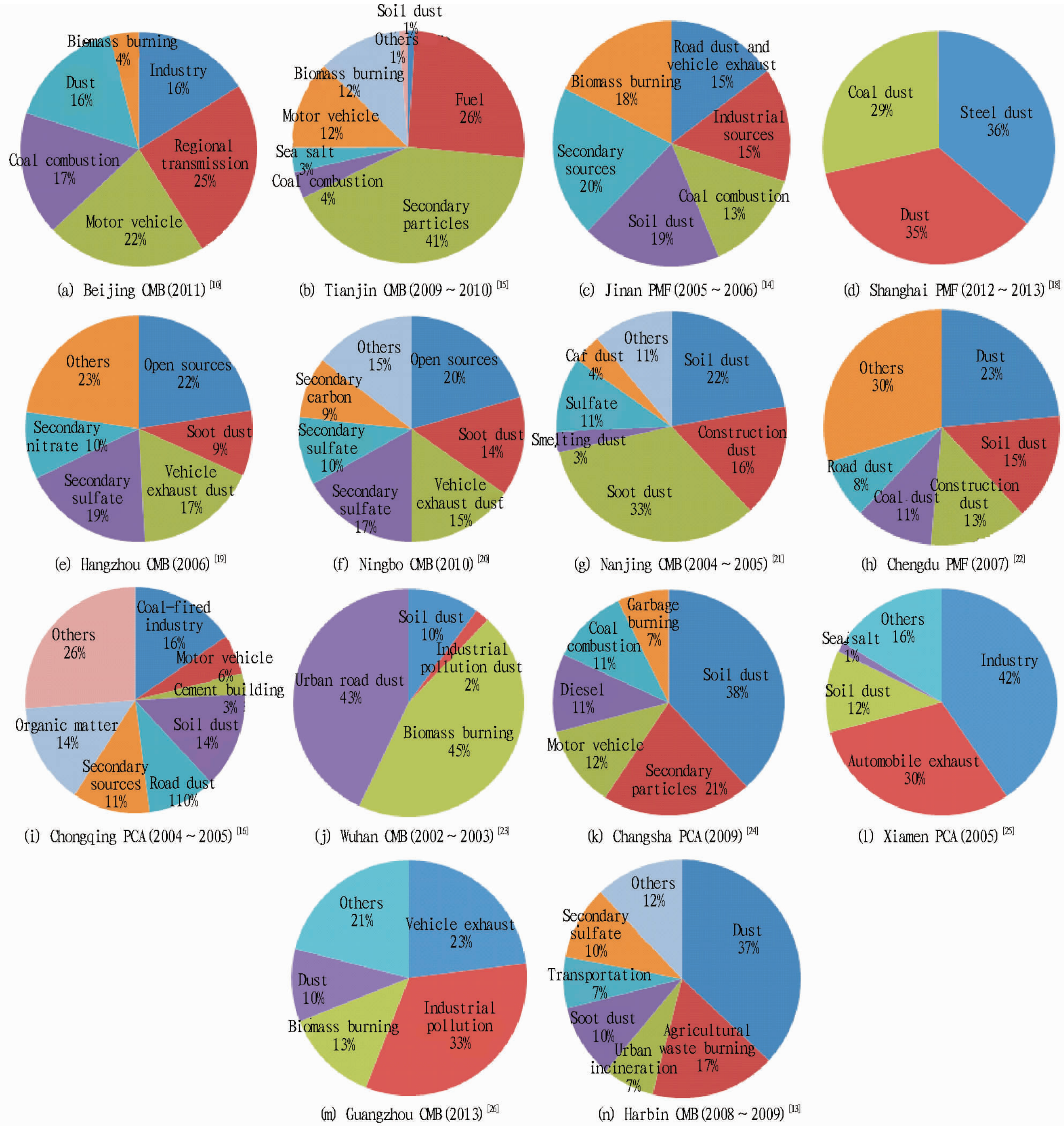


Fig. 3 $PM_{2.5}$ source apportionment results in different cities

that in terms of seasonal changes in $PM_{2.5}$ concentration in the eight cities, it is sequenced as follows: winter > spring > autumn > summer. The $PM_{2.5}$ mass concentration in winter and spring is significantly higher than in summer and fall. The highest values occur in winter, and the average concentration in winter in the eight cities is 111.1 $\mu g/m^3$; the lowest values occur in summer, and the average concentration in winter in the eight cities is 75.6 $\mu g/m^3$. There is little difference in the concentration between spring and fall. The average concentration of $PM_{2.5}$ in winter in the northern cities is significantly higher than in the southern cities. Winter is the heating season, so the pollution is heavy. In the southern cities, the precipitation is great, and the average concentration of particulate matter is not too high. Due to unstable weather system changes, the dispersion conditions in Spring and fall are better than in other seasons.

