Science of the Total Environment 506–507 (2015) 538–545

Contents lists available at ScienceDirect

Science of the Total Environment

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

Polluted dust derived from long-range transport as a major end member of urban aerosols and its implication of non-point pollution in northern China

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HIGHLIGHTS

- Polluted long-range dust became a major component of urban dust in northern China.
- Human habitats in this region are becoming a non-point source of polluted dust.
- More developed area is more influenced by polluted dust from long-range transport.

ARTICLE INFO

Article history:
Received 21 April 2014
Received in revised form 20 November 2014
Accepted 21 November 2014
Available online 27 November 2014

Editor: Xuexi Tie

Keywords:
Polluted dust from long-range transport
Urban dust aerosols
Non-point dust pollution
Northern China

ABSTRACT

The contribution of polluted dust transported from local and distal sources remains poorly constrained due to their similar geophysical and geochemical properties. We sampled aerosols in three cities in northern China (Xi'an, Beijing, Xifeng) during the spring of 2009 to determine dust flux, magnetic susceptibility and elemental concentrations. Combining dust fluxes with wind speed and regional visibility records enabled to differentiate between dust transported from long range and derived from local sources, while the combination of magnetic susceptibility and enrichment factors (EF) of heavy metals (Pb, Zn) allowed to distinguish natural aerosols from polluted ones. Our results indicate that polluted dust from long-range transport became a major end member of urban dust aerosols. Human settlements as its potential sources were confirmed by a pollutant enriched regional dust event originating from populated areas to the south as inferred by back trajectory modeling, implying their non-point source nature of dust pollution.

1. Introduction

The vast deserts and sandy lands in northern China and southern Mongolia constitute the world's second largest natural mineral dust source region (NMDSR) (Ginoux et al., 2004; Tanaka and Chiba, 2006). Important quantity of mineral dust emitted from this area propagates eastwards and southeastwards via the Asian winter monsoon at the surface level and the westerlies in the free troposphere (Zhao et al., 2006). This process has profound influence on the global atmospheric environment (Tegen et al., 1996; Uno et al., 2009) and biogeochemical cycle (Jickells et al., 2005; Zhuang et al., 1992). Of immediate environmental concerns are the elevated dust aerosol concentration and hazardous weather events, i.e. dust events, reaching areas downwind, including China, Korea, Japan, and North America (Arimoto et al., 2006; Zhang et al., 2010a; Zhao et al., 2008), especially in the springtime. A major challenge for the city administrations in these areas is to evaluate the importance of natural mineral dust derived from long-range transport versus dust from other sources on local air quality (hereafter 'dust' is used interchangeably with 'dust aerosols' for simplicity).

Studies assessing contributions of natural and anthropogenic sources to urban dust aerosols in these areas have been extensive. Anthropogenic dust is usually polluted and characterized with high magnetic susceptibility and elevated concentrations of heavy metals (e.g., Cu, Pb, Zn), which have been widely used to assess the extent of

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http://dx.doi.org/10.1016/j.scitotenv.2014.11.071
0048-9697/

pollution and to constrain their sources (Feng et al., 2011; Han et al., 2006; Hjortenkrans et al., 2006; Hoffmann et al., 1999; Lee et al., 2007; Maher, 2009; Petrovsky et al., 2000; Wang et al., 2012). The assumption that polluted dust is derived mainly from local sources, while mineral dust mainly comes from remote natural sources or local soil, is used in these studies to interpret the provenance of urban dust aerosols (Feng et al., 2011; Kim et al., 2009; Li et al., 2008; Wang et al., 2012; Xia et al., 2008; Yang and Chen, 2002). Several studies, however, show that natural mineral dust from long-range transport can be polluted along its path (Guo et al., 2004; Sun et al., 2005; Zhang et al., 2010b; Zhao et al., 2007), and a significant contribution of polluted dust derived from other cities can occur (Fu et al., 2008; Lee et al., 2007; Moreno et al., 2011; Wehner et al., 2008). Therefore, source apportionment analysis using the chemical element balance (CEB) method based upon the previous assumption might lead to incomplete source inventories and inaccurate interpretations. We propose that polluted dust via long-range transport is one of the four major end members of urban dust aerosols downwind from the NMDSR, along with natural dust from long-range transport, and natural and polluted dust from local sources.

To test this hypothesis, we collected dust aerosols in three cities in northern China, including Beijing, Xi'an, and Xifeng, in the spring of 2009. Physical–chemical characteristics, including magnetic susceptibility, elemental concentrations, as well as dust flux, were measured to differentiate between natural and polluted dust. Combining these proxies with meteorological observations (i.e., wind speed, and regional visibility) and back trajectory analysis, we identified different contributions of natural and polluted dust derived via local and from long-range transport.

