CONTENTS

Aquatic environment

Removal of total cyanide in coking wastewater during a coagulation process: Significance of organic polymers
Jian Shen, He Zhao, Hongbin Cao, Yi Zhang, Yongsheng Chen .................................................. 231
Removal of arsenate with hydrous ferric oxide coprecipitation: Effect of humic acid
Jingjing Du, Chuanyong Jing, Jinming Duan, Yongli Zhang, Shan Hu .......................................... 240
Arsenic removal from groundwater by acclimated sludge under autohydrogenotrophic conditions
Siqing Xia, Shuang Shen, Xiaoyin Xu, Jun Liang, Lijie Zhou ...................................................... 248
Characteristics of greenhouse gas emission in three full-scale wastewater treatment processes
Xu Yan, Lin Li, Junxin Liu ............................................................................................................... 256
Effect of temperature on anoxic metabolism of nitrites to nitrous oxide by polyphosphate accumulating organisms
Zhijia Miao, Wei Zeng, Shuying Wang, Yongzhen Peng, Guihua Cao, Dongchen Weng, Guisong Xue, Qing Yang ................................................................. 264
Efficacy of two chemical coagulants and three different filtration media on removal of Aspergillus flavus from surface water
Hamid Mohammad Al-Gabr, Tianling Zheng, Xin Yu ..................................................................... 274
Beyond hypoxia: Occurrence and characteristics of black blooms due to the decomposition of the submerged plant Potamogeton crispus in a shallow lake
Qushi Shen, Qilin Zhou, Jingge Shang, Shiguang Shao, Lei Zhang, Chengxin Fan ......................... 281
Spatial and temporal variations of two cyanobacteria in the mesotrophic Miyun reservoir, China
Ming Su, Jianwei Yu, Shenling Pan, Wei An, Min Yang ................................................................. 289
Quantification of viable bacteria in wastewater treatment plants by using propidium monoazide combined with quantitative PCR (PMA-qPCR)
Dan Li, Tiezheng Tong, Siyu Zeng, Yiwen Lin, Shuxu Wu, Miao He .............................................. 299
Antimony(V) removal from water by hydrated ferric oxides supported by calcite sand and polymeric anion exchanger
Yangyang Miao, Feichao Han, Bingcai Pan, Yingjie Niu, Guangze Nie, Lu Lv ................................ 307
A comparison on the phytoremediation ability of triazophos by different macrophytes
Zhu Li, Huiping Xiao, Shuiping Cheng, Liping Zhang, Xiaolong Xie, Zhenbin Wu ......................... 315
Biostability in distribution systems in one city in southern China: Characteristics, modeling and control strategy
Pinpin Lu, Xiaojian Zhang, Chuiqian Zhang, Zhangbin Niu, Shuguang Xie, Chao Chen .................. 323

Atmospheric environment

Characteristics of ozone and ozone precursors (VOCs and NOx) around a petroleum refinery in Beijing, China
Wei Wei, Shuiyuan Cheng, Guohao Li, Gang Wang, Haiyang Wang .............................................. 332
Identification of sources of lead in the atmosphere by chemical speciation using X-ray absorption near-edge structure (XANES) spectroscopy
Kohei Sakata, Aya Sakaguchi, Masaharu Tanimizu, Yuichi Takaku, Yuka Yokoyama, Yoshio Takahashi ................................................................. 343
Online monitoring of water-soluble ionic composition of PM10 during early summer over Lanzhou City
Jin Fan, Xiaoqing Yue, Yi Jing, Qiang Chen, Shigong Wang ......................................................... 353
Effect of traffic restriction on atmospheric particle concentrations and their size distributions in urban Lanzhou, Northwestern China
Suping Zhao, Ye Yu, Na Liu, Jianjun He, Jinbei Chen .................................................................. 362

