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Atmospheric particulate pollution of Lanzhou using magnetic measurements*

Chen Fa-hu, Yang Li-ping, Wang Jian-min, Zhang Jia-wu

Institute of Environment & Hazards, Lanzhou University, Lanzhou 730000, China. E-mail: fhchen@lzu.edu.cn

Abstract—To differentiate between natural and anthropogenic particulate sources in the atmosphere in Lanzhou City, samples were collected in different sites. The dust flux was calculated and magnetic measurements were conducted. Results show a distinct pattern of variation of dust flux within a year and it agrees with the shifts of atmospheric circulation regime. The magnetic parameters indicate that natural sources are the major components of atmospheric particulate during late spring and early summer, while anthropogenic sources contribute much more during winter months. The data also support the earlier findings that magnetic parameters are effective for differentiating between particulate arising from natural sources such as soil erosion and from anthropogenic sources such as coal combustion.

Keywords: atmospheric particulate, dust flux, magnetic measurement, Lanzhou of China.

1 Introduction

Atmospheric particulate is one of the main atmospheric pollutants in China. It may be harmful itself and can act as a carrier of toxic matters which may have remarkable impacts on human health and atmospheric environment quality. Combustion of coal, which still serves as primary energy source in China, for both domestic and industrial purposes, leads to serious particulate pollution. This situation is particularly serious in cities of north China during winter. Besides, a great amount of atmospheric particulate pollutants in northwest China are contributed by natural dust storms originated from soil erosion in arid China, which formed up to 500m loess in the Chinese Loess Plateau, the thickest loess in the world, during the Quaternary of the last 2.4 Ma. Lanzhou City is one of the most heavily polluted cities in North China, with great particulate contribution from both natural and anthropogenic sources (Wei, 1988; Fu, 1995). It is imperative to distinguish between the atmospheric particulate pollutants of natural and anthropogenic sources so that control strategies can be promulgated which will protect the environment and human health. A lot of researches concerning the differentiation of atmospheric particulate have been carried out by using chemical, morphological and mineralogical methods (Chen, 1985; Wei, 1988; Yang, 1987; Zhu, 1995; Hunt, 1986; Mamane, 1988; Crecellius, 1980; Battarbee, 1997; Brown, 1995). During the past few years magnetic measurement of atmospheric particulate has drawn great attention because of its simple, rapid and non-destructive characteristics. While atmospheric particulate pollution is not uncommon worldwide, in northwest China this phenomenon differs from other parts of the world in that there is a strong natural dust contribution to air environment pollution. Furthermore, previous studies have paid little attention to seasonal variations of air particulate. Here we present results of a long-term variation of atmospheric particulate by means of magnetic measurements to monitor and differentiate the two sources of atmospheric particulate pollution in Lanzhou City. The seasonal variations of the natural dust flux is also studied, which is quite important for understanding the winter monsoon change and the dust flux acting as a proxy of winter monsoon index.

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2 Sampling and laboratory methods

Air particulate dust flux has been monitored at ten sites within Lanzhou City since 1994. To eliminate influence of local sources on the dust flux, the sample sites are located at non-point pollution area of the city, and the average flux is used in this study. Dust flux is also observed in a non-polluted rural site of Yuzhong County, about 50 km southeast to Lanzhou City. Samples were collected every month and weighed. The dust flux was thus calculated based on the weight, duration and sampling area.

Since April 1997, samples have been collected every half month at four new sites, site TOB is at the top of a five-floor building (18m above ground) within Lanzhou University campus, site RM at a storage room (10m above ground) at third floor of the building, site TOH at top of 10 m high building on Jiuzhoutai Hill (550m above Lanzhou City), and site GL at the top of a 4m high house in a rural area 46 km north to Lanzhou City. The samples were packed with cling film into polystyrene sample holders after they were weighed and the dust flux was calculated. Low frequency (0.47 kHz) susceptibility and high frequency (4.7 kHz) susceptibility were then measured using a Bartington Instruments magnetic susceptibility meter with MS2B dual-frequency susceptibility sensor. Each sample was measured six times. The average result was used in this study. Mass specific magnetic susceptibility (X_{lf}) and percent frequency dependent susceptibility ($X_{fd\%}$) were calculated according to Thompson and Oldfield (Thompson, 1986). Basically, magnetic susceptibility provides information on the concentration, grain-size and mineralogy of sedimentary magnetic mineral assemblages. The X_{lf} is proven to be roughly proportional to the concentration of ferromagnetic material (normally magnetite) in a sample, although there may be significant contributions by diamagnetic and paramagnetic minerals when the concentration of ferromagnetic minerals is low (Thompson, 1986). Because the anthropogenic source of atmospheric particulate has normally higher magnetic concentration than the natural source of soil erosion, it possibly can be used as a tool to identify the two sources of the air particulate in Lanzhou City. Furthermore, $X_{fd\%}$ is mainly controlled by magnetic grain size and characteristic of ferrimagnetic grains with a diameter just below the low limit for stable single domain (SSD) grain (Schiavon, 1996). It has been reported that the soil formation would produce fine grain size magnetic minerals which results relatively high percent frequency dependent susceptibility (Zhou, 1990; Maher, 1986; Chester, 1984). However, the coal combustion produces magnetic minerals, which may have high X_{lf} but low $X_{fd\%}$. Therefore, it is possible to use the magnetic parameters to identify the anthropogenic source from the natural soil erosion, and to monitor its seasonal intensity variations.