4 Source apportionment results of the key cities

Coal, cars, cooking fumes and burning firewood in rural areas are all direct sources of $PM_{2.5}$, forming the primary particulate matter; sulfur dioxide, nitrogen oxides in the exhaust after the coal and oil combustion as well as the volatile organic matter generated in the process of motor vehicle use, oil processing and solvent use, produce physical and chemical reaction in the air, forming secondary particulate matter. The particulate matter source apportionment methods include receptor model method, source inventory method, diffusion model simulation method, and the combination of source model and receptor model. Source inventory method is to identify the major sources of emissions that contribute to the receptor according to the collection of pollutants emitted by various sources of emissions into the air in a certain time span and space. Source model method is to estimate the contribution of pollution sources to receptors according to various pollution sources intensity data, meteorological data and atmospheric chemical processes. Receptor model method is to estimate the contribution of various pollution sources to receptors based on the chemical, physical and biological information of atmospheric particulate matter, including CMB model on the basis of source and receptor component spectrum and statistical model only based on receptor component spectrum. The combination of source model and receptor model is to use the two models at the same time, making analytical results more reasonable. Currently receptor model is widely used in China, and CMB model is used in 47% of current domestic literature and reports on source apportionment[6]. To better illustrate the $PM_{2.5}$ sources in various cities of China, we consult the literature and research reports published on $PM_{2.5}$ source apportionment in China, and summarize the $PM_{2.5}$ source apportionment results of each city.

It can be found that although different cities use different source apportionment methods, the main source of fine particulate matter in the region is the local emissions, including coal-fired sources, industrial sources, vehicle exhaust, dust, secondary sources and regional transmission. Coal-fired sources, industrial sources and vehicle exhaust make the greatest contribution to $PM_{2.5}$, and the contribution of various pollution sources to $PM_{2.5}$ is mainly related to local energy structure, economic development, and weather conditions. Fig. 3 shows that vehicle exhaust contributes 10% – 50% to $PM_{2.5}$, while the contribution rate of other sources is 10% – 30%. Taking Beijing as an example, the literature results[10] indicate that vehicle contributed 22% to $PM_{2.5}$ in 2011, basically consistent with the study results of Tsinghua University[27] and Peking University[28–31]. There is a slight difference between this study result and $PM_{2.5}$ source apportionment results released by Beijing Municipal Environmental Protection Bureau during 2012 – 2013[32]. The differences between various research results are primarily due to variability of $PM_{2.5}$, methods and researchers' subjective factors. At the same time, we should note the differences in the pollution status, source apportionment results and economic development between various cities, and avoid the pure emphasis on local $PM_{2.5}$ emission reduction. Due to lack of complete list of air pollution emission sources as yet, there are great uncertainties in the current studies on $PM_{2.5}$ source apportionment[33–34], and we need to further verify, assess and study the ways to effectively combine a variety of source apportionment methods to form reliable comprehensive source apportionment results and reduce errors in various links.

5 Conclusions

(i) $PM_{2.5}$ in China shows significant spatial and temporal distribution characteristics. $PM_{2.5}$ concentration is mainly distributed in the North China Plain, Sichuan Basin and Yangtze River Delta. The average annual concentration in North China is about 80 $\mu g/m^3$, and in terms of the seasonal variation in $PM_{2.5}$ concentration in various cities, it is sequenced as follows: winter > spring > autumn > summer.

(ii) Coal-fired sources, industrial sources and vehicle exhaust are the major sources of emissions making a significant contribution to $PM_{2.5}$, and motor vehicle exhaust contributes about 10% – 30% to $PM_{2.5}$.

(iii) Only by conducting systematic large-scale monitoring can we have a clear understanding of $PM_{2.5}$ pollution in China. Due to the lack of detailed $PM_{2.5}$ source inventory and differences in the methods for source apportionment, there are great uncertainties in the current studies.

References

[1] REN ZH, WAN BT, SU FQ, *et al*. Several characteristics of atmospheric environmental quality in China at present[J]. Research of Environmental Sciences, 2004, 17(1): 1 – 6. (in Chinese).

[2] WANG W, TANG DG, LIU HJ, *et al*. Research on current pollution status and pollution characteristics of $PM_{2.5}$ in China[J]. Research of Environmental Sciences, 2000, 13(1): 1 – 5. (in Chinese).

[3] China National Environmental Monitoring Center. Monitoring report on haze pilot, 2010[OL]. (2011 – 07 – 04)[2011 – 10 – 19]. http://www.cnemc.cn/publish/106/news/news_18191.html. (in Chinese).

[4] TANG XY, ZHANG YH, SHAO M, *et al*. Atmosphere environmental chemistry[M]. Beijing: Higher Education Press, 2006: 425 – 428. (in Chinese).

