Atmospheric Environment 142 (2016) 433–441

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Atmospheric particulate mercury in Lhasa city, Tibetan Plateau

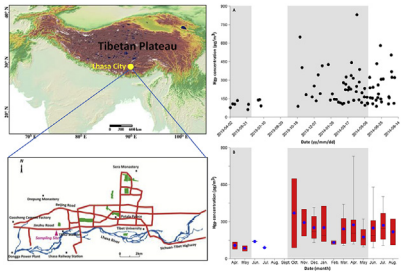
Jie Huang [a, c, d], Shichang Kang [b, c, *], Junming Guo [a, f], Qianggong Zhang [a, c], Zhiyuan Cong [a, c], Mika Sillanpää [d, e], Guoshuai Zhang [a], Shiwei Sun [b, f], Lekhendra Tripathee [b]

[a] Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100101, China
[b] State Key Laboratory of Cryospheric Sciences, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China
[c] CAS Center for Excellence in Tibetan Plateau Earth Sciences, Chinese Academy of Sciences, Beijing 100101, China
[d] Laboratory of Green Chemistry, Lappeenranta University of Technology, Sammonkatu 12, Mikkeli, FI-50130, Finland
[e] Department of Civil and Environmental Engineering, Florida International University, Miami, FL 33174, USA
[f] University of the Chinese Academy of Sciences, Beijing 100049, China

HIGHLIGHTS

- Unexpectedly high levels of atmospheric Hg_P concentrations were found at Lhasa city.
- No significant pattern was found for seasonal characteristics of atmospheric Hg_P.
- Estimated Hg_P dry deposition rate was higher than the measured and modeled wet fluxes.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 1 July 2016
Received in revised form
2 August 2016
Accepted 8 August 2016
Available online 9 August 2016

Keywords:
Mercury
Atmospheric particulate
Lhasa
Tibetan Plateau
China

ABSTRACT

In an effort to understand the biogeochemical cycling and seasonal characteristics of atmospheric Hg, a total of 80 daily sampled total suspended particulates were collected at Lhasa, the largest city of Tibet, from April 2013 to August 2014 for particulate-bound Hg (Hg_P) analysis. Daily concentrations of atmospheric Hg_P ranged from 61.2 to 831 pg m^{-3} with an average of 224 pg m^{-3}, which were unexpectedly comparable to those measured in most of the Chinese metropolises. Both the daily/monthly average Hg_P concentrations were slightly but not significantly higher during the non-monsoon season than during the monsoon season. Together with the fact that there was lack of significant relationship between Hg_P concentration and most meteorological parameters, no significant and distinct pattern for the seasonal characteristics of atmospheric Hg_P could be mainly attributed to the almost equal emission strength of two principal anthropogenic Hg sources (i.e., industrial emission sources during the non-monsoon season, and vehicular traffic and religious sources during the monsoon season). Moreover, the Hg_P dry deposition rate was estimated to be 35.3 μg m^{-2} yr^{-1} by using a theoretical model, which was significantly higher than those Hg wet fluxes. The elevated deposition rate implied that dry deposition may play an important role in the biogeochemical Hg cycling over the Tibetan Plateau.

* Corresponding author. State Key Laboratory of Cryospheric Sciences, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China.
E-mail address: shichang.kang@lzb.ac.cn (S. Kang).

http://dx.doi.org/10.1016/j.atmosenv.2016.08.021
1352-2310/

1. Introduction

Mercury (Hg) is among the most highly bioaccumulated toxic trace metals in the global environment as it has significant adverse impacts on human health and the environment (Boening, 2000; Kessler, 2013; Larson, 2014; Selin, 2014). Once emitted into the atmosphere by various anthropogenic and natural sources (Pirrone et al., 2010), Hg can undergo a series of complex physical and chemical transformations before being deposited onto environmental surfaces (Lin and Pehkonen, 1999). Therefore, the atmosphere plays an important role in the transformation and subsequent wet/dry deposition of Hg (Guentzel et al., 2001; Sakata and Asakura, 2007; Selin, 2009). Generally, Hg in ambient air can be categorized into gaseous elemental Hg (GEM), gaseous oxidized mercury (GOM) and particulate-bound Hg (Hg_P) in physical form (Lindqvist and Rodhe, 1985). GEM is the predominant form of Hg in atmosphere (>90%) with an atmospheric lifetime of about 1 year, enabling Hg to undergo long-range transport on a global scale (Schroeder and Munthe, 1998). In contrast, GOM and Hg_P are reported to have much shorter residence time in the atmosphere, usually ranging between several days and a few weeks (Schroeder and Munthe, 1998), and consequently they are most likely to be deposited at intermediate distances from the anthropogenic point sources (Lindberg and Stratton, 1998). These different forms of atmospheric Hg have different characteristics in terms of distribution, transport, deposition and impact on ecosystems (Lindqvist and Rodhe, 1985; Lin and Pehkonen, 1999; Boening, 2000). Even though present as a very small fraction of total Hg in the atmosphere, GOM and Hg_P have been suggested to be crucial in removal processes, deposition and cycling of atmospheric Hg (Lindberg and Stratton, 1998).