3 Results and discussion

3.1 Variations of seasonal atmospheric particulate flux

The dust flux observed in the non-polluted rural area of Yuzhong shows a pronounced annual cycle in particulate flux with maximum occurring from March to July. In some years, high dust flux appears in late winter months to early spring months, while in other years, high dust flux appears in summer months such as July and August (Fig.1). It can be up to 23 g/(m^2·mon) in spring or summer, but less than 5 g/(m^2·mon) in autumn or early winter. The three month moving average flux shows a quite clear single peak annually. However, there are marked abrupt changes from month to month (Fig.1), they may result from dust storms in the month. The periodical variations of the dust flux is due to the summer and winter monsoon alternations in a year. During winter months, most China is controlled by the winter monsoon. Thus, dry and windy situation is expected. However, surface atmospheric circulation is quite stable under the strong Mongolian High, resulting in low dust flux of natural origin even though the arid China is quite dry in winter (Fig. 2). From late winter to early summer, the Mongolian High decreases and atmospheric circulation alternates from the winter pattern to summer pattern. The surface atmospheric circulation become unstable, which disturbs the long-dried soil in desert area and carries the dust into atmosphere. Therefore, high dust flux is expected. From late summer to early winter, the summer monsoon is strong in most part of China, resulting in high precipitation. Relative moist land surface in arid China and stable atmospheric circulation results low dust flux. Therefore, the annual cycle of the dust flux reflects the summer and winter monsoon variations, which should partly respond to the seasonal air quality variations for the cities in north China.

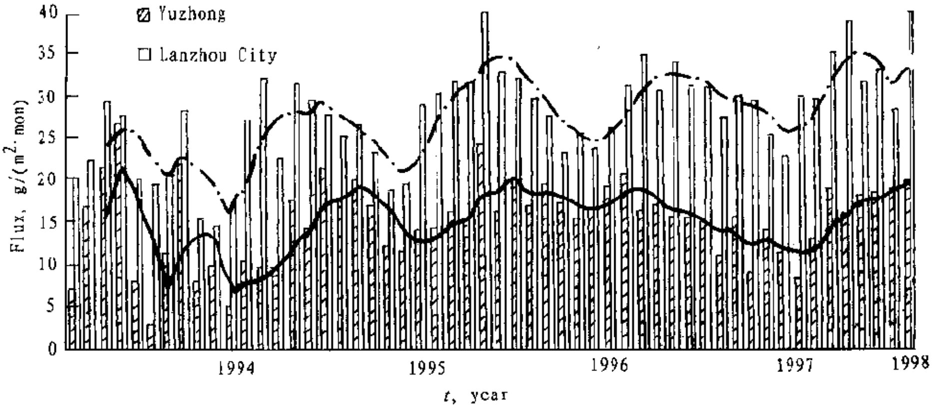

Fig. 1 The variations of the atmospheric particulate flux in Lanzhou City and in non-polluted rural Yuzhong since 1994. The dash and heavy lines are three month moving everage

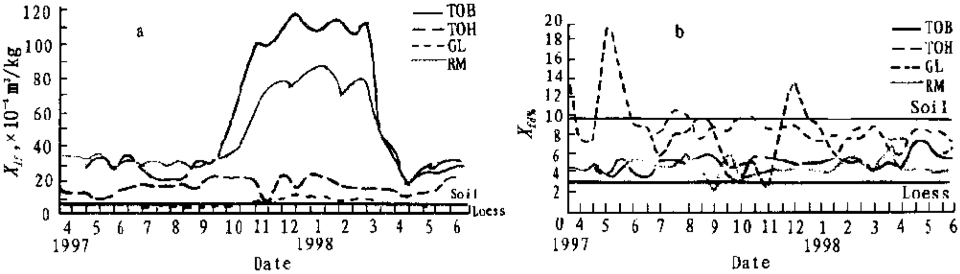

Fig. 2 a: Variations of mass specific magnetic susceptibility (X_{lf}) of the samples from the observed four sites in Lanzhou region; b: same as a but for the percent frequency susceptibility ($X_{fd\%}$) (the dark heavy line indicates the value for modern soil, and the light heavy line for loess in Lanzhou region)

The variation of the atmospheric particulate flux in Lanzhou City coincides with that of non-polluted Yuzhong (Fig. 1), this points to great natural dust contribution to atmospheric particulate of Lanzhou City. The low flux appears from July to October, while the high flux is from November to next June. It forms a broad peak. The abrupt increase of the flux in November, we believe, results from coal combustion for heating which normally begin in late of the month. The flux, however, is still high after the end of March, the termination of heating period. From early spring to early summer, natural dust input contributes to the high atmospheric particulate flux in Lanzhou City. Therefore, both anthropogenic and natural particulate are responsible for heavy particulate pollution in Lanzhou City.