Environmental health and toxicology

A review on completing arsenic biogeochemical cycle: Microbial volatilization of arsines in environment
Peipei Wang, Guoxin Sun, Yan Jia, Andrew A Meharg, Yongguan Zhu ........................................ 371
Alginates modifies the physiological impact of CeO2 nanoparticles in corn seedlings cultivated in soil
Lijuan Zhao, Jose R. Peralta-Videa, Bo Peng, Susmita Bandopadhuyay, Baltazar Corral-Diaz, Pedro Osuna-Avila, Milka O. Montes, Arturo A. Keller, Jorge L. Gardea-Torresdey ................................................................. 382
Humification characterization of biochar and its potential as a composting amendment
Jinping Zhang, Fan Li, Chenghao Luo, Liming Shao, Jinping He .................................................. 390
Immigrant Pantoea agglomerans embedded within indigenous microbial aggregates: A novel spatial distribution of epiphytic bacteria
Qing Yu, Anzhou Ma, Mengmeng Cui, Xuliang Zhuang, Guoqiang Zhuang ................................. 398
Remediation of nutrient-rich waters using the terrestrial plant, Pandanus amaryllifolius Roxb.
Han Ping, Prakash Kumar, Bee-Lian Ong .................................................................................... 404
Introduction

Atmospheric particulate matter, also known as particulates or particulate matter (PM), are tiny pieces of solid or liquid matter associated with the Earth’s atmosphere. They are suspended in the atmosphere as atmospheric aerosol (Seinfeld and Spyros, 1998). PM$_{10}$ is the atmospheric aerosol with air dynamic equivalent diameter less than 10 $\mu$m; it can penetrate into the lower respiratory system of humans and increase mortality due to respiratory and cardiovascular disease (Bert and Stephen, 2002). Moreover, it affects the Earth’s climate by changing incoming solar radiation and outgoing terrestrial long wave radiation retained in the Earth’s system (Huang et al., 2008), and its climate effects are the largest source of uncertainty in future climate predictions (Solomon et al., 2007). From the definition of air pollution (Juliann and Jim, 2001), PM$_{10}$ is an atmospheric pollutant and can create significant global health, welfare and ecological impacts. In the latest Ambient Air Quality Standards promulgated in Feb 29, 2012 by the Ministry of Environmental Protection of China (MEP-China, 2012a), the mass concentration of PM$_{10}$ is a basic monitoring item and a daily concentration lying above 150 $\mu$g/m$^3$ is used as an indicator of pollution days.

The Air Quality Index (AQI) is a quantitative method to profile air pollution level. It is determined by the maximum value of the Individual Air Quality Index (IAQI), which is calculated from mass concentrations of PM$_{10}$, PM$_{2.5}$, SO$_2$, NO$_2$, CO and O$_3$ in ambient air respectively; furthermore, the pollutant with maximum IAQI is called the primary pollutant. AQI is measured at monitoring stations throughout 120 cities and reported daily by MEP-China. More detail on the algorithm of AQI was presented in the Technical Regulation on Ambient Air Quality Index...
promulgated by MEP-China (MEP-China, 2012b). Table 1 lists levels of AQI with corresponding health implications. Air is polluted and might impact human health when AQI is more than 100.

<table>
<thead>
<tr>
<th>AQI</th>
<th>Air Pollution Level</th>
<th>Health implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–50</td>
<td>Excellent</td>
<td>No health implications</td>
</tr>
<tr>
<td>51–100</td>
<td>Good</td>
<td>No health implications</td>
</tr>
<tr>
<td>101–150</td>
<td>Slightly polluted</td>
<td>Slight irritations may occur</td>
</tr>
<tr>
<td>151–200</td>
<td>Lightly polluted</td>
<td>Slight irritations may occur</td>
</tr>
<tr>
<td>201–250</td>
<td>Moderately polluted</td>
<td>Healthy people will be noticeably affected</td>
</tr>
<tr>
<td>251–300</td>
<td>Heavily polluted</td>
<td>Healthy people will be noticeably affected</td>
</tr>
<tr>
<td>300+</td>
<td>Severely polluted</td>
<td>Healthy people will experience problems</td>
</tr>
</tbody>
</table>