The Tibetan Plateau, known as the “Roof of the World” or the “Third Pole” (Qiu, 2008), is the highest and largest plateau in the world, with the mean elevation of over 4000 m a.s.l. and has an immense land area of about 2.5 million square kilometers. In general, the air quality of the Tibetan Plateau is universally considered to be good owing to its remote location, high altitude, sparse human population and pristine atmosphere. However, recent compilations of a certain number of studies have suggested the atmospheric environment of the Tibetan Plateau has been suffering from anthropogenic perturbations (e.g., Huang et al., 2015; Kang et al., 2016). Lhasa is the largest and the most famous tourist-historic city of the Tibet Autonomous Region, China (hereafter, Tibet). As a result of rapid economic development (Xizang Bureau of Statistics, 2014), Lhasa has experienced expedited urbanization and industrialization, leading to a dramatic increase of power demand and industrial production. Numerous studies have suggested that the air quality of Lhasa has been influenced by anthropogenic activities from local emissions (i.e., power plants, cement facilities, vehicular traffic, and religious activities (e.g., Li et al., 2008; Cong et al., 2011; Huang et al., 2010; Guo et al., 2015; Wan et al., 2016; Li et al., 2016) and long-range transboundary atmospheric transport (e.g., Gong et al., 2010; Ma et al., 2013; Huang et al., 2016)). Therefore, all these anthropogenic processes may have caused an increase of local atmospheric Hg pollution. A prior study of precipitation Hg has suggested that Hg_P was a very significant and important form of atmospheric Hg of Lhasa, which could distinctly influence the deposition, cycling and behavior of this element in the atmospheric environment (Huang et al., 2013a). As a consequence, Hg_P is important for understanding transport, deposition and cycling of Hg in the atmosphere (Keeler et al., 1995; Gichuki and Mason, 2014). Such information is also important for understanding the bioavailability of Hg and, hence, the toxicity of Hg present in the particulate-bound form in the atmosphere (Lu and Schroeder, 1999). Although the importance of fractionation measurements of Hg_P in atmosphere was well recognized, a very small amount of investigations regarding the characteristics of speciated atmospheric Hg have been conducted in Chinese metropolises (Fang et al., 2001; Wang et al., 2006; Xiu et al., 2009; Fu et al., 2011; Zhu et al., 2014). To date, studies on speciation of atmospheric Hg are extremely rare in the inland Tibetan Plateau (Fu et al., 2008, 2012a; Zhang et al., 2015a), and there are currently no data available in terms of speciation, concentration and deposition rate of Hg in the urban atmosphere of Tibet. Moreover, previous studies have highlighted that atmospheric Hg_P was most likely a dominant factor influencing wet/dry Hg deposition rates at Lhasa, and the contributions of anthropogenic processes could significantly impact environmental burdens of Hg on local and regional scales (Huang et al., 2013a,b).

To address the above concerns, therefore, measurements of total suspended particulate (hereafter, TSP) were conducted for atmospheric Hg_P analysis at Lhasa, the largest and capital city of Tibet, from April 2013 to August 2014. This study present for the first time the characteristics of atmospheric Hg_P collected from urban areas of the Tibetan Plateau. The principal purposes of this research are to: (i) quantify and identify the amount and levels of atmospheric Hg_P in a typical urban area of the Tibetan Plateau; (ii) make a comprehensive comparison with those reported for remote and urban areas of China; and (iii) investigate the controlling factors and potential mechanisms influencing the seasonal patterns of atmospheric Hg_P. Our study will not only provide a general understanding of current atmospheric Hg scenario in the urban areas of the Tibetan Plateau, but also facilitate the effectiveness of any control strategies on Hg emission reductions and the risk minimization of Hg adverse impacts on human health and the environment.

2. Experimental

2.1. Location description

Lhasa is located in the southern Tibetan Plateau with a total population of around 300,000 in the central urban area (Fig. 1). The sampling site was situated on the rooftop of the tallest campus building (height approximately 20 m from the ground level) at the Lhasa branch (29°38.59′N, 91°09′E, 3640 m a.s.l.), Institute of Tibetan Plateau Research, Chinese Academy of Sciences, in the western part of Lhasa (Fig. 1). Annual mean precipitation amount was about 400 mm with the majority of precipitation occurring from the end of May to early September (i.e., monsoon season). Except for the monsoon period, the other seasons in the year represent non-monsoon season. Our study site was considered as an urban site, where air quality was largely affected by anthropogenic emission sources from industrial facilities and from vehicular traffic and religious activities (e.g., Cong et al., 2011; Huang et al., 2010; Gong et al., 2011; Guo et al., 2015; Wan et al., 2016; Li et al., 2016). The largest power plant (Dongga power plant) and cement factory (Gaozheng cement factory) of Tibet were located about 10 km westward of our study site (Fig. 1). The electric power for Lhasa in winter and spring (i.e., non-monsoon season) was mainly supplied by Dongga power plant when the hydropower cannot provide sufficient electricity (Meng, 2010), and the industrial production of Gaozheng cement factory mainly occurred in the non-monsoon season (Huang et al., 2013a). Moreover, our sampling site was situated close to the Jinzhu road which was one of the most heavily used roads (Fig. 1) and the religious activities of local residents occurred frequently and intensively in the monsoon season, vehicular traffic and religious activities could thus largely contribute Hg to the atmosphere as a result of the fact that this