The flux of dust collected at site RM from April to June is generally low (less than 15 $g/(m^2 \cdot mon)$), compared with that of Lanzhou City. The higher values occur from December 1997 to March 1998, which is consistent with the heating period in Lanzhou City and with variation trend of the total suspend particle (TSP) of Lanzhou City (not show here). It can be inferred that particulate in the atmosphere is dominated by anthropogenic source through coal and other fossil combustion. The flux of dust collected at site TOH could represent the dust at 500m higher than Lanzhou City, which reflects dust flux in high atmosphere. It is quite low from August 1997 to February 1998, but high in spring and even summer. This again suggests that the high dust flux of Lanzhou in the winter month is from anthropogenic source, while in late spring and early summer from natural source.

3.2 Variation of the magnetic susceptibility of the atmospheric particulate

Magnetic measurement is a potential proxy to identify the sources of the atmospheric particulate (Oldfield, 1985; 1978; Chester, 1984; Morris, 1995). The percent frequency susceptibility ($X_{fd\%}$) at the four sampling sites (TOB, RM, TOH and GL) shows that there are no distinct changes since April, 1997. $X_{fd\%}$ of TOB and RM is quite low and close to that of pure loess in Lanzhou area (Fig.2). This indicates that magnetic minerals are probably originated from combustion of coal rather than pedogenic origin. The samples at sites TOH and GL has high $X_{fd\%}$ values. The value at site GL is essentially the same as that in the paleosol S0, which was formed during a warmer and moister period about 6000 years ago. Because the paleosol S0 was better developed than present soil in North China (Chen, 1993), the collected atmospheric particulate indicates that the dust is originated from modern soil erosion, which supports the fact that the site GL is not affected by human activities. $X_{fd\%}$ of site TOH has large variations from as low as that of loess to a value much higher than that of the paleosol S0. The large variations may indicate that the anthropogenic particulate may occasionally be transported to the top of Jiuzhoutai Hill through the atmospheric vertical mixing. Although the extremely high values of $X_{fd\%}$ in May and early June of 1997 cannot be explained, the $X_{fd\%}$ shows that there is a distinctive difference of atmospheric particulate between anthropogenic and natural sources.

Fig.2 displays that the four sites can be placed in two well defined groups according to their X_{lf} values. The high values of X_{lf} at site TOB and RM suggest high ferromagnetic concentrations. Their average values are around $55 \times 10^{-8} m^3/kg$, which are much higher than the local soil and loess in this area. The values of X_{lf} from late September to March indicate the enhanced anthropogenic particulate. The variation of the magnetic susceptibility from April to next July is different from that of the flux of atmospheric particulate. This can be explained that the variation of the particulate flux in Lanzhou City depends on both anthropogenic and natural sources, but the magnetic susceptibility of atmospheric particulate of the anthropogenic source has very high content of ferrimagnetic material such as iron (Hulett, 1980; Theis, 1977). However, the X_{lf} of GL and TOH have low values with the lowest values at site GL. The value at GL is around that of the modern soil in the region, implying non-anthropogenic particulate contribution. Although the X_{lf} value at TOH is low, it is higher than GL (Fig.2). This confirms that the top of Jiuzhoutai can still be polluted by coal combustion in Lanzhou City. Therefore, the X_{lf} can be used to monitor the anthropogenic particulate in urban atmosphere.

4 Conclusion

The data showed that within a year both natural and anthropogenic sources are responsible for atmospheric particulate pollution in Lanzhou City. Dust flux of natural sources is high from late spring to early summer, and during winter months anthropogenic sources are the major sources of atmospheric particulate. Flux variation is consistent with atmospheric circulation pattern shifts. In addition, $X_{fd\%}$ changes little within a year, suggesting that the SD domain particles, mainly from natural sources, have effect on atmosphere pollution all the year. Meanwhile, single peak of X_{lf} was found during winter months which confirms the enhanced anthropogenic particulate from coal combustion. The results, together with those referred to above, suggest that magnetic measurement can be used as a tool in monitoring and differentiating atmospheric particulate pollutants for both present and past.

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