Lanzhou is located in a narrow and long valley basin in northwest China; this topographic characteristic causes low wind speed, and inversion layers occur frequently. Pollutants are difficult to disperse when encountering these meteorological conditions (Chu et al., 2008). It was already known that air pollution events occur frequently in Lanzhou in wintertime, and many works have investigated these wintertime pollution events (Zhang et al., 2008; An et al., 2005, 2007). In spring and summer, the formation mechanism of dust storms was the research focus (Wang et al., 2006; Liu et al., 2004; Zhang et al., 2003). However, no works have been carried out to measure water-soluble ions and trace gases in PM$_{10}$ during early summer by an online instrument with 1-hour sampling time, the sampler was located seven meters away from the roof of a two-story building belonging to the College of Environmental Science, Lanzhou University (E) was located on the campus of Lanzhou University (Fig. 5). The observation site (36.05°N, 103.86°E) was on the roof of a two-story building belonging to the College of Environmental Science, about seven meters in height above ground, within the campus of Lanzhou University (Fig. 5). The site represented a mixed influence of residential, traffic and construction emissions in an urban district.

A model ADI 2080 online analyzer for Monitoring for AeRosols and Gases (MARGA, Applikon Analytical B.V., Netherlands) with a PM$_{10}$ sampling inlet was used to obtain an hourly integrated dataset from Apr 1 to May 24, 2011. The MARGA, which was developed and affirmed by the Energy Research Centre of the Netherlands, is a commercialized version of the GRAEGOR system (Thomas et al., 2009) and consists of sampling and analytical boxes (Jongejan et al., 1997). The two most important modules in the sampling box are the Wet Rotating Denuder (WRD) for collection of the precursor gases (Keuken et al., 1988) and Steam Jet Aerosol Collector (SJAC) for collection of the PM (Khlystov et al., 1995). The detection system in the analytical box has the capability to measure mass concentrations of major water-soluble inorganic ions in PM (NH$_4^+$, Na$^+$, K$^+$, Ca$^{2+}$, Mg$^{2+}$, SO$_4^{2-}$, NO$_3^-$, Cl$^-$) and trace gases (HCl, HONO, SO$_2$, HNO$_3$, NH$_3$) at 1-hour time resolution. To track changes in retention time and detector response for each sampling, the MARGA was continuously controlled by an internal calibration method using bromide for the anion chromatograph and lithium for the cation chromatograph over the whole observation period. Full details on the MARGA are given elsewhere (Trebs et al., 2004). Methodologies of MARGA operation and maintenance followed the manual provided by the manufacturer.

Mass concentrations of daily PM$_{10}$ during the field campaign were acquired from the continuous monitoring using a TH-150C Automatic Medium Volume TSP Sampler (Wuhan Tianhong Instruments Co., Ltd., China) with TH-PM$_{10}$ Impactor and Whatman QMA. In order to avoid interaction between MARGA and TH-150C during the sampling time, the sampler was located seven meters away from MARGA. AQI of Lanzhou City was obtained from the website of MEP-China (http://datacenter.mep.gov.cn/). Three-hour meteorological data including mixed layer depth (MLD, m), relative humidity (RH, %), ambient temperature (K), rainfall (mm/hr) and downward solar radiation flux (W/m$^2$) were obtained from the Global Data Assimilation System (GDAS, global, 2006–present) of NOAA Air Resources Laboratory.

### 2 Results and discussion

#### 2.1 Air pollution events

In mainland China, AQI is viewed as a comprehensive index to measure levels of ambient air pollution. In this research, we considered the air to be polluted when intra-day AQI > 100 and clear when AQI < 50 in Lanzhou City. On the basis of this method, Lanzhou experienced five air pollution events (sequences shown with light gray in Fig. 1) during the field campaign, and the primary pollutant for all of these events was inhalable particles (PM$_{10}$). May 12 and 21 to 24 were clear days (sequences shown with light blue in Fig. 1).