[5] Ministry of Environmental Protection of the People's Republic of China. GB 3095 – 2012 environmental air quality standard[S]. Beijing: China Environmental Science Press, 2012. (in Chinese).

[6] ZHENG M, ZHANG YJ, YAN CQ, *et al*. Review on analysis method of source apportionment of $PM_{2.5}$[J]. Acta Scientiarum Naturalium Universitatis Pekinensis, 2014(68): 1 – 7. (in Chinese).

[7] Ministry of Environmental Protection of the People's Republic of China. Air particulate matter source apportionment guide No. [2013] 92 (trial) [S]. Beijing: China Environmental Science Press, 2013. (in Chinese).

[8] Greenpeace. Rank of $PM_{2.5}$ annual concentration in 2013 from 74 cities[N/OL]. Beijing: www.QQ.com, 2013[2014 – 01 – 02]. http://news.qq.com/a/20140109/013303.htm. (in Chinese).

[9] Davis, John C. Statistics and data analysis in geology (3rd Edition) [M]. New York: John Wiley&Sons, Inc, 2002: 57 – 61.

[10] Chinese Research Academy of Environmental Sciences. The compliance rate calculation of ambient air quality new standard in heavy pollution cities[R]. Beijing: Chinese Research Academy of Environmental Sciences, 2012. (in Chinese).

[11] JIAO Y. Observational study of $PM_{2.5}$ mass concentration and aerosol optical characteristics in Shanghai urban areas[D]. Qingdao: Ocean University of China, 2013. (in Chinese).

[12] WEI YX, YIN Y, YANG WF, *et al*. Analysis of the pollution characteristics & influence factors of $PM_{2.5}$ in Nanjing Area[J]. Environmental Science and Management, 2009, 34(9): 29 – 34. (in Chinese).

[13] WANG WS. Apportionment of air – borneparticulate during heating period in Harbin[D]. Harbin: Harbin Institute of Technology, 2009. (in Chi-

nese).
[14] YANG LX. Analysis on the main source of $PM_{2.5}$ pollution in Ji'nan City and its influence on visual range[D]. Ji'nan: Shandong University, 2008. (in Chinese).
[15] JI HL. Research on characterization and source apportionment of $PM_{2.5}$ and PM_{10} in Tianjin City[D]. Tianjin: Nankai University, 2011. (in Chinese).
[16] WANG TG. Source apportionment and pollution characteristics of $PM_{2.5}$ in Chongqing[D]. Chongqing: Chongqing University, 2007. (in Chinese).
[17] LAI SC. Characterizing the PM_{10} and $PM_{2.5}$ urban aerosols in Guangzhou [D]. Guangzhou: Sun Yat – sen University, 2002. (in Chinese).
[18] YAN XH. The character and source apportionment of fine particles $PM_{2.5}$ in Baoshan District, Shanghai[D]. Shanghai: East China University of Science and Technology, 2011. (in Chinese).
[19] BAO Z, FENG YC, JIAO Z, *et al*. Characterization and source apportionment of $PM_{2.5}$ and PM_{10} in Hangzhou[J]. Environmental Monitoring in China, 2010, 26(2): 44 – 48. (in Chinese).
[20] XIAO ZM, BI XH, FENG YC, *et al*. Source apportionment of ambient PM_{10} and $PM_{2.5}$ in urban area of Ningbo City[J]. Research of Environmental Sciences, 2012, 25(5): 549 – 555. (in Chinese).
[21] HUANG HJ, LIU HN, JIANG WM, *et al*. Physical and chemical characteristics and source apportionment of PM2. 5 in Nanjing[J]. Climatic and Environmental Research, 2006, 11(6): 713 – 722. (in Chinese).
[22] CHEN T. Analyse on resource apportionment of $PM_{2.5}$ in the center of Chengdu[D]. Chengdu: Southwest Jiaotong University, 2009. (in Chinese).
[23] YI F. Source apportionment for inhalable particles in the city atmosphere [D]. Wuhan: Huazhong University of Science and Technology, 2004. (in Chinese).
[24] YANG TZ. Chemical compositions and source apportionment of $PM_{2.5}$ in Changsha[D]. Changsha: Central South University(CSU), 2010. (in Chinese).
[25] ZHANG XM, ZHUANG MZ. Research on source apportionment of $PM_{2.5}$ in fine air particles of Xiamen[J]. Xiamen Science & Technology, 2007(3): 41 – 43. (in Chinese).
[26] Chinese Research Academy of Environmental Sciences. Study on on haze characteristics and control ways of typical areas[R]. Beijing: Chinese Research Academy of Environmental Sciences, 2013. (in Chinese).
[27] HE KB, YANG FM, DUAN FK, *et al*. Atmospheric particulates and regional complex pollution[M]. Beijing: Science Press, 2011: 165 – 185. (in Chinese).
[28] HU M. Study on physical and chemical characteristics, sources and formation mechanism of Beijing particulate air pollution and ultrafine particle [M]. Beijing: Science Press, 2009. (in Chinese).
[29] YU N, WEI YJ, HU M, *et al*. Characterization and source identification of ambient organic carbon in $PM_{2.5}$ in urban and suburban sites of Beijing [J]. Acta Scientiae Circumstantiae, 2009, 29(2): 243 – 251. (in Chinese).
[30] ZHU XL, ZHANG YH, ZENG LM, *et al*. Source identification of ambient $PM_{2.5}$ in Beijing[J]. Research of Environmental Sciences, 2005, 18(5): 1 – 5. (in Chinese).
[31] SONG Y, TANG XY, FANG C, *et al*. Source apportionment on fine particles in Beijing [J]. Chinese Journal of Environmental Science, 2002, 23 (6): 11 – 16. (in Chinese).
[32] Beijing Municipal Environmental Protection Bureau. Beijing released research achievement of $PM_{2.5}$ source apportionment[OL]. (2014 – 04 – 16) [2014 – 04 – 19]. http://www.bjepb.gov.cn/bjepb/323265/340674/396253/index.html. (in Chinese).
[33] ZHU T, WU L, BI XH, *et al*. Improving receptor models for ambient air particulate matter source apportionment [J]. China Environmental Science, 2010, 30(7): 865 – 870. (in Chinese).
[34] HAO MT, HOU WG, QU XH, *et al*. The method amending of improved – source – analysis technique of atmospheric particulate matter[J]. China Environmental Science, 2005, 25(2): 138 – 141. (in Chinese).