2. Material and methods

2.1. Environmental setting

In northern China, geographical areas downwind from the NMDSR are grouped into two dust deposition systems based on their major natural mineral dust sources. Chinese Loess Plateau (CLP) belongs to one system with its mineral dust derived mainly from the northern and northwestern Chinese desert areas, including Badain Juran, Tengger, and Gobi deserts, and mid-west Mongolian Gobi (Chen et al., 2007; Li et al., 2009; Sun et al., 2001, 2008; Zhang, 2001; Zhang et al., 2003). To the east of the CLP, the plains of north and northeast China belong to another deposition system. Their natural mineral dust fall mainly originates from the southeast Mongolian Gobi and the adjacent Inner Mongolian Gobi deserts, including Otindag and Horqin sandy lands (Qin et al., 2004; Sun et al., 2000; Yan et al., 2002; Yang et al., 2009). One metropolis in each deposition system (i.e. Beijing and Xi'an) was chosen in this study. Moreover, Xifeng, close to the dust sources of the CLP, was chosen to compare with Xi'an, since it should receive more natural dust deposition than Xi'an.

Beijing (BJ) is situated on the northern tip of Huabei Plain (Fig. 1), with an elevation below 100 m.a.s.l., and surrounded by the Taihang Mountains to the west, which represent the natural division between the Chinese Loess Plateau (CLP) and Huabei Plain, and the Yan Mountains to the north. Beijing has a population of around 18 million, 4 million motor vehicles, and a prosperous industry and construction industry accounting for around a quarter of the city's gross domestic product (GDP), 1215 billions, up to the end of 2009 (2010 Beijing Statistical Yearbook). Xi'an and Xifeng lie on the CLP. Situated inside the Guanzhong Basin in the southern CLP, Xi'an is surrounded by the Qinling Mountains in the south and the Loess Plateau in the north, with an average elevation of around 400 m.a.s.l. In 2009, Xi'an (XA) had around 8.5 million people and 1 million motor vehicles, with a GDP of 271.91 billions, in which industry and construction industry account for about 42% (2010 Xi'an Statistical Yearbook). Xifeng (XF) is situated on the top of the largest tableland (the Dongzhi tableland) of the CLP, with an average elevation of around 1400 m.a.s.l. It has a population of around 350,000, and a GDP of 6.9 billions (Bureau of Statistics of Xifeng). Huge GDP and population differences suggest that these cities have different social structures and different living and working activities, suitable for evaluating distinct impacts of natural and anthropogenic processes on urban dust aerosols.

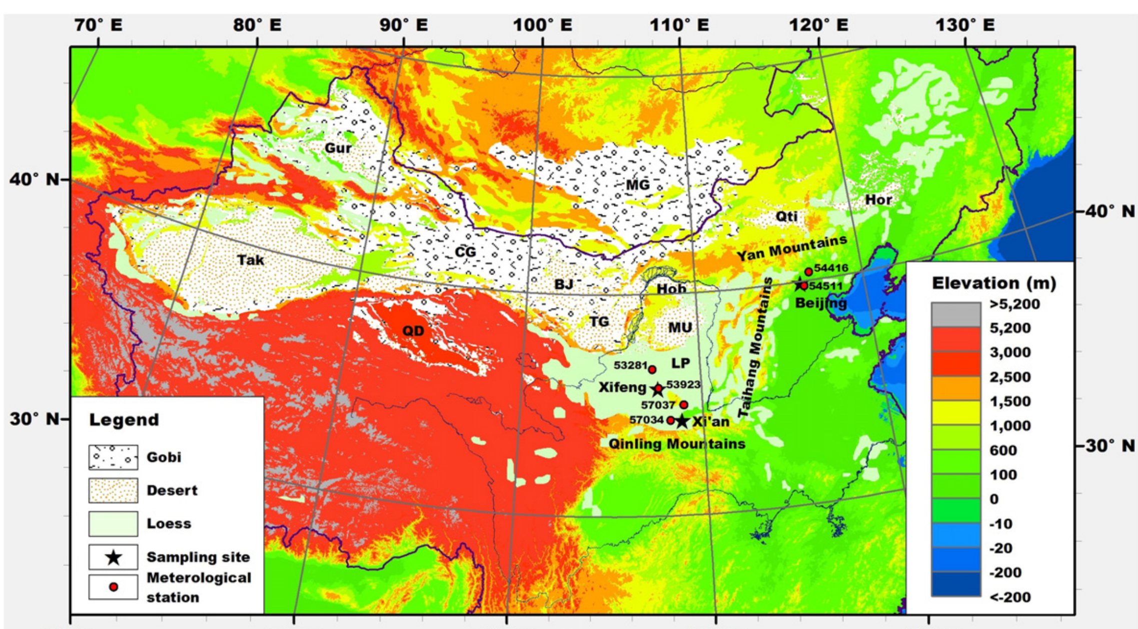

Fig. 1. Locations of sampling sites, meteorological stations, and major natural dust sources in East Asia. Distributions of Gobi and deserts are adapted from 1:200,000 desert distribution dataset provided by the Environmental and Ecological Science Data Center for West China, National Natural Science Foundation of China (http://westdc.westgis.ac.cn). The distribution of the Mongolian Gobi is only schematic. Loess distribution is adapted from Lu et al. (2008). Gur — Gurbantunggut desert, Tak — Taklimakan desert, QD — Qaidam basin, CG — Chinese Gobi, MG — Mongolian Gobi, BJ — Badain Juran desert, TG — Tengger desert, Hob — Hobq desert, MU — Mu Us desert, LP — Loess Plateau, Oti — Otindag sandy land, and Hor— Horqin sandy land.