**Figure 1** shows the time series of daily PM$_{10}$ mass concentrations and Three-hour precipitation from Apr 1
to May 24. Viewing the variation of PM$_{10}$ for the whole period, the maximum daily concentration was 487 µg/m$^3$ on Apr 2, and these pollution events all exceeded the secondary standard (150 µg/m$^3$) of Ambient Air Quality Standards (MEP-China, 2012a) in China; only 41 µg/m$^3$, on May 21, was lower than the primary standard (50 µg/m$^3$). Three-hour precipitation during the field campaign revealed that the pollution events could be referred to as continuous air contamination lasting throughout a free-rain period, and could be cleared by rainfall.

### 2.2 Water-soluble ions in PM$_{10}$

Water-soluble ions like NH$_4^+$, Na$^+$, K$^+$, Ca$^{2+}$, Mg$^{2+}$, SO$_4^{2-}$, NO$_3^-$ and Cl$^-$ are important components in atmospheric particles. The sum of total water-soluble ions (TWSI) contributed a mean mass fraction of 16.03% in PM$_{10}$ for the field campaign, which was little higher than a previous observation in Beijing summertime (12.1%) (Cui et al., 2008) and much lower than in Lanzhou wintertime (27.34%) (Zhang et al., 2008). The average mass percentage of TWSI in PM$_{10}$ reached 14.4% during the five pollution events.

Figure 2 presents a time series of these water-soluble ions in PM$_{10}$ from Apr 1 to May 24. Here we convert mass concentrations (µg/m$^3$) to molar concentrations (nmol/L) for these water-soluble (Fig. 2), because molar concentrations can better reflect the quantitative relationships between water-soluble ions. Based on the average molar concentrations of water-soluble ions during field campaign, we ordered water-soluble ions from high to low: Ca$^{2+} >$ NH$_4^+ >$ SO$_4^{2-} >$ NO$_3^- >$ Cl$^- >$ Mg$^{2+} >$ Na$^+ >$ K$^+$. Compared with the decreasing order: NH$_4^+ >$ Ca$^{2+} >$ SO$_4^{2-} >$ Cl$^- >$ NO$_3^- >$ Na$^+ >$ K$^+ >$ Mg$^{2+}$ in winter listed in Table 2 (Zhang et al., 2008), contents of all water-soluble ions were roughly one- to nine-fold higher in winter, except Ca$^{2+}$.

Na$^+$, Mg$^{2+}$ and Ca$^{2+}$ in aerosols of northwest China are known to derive mainly from crustal sources, such as resuspended soil particles, and are strongly influenced by dust storms in spring and early summer. SO$_4^{2-}$, NO$_3^-$ and NH$_4^+$ in aerosols are believed to originate from secondary particles produced by the transformation of their gaseous precursors: SO$_2$, NO$_x$ and NH$_3$, mainly emitted by anthropogenic sources and partially from natural sources (Wang et al., 2006). K$^+$ and Cl$^-$ are detected in biomass burning particles, and aerosol potassium has been regarded as a common useful tracer of biofuel combustion and biomass burning emissions (Dibb et al., 1995; Dabell et al., 2004; Liu et al., 2000; Hsu et al., 2009; Duan et al., 2004).

Data from the 923 samples obtained during field campaign were analyzed by IBM SPSS Statistics 19 to derive the Pearson correlation coefficients (PCC) among water-soluble ions. The PCCs are shown in Table 3 and Fig. 2; we can see high PCCs among Na$^+$, Mg$^{2+}$ and Ca$^{2+}$; NH$_4^+$, SO$_4^{2-}$ and NO$_3^-$; K$^+$ and Cl$^-$. Moreover, three predominant

| Table 2 Comparison of water-soluble ions in PM$_{10}$ between summer and winter (unit: nmol/L) |
|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
|                  | SO$_4^{2-}$      | NO$_3^-$         | Cl$^-$           | NH$_4^+$         | Ca$^{2+}$        | Na$^+$           |
| Summer           | 0.087            | 0.072            | 0.070            | 0.160            | 0.460            | 0.022            |
| Winter (Zhang et al., 2008) | 0.354            | 0.229            | 0.333            | 1.055            | 0.395            | 0.192            |
| Winter/Summer    | 4.076            | 3.183            | 4.775            | 6.598            | 0.859            | 8.545            |
|                  |                  |                  |                  |                  |                  |                  |

Fig. 1 Daily PM$_{10}$ mass concentration and 3-hour precipitation from Apr 1 to May 24.