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[15] QIN CY, FANG ZQ, TANG YJ, *et al*. Contents and evaluation of heavy metals in common aquatic from Lingdingyang in Peal River Estuary, South China Ocean[J]. Journal of South China Normal University(Natural Science Edition), 2010(3): 104 – 109, 114. (in Chinese).
[16] YANG XY, WEN Y, CHEN XY, *et al*. Heavy metal enrichment in aquatic organisms of Beijiang River: Its characteristics and pollution evaluation [J]. Environmental Science and Technology, 2010, 33(6): 194 – 198. (in Chinese).
[17] HE L, FAN BW. Study on the law of accumulation of copper in fish[J]. Trace Elements Science, 2007, 14(4): 15 – 19. (in Chinese).
[18] YANG ML, JIA XP. Heavy metal in main economic fish in the Beibuwan Basin
[J]. Marine Science Bulletin, 1990, 9(5): 39 – 45. (in Chinese).
[19] LU CH. Heavy metal contamination of commercial aquatic products and its evaluation in in northern South China Sea[J]. Marine Environmental Science, 1995, 14(2): 12 – 18. (in Chinese).
[20] DAI ZR. Assessment of contents of heavy metals in the body of Pampano trachinotus ovatus derbio and its regular distributed pattern[J]. Food Science and Technology, 2012, 37(12): 298 – 300. (in Chinese).
[21] LIU FF, LI ZH, FU XJ, *et al*. Enrichment of heavy metals in growth period of cage cultured carp (Cyprinus carpio) from the East Dongting Lake [J]. Research of Environmental Sciences, 2013, 26(2): 166 – 172. (in Chinese).
[22] SHANG XD, HE ZQ. Advances in heavy metal accumulation in fish[J]. Hebei Fisheries, 2009(5): 44 – 45. (in Chinese).
[23] LIU WP, LIU XY, PAN JM, *et al*. Levels of heavy metals in commercial fish species from the near – shore of Zhejiang Province[J]. Journal of Zhejiang University(Sciences Edition), 2012, 39(3): 338 – 344. (in Chinese).
[24] LIU DC, SHAO CM. Assessment of contents of heavy metals in fish body and its regular distributed patter[J]. China Measurement & Testing Technology, 2007, 33(4): 121 – 122, 132. (in Chinese).
[25] ZENG LY, LI WL, LI Y. Analysis and evaluation on heavy metals pollution of fish in Xiangjiang River Changsha[J]. Guangxi Journal of Light Industry, 2012(9): 94 – 95. (in Chinese).
[26] Meador JP , Ernest DW, Kagley AN. A comparison of the non – essential elements cadmium, mercury and lead found in fish and sediment from Alaska and California[J]. Sci Total Environ, 2005, 339(1 – 3): 189 – 205.
[27] Bowles KC, Apte SC, Maher WA, *et al*. Bioaccumulation and biomagnification of mercury in Lake Murray, Papua New Guinea[J]. Can J Fish Aquat Sci, 2001, 58(5): 888 – 897.
[28] Prahalad AK, Seenayya G. In situ compartmentation and biomagnifications of copper and cadmium in industrially polluted Husainsagar Lake, Hyderbad, India[J]. Arch Environ Contam Toxicol, 1986, 15(4): 417 – 425.