Fig. 2 presents a time series of these water-soluble ions in PM$_{10}$ from April 1 to May 24. Here we convert mass concentrations (µg/m$^3$) to molar concentrations (nmol/L) for these water-soluble ions (Fig. 2), because molar concentrations can better reflect the quantitative relationships between water-soluble ions. Based on the average molar concentrations of water-soluble ions during field campaign, we ordered water-soluble ions from high to low: Ca$^{2+} >$ NH$_4^+ >$ SO$_4^{2-} >$ NO$_3^- >$ Cl$^- >$ Mg$^{2+} >$ Na$^+ >$ K$^+$. Compared with the decreasing order: NH$_4^+ >$ Ca$^{2+} >$ SO$_4^{2-} >$ Cl$^- >$ NO$_3^- >$ Na$^+ >$ K$^+ >$ Mg$^{2+}$ in winter listed in Table 2 (Zhang et al., 2008), contents of all water-soluble ions were roughly one- to nine-fold higher in winter, except Ca$^{2+}$.

Na$^+$, Mg$^{2+}$ and Ca$^{2+}$ in aerosols of northwest China are known to derive mainly from crustal sources, such as resuspended soil particles, and are strongly influenced by dust storms in spring and early summer. SO$_4^{2-}$, NO$_3^-$ and NH$_4^+$ in aerosols are believed to originate from secondary particles produced by the transformation of their gaseous precursors: SO$_2$, NO$_x$ and NH$_3$, mainly emitted by anthropogenic sources and partially from natural sources (Wang et al., 2006). K$^+$ and Cl$^-$ are detected in biomass burning particles, and aerosol potassium has been regarded as a common useful tracer of biofuel combustion and biomass burning emissions (Dibb et al., 1995; Dabell et al., 2004; Liu et al., 2000; Hsu et al., 2009; Duan et al., 2004).

Data from the 923 samples obtained during field campaign were analyzed by IBM SPSS Statistics 19 to derive the Pearson correlation coefficients (PCC) among water-soluble ions. The PCCs are shown in Table 3 and Fig. 2; we can see high PCCs among Na$^+$, Mg$^{2+}$ and Ca$^{2+}$; NH$_4^+$, SO$_4^{2-}$ and NO$_3^-$; K$^+$ and Cl$^-$. Moreover, three predominant
salts with their PCCs between cation and anion were: NH₄NO₃ (0.768), KCl (0.766), (NH₄)₂SO₄/NH₄HSO₄ (0.702). Examining KCl, the reason why the PCC 0.766 was lower than the value of 0.923 reported by Du et al. (2011) in Shanghai, was caused by heavier biomass burning pollution in east China during summertime (Li et al., 2010) as shown in Fig. 2d, with southeast China, where agriculture is much more advanced and influenced by biomass burning pollution in summer. (Li et al., 2010) As shown in Table 3, the biomass burning source (1.1%) was much lower than crust (7.3%) and secondary aerosol sources (5.7%) because the ground fire points, which were detected by the Moderate Resolution Imaging Spectroradiometer (MODIS) on Terra and Aqua during Apr 1 to May 24 (Fig. 4), were small compared with southeast China, where agriculture is much more advanced and influenced by biomass burning pollution in summer. (Li et al., 2010) As shown in Fig. 2d, the molar concentration of biomass burning species in PM₁₀ exhibited moderate variations compared with the other two, indicating that biomass burning pollution played an

<table>
<thead>
<tr>
<th></th>
<th>Cl⁻</th>
<th>NO₃⁻</th>
<th>SO₄²⁻</th>
<th>Na⁺</th>
<th>NH₄⁺</th>
<th>K⁺</th>
<th>Mg²⁺</th>
<th>Ca²⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl⁻</td>
<td>1</td>
<td>0.556**</td>
<td>0.366**</td>
<td>0.629**</td>
<td>0.539**</td>
<td>0.766**</td>
<td>0.186**</td>
<td>0.274**</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>1</td>
<td>0.437**</td>
<td>0.321**</td>
<td>0.768**</td>
<td>0.516**</td>
<td>0.050</td>
<td>0.016</td>
<td></td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>1</td>
<td>0.319**</td>
<td>0.702**</td>
<td>0.442**</td>
<td>0.264**</td>
<td>0.170**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na⁺</td>
<td>1</td>
<td>0.178**</td>
<td>0.465**</td>
<td>0.513**</td>
<td>0.609**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH₄⁺</td>
<td>1</td>
<td>1.067**</td>
<td>-0.011</td>
<td>-0.122</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K⁺</td>
<td>1</td>
<td>0.073*</td>
<td>0.091**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>1</td>
<td>0.752**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p = 0.05; **p = 0.01

PMF is a multivariate factor analysis tool that decomposes a matrix of speciated sample data into two matrices, factor contributions and factor profiles, which then need to be interpreted by an analyst as to what source types are represented using measured source profile information, wind direction analysis, and emission inventories. The method is described in greater detail elsewhere (Paatero and Tapper, 1994; Paatero, 1997). We used EPA-PMF 3.0 to apportion sources of water-soluble in PM₁₀. Figure 3 shows the model execution result with source profiles. The different sources were classified in three groups: representative of crust (Na⁺, Mg²⁺, Ca²⁺), secondary aerosol (SO₄²⁻, NO₃⁻, NH₄⁺) and biomass burning (K⁺, Cl⁻), and the mass contribution to PM₁₀ of each source was 7.3%, 5.7%, and 1.1% respectively, which resolved 14.1% of PM₁₀ mass concentration. It was remarkable that the biomass burning source (1.1%) was much lower than crust (7.3%) and secondary aerosol sources (5.7%) because the ground fire points, which were detected by the Moderate Resolution Imaging Spectroradiometer (MODIS) on Terra and Aqua during Apr 1 to May 24, were small compared with southeast China, where agriculture is much more advanced and influenced by biomass burning pollution in summer.
insignificant role in the formation of air pollution events in Lanzhou in early summertime.

According to the source apportionment result (Fig. 3) and time series shown in Fig. 2d, the primary pollutant (PM$_{10}$) in the five air pollution events (AQI > 100) was classified into crustal species- and secondary aerosol-induced. The average molar concentrations of water-soluble ions in PM$_{10}$ during these two types of pollution events are presented in Table 4. The content of each water-soluble ion per air volume in the periods of air pollution days was almost always higher than on clear days; as shown in Table 4, molar concentrations of water-soluble ions showed drastic changes of roughly one- to three-fold between air pollution and clear days.

### 2.3 Formation mechanism of pollution events

#### 2.3.1 Crustal species-induced pollution

Lanzhou is located in an arid and semi-arid area of China where Taklamakan, Gurbantunggut, Tsaidam Basin, Kumutage, Badain Juran, Tenger, Ulun Buh, Hobq, Mu Us and other smaller deserts are distributed from west to east (Fig. 5). In spring and early summer, sand-dust weather influenced Lanzhou severely, and crustal species flew up in the air to reduce visibility (Wang et al., 1999; Liu et al., 2004; Ta et al., 2004). Na$^+$, Mg$^{2+}$, and Ca$^{2+}$ content in PM$_{10}$ are excellent indicators to use in estimating crustal species emission and tracing long-range transport of aerosol from natural sources in the atmosphere (Arimoto et al., 2004).

![Fig. 3 Factor profiles from execution of EPA-PMF 3.0.](image)

<table>
<thead>
<tr>
<th>Date</th>
<th>Crust</th>
<th>Secondary</th>
<th>Ave</th>
<th>Clear days (CD)</th>
<th>Ave/CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 Apr</td>
<td>0.056</td>
<td>0.045</td>
<td>0.079</td>
<td>0.072</td>
<td>2.528</td>
</tr>
<tr>
<td>10 Apr</td>
<td>0.068</td>
<td>0.042</td>
<td>0.170</td>
<td>0.125</td>
<td>0.912</td>
</tr>
<tr>
<td>20–21 Apr</td>
<td>0.027</td>
<td>0.047</td>
<td>0.151</td>
<td>0.109</td>
<td>0.036</td>
</tr>
<tr>
<td>18 May</td>
<td>0.067</td>
<td>0.033</td>
<td>0.108</td>
<td>0.088</td>
<td>0.036</td>
</tr>
<tr>
<td>1–3 Apr</td>
<td>0.079</td>
<td>0.084</td>
<td>0.170</td>
<td>0.125</td>
<td>0.091</td>
</tr>
<tr>
<td>8–9 Apr</td>
<td>0.125</td>
<td>0.116</td>
<td>0.151</td>
<td>0.109</td>
<td>0.091</td>
</tr>
<tr>
<td>11–13 Apr</td>
<td>0.109</td>
<td>0.101</td>
<td>0.108</td>
<td>0.088</td>
<td>0.091</td>
</tr>
<tr>
<td>15–17 Apr</td>
<td>0.116</td>
<td>0.048</td>
<td>0.125</td>
<td>0.088</td>
<td>0.091</td>
</tr>
<tr>
<td>Ave</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Clear days (CD)</td>
<td>0.036</td>
<td>0.079</td>
<td>0.036</td>
<td>0.072</td>
<td>2.528</td>
</tr>
<tr>
<td>Ave/CD</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>
Pollution days caused by crustal species are listed in Table 4. Molar concentrations of crustal species occurred on Apr 7 with a value of 0.991 nmol/L, higher than secondary aerosol pollution (0.269 nmol/L) and biomass burning (0.067 nmol/L); this was a typical sand-dust day caused by long-range transport. The NOAA Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model and meteorological data GDAS were used to study the formation mechanism of this typical event. More information about HYSPLIT and GDAS can be found at the website: http://ready.arl.noaa.gov/hysplit-bin/trajsrc.pl. The HYSPLIT model was applied to trace the air parcel 3-days back, and 300 m (above ground level) was selected as the simulation altitude because air pollution at this height was mainly influenced by large-scale long-range transport. Moreover, 300 meters also represented the air flow near the ground, but reduced the influence of ground surface friction (Wang et al., 2009). The backward trajectory for the receptor site of Lanzhou is shown in Fig. 5. In order to track the whole process of this typical sand-dust weather event, the trajectory end time was set to 01:00 UTC Apr 7 (09:00 local time, LT hereafter), 04:00 UTC Apr 7 (12:00 LT) and 07:00 UTC Apr 7 (15:00 LT) respectively. As shown in Fig. 5, the air parcel outflowed in a northwesterly pathway, traveled a distance over the Gobi desert, and passed through Hexi Corridor arriving at the sampling site, showing the features of a sand-dust event that was induced by long-range transport. The result was similar with a previous observation by Tao et al. (2007) in Lanzhou, who indicated that the Hexi Corridor was the major passageway for sand and dust from northwest to south and east.

Besides long-range transport, sand-dust pollution could also be induced by local emission. Construction sites in urban districts are the main local sources of crustal species. Strong wind could combine long-range transport and local emission, increasing the adverse impact on the city environment (Ye et al., 2000).

2.3.2 Secondary aerosol pollution

High concentrations of \( SO_2^2- \), \( NO_3^- \) and \( NH_4^+ \) were representative of the air pollution days due to secondary aerosol pollution, covering the periods of Apr 1 to 3, Apr 7 to 8, Apr 11 to 13 and Apr 15 to 17 listed in Table 4. Three kinds of salts with their PCCs between cation and anion were \( NH_4NO_3 \) (0.768), \( (NH_4)_2SO_4/NH_4HSO_4 \) (0.702) and \( NH_4Cl \) (0.539) in \( PM_{10} \) as shown in Table 3. Semi-volatile \( NH_4NO_3 \) and \( NH_4Cl \) are formed via reversible phase equilibrium with \( NH_3 \), \( HNO_3 \), and \( HCl \) (Pio and Harrison, 1987) and the main form of \( NO_3^- \) in the fine mode was \( NH_4NO_3 \) (Pierson and Brachaczek, 1988). \( NH_3 \) was emitted from livestock and ammonia synthesis; more importantly, \( NH_3 \) in the atmosphere is a major gas-phase neutralizing agent (Krupa, 2003). At lower concentrations, \( NH_3 \) would primarily react with \( H_2SO_4 \) and generate \( (NH_4)_2SO_4/NH_4HSO_4 \).

SO\(_2\) was emitted by fossil fuel combustion, and the formation of \( SO_2^2- \) from \( SO_2 \) usually occurred by aqueous- and gas-phase oxidation reaction with \( OH \) radical (Meng and Seinfeld, 1994). Therefore, the chemical formation of \( SO_2^2- \) from \( SO_2 \) should not be neglected in these secondary aerosol pollution days. The sulfur oxidation ratio (SOR =...
$n$-$SO_2^-/n$-$SO_3^2-+n$-$SO_2$ while, $n$ is molar concentration) is an available indicator to quantitatively characterize the secondary transformation reactions of SO$_2$. The time variation of SOR calculated from the 923 samples and meteorological factors during the field campaign is shown in Fig. 6. The average value of SOR was 0.30 ± 0.02 during the secondary aerosol pollution days, compared with previous observation by Fu et al. (2008) and Yao et al. (2002). SOR above 0.10 implied sulfate was mainly produced through the transformation of SO$_2$ by oxidation. As seen in Fig. 6, the average value of SOR in Apr 1 to 3, which were typical secondary pollution days, was 0.40, lower than on clear days (0.57) and crust species pollution days (0.84). This result indicated that SOR could not appear alone, instead, the concentrations of SO$_4^{2-}$ and SO$_2$ must be presented with SOR simultaneously. For example, although SOR (0.40) was lower on secondary aerosol pollution days than on clear days (0.57), the molar concentrations of SO$_4^{2-}$ and SO$_2$ during those days were 3 and 4 times higher than on clear days. High SO$_2$ concentration and high SOR directly resulted in a large amount of secondary sulfate particles in the atmosphere. Meanwhile, meteorological factors also played a key role in the formation processes of these secondary aerosol pollutants. From Fig. 6, it was remarkable that high positive correlation occurred between RH and SOR, and we could conclude that higher RH, lower MLD and lower ambient temperature were conducive to the formation of secondary pollution. Low MLD was favorable for gaseous and particulate pollutants to accumulate in the atmospheric boundary layer and persist for a long time, and higher RH could offer the proper conditions for heterogeneous reaction on pre-existing particles. Furthermore, high downward solar radiation flux could promote the photolysis of HONO by the equation: HONO + hv = OH + NO (300 nm < $\lambda$ < 405 nm) (Alicke et al., 2003), and OH radical provided strong atmospheric oxidation ability and accelerated gas-to-particle transformation.

3 Conclusions

Urban pollution events (AQI > 100) were monitored in Lanzhou during early summer from Apr 1 to May 24, 2011. An online instrument (MARGA) was deployed to measure hourly concentrations of major water-soluble inorganic ions (NH$_4^+$, Na$^+$, K$^+$, Ca$^{2+}$, Mg$^{2+}$, SO$_4^{2-}$, NO$_3^-$, Cl$^-$) in aerosols and trace gases (HCl, HONO, SO$_2$, HNO$_3$, NH$_3$) in the atmosphere. Compared with Lanzhou wintertime, water-soluble ions were roughly one- to nine-fold higher except for Ca$^{2+}$, revealing that Lanzhou is more influenced by sand-dust during early summer and heavy secondary aerosol pollution in winter. Based on different concentration levels of water-soluble ions and the result of EPA-PMF 3.0 modeling, the pollution events were classified as crustal species-induced and secondary aerosol-induced pollution. Air parcels containing crustal species outflowing from northwest of Lanzhou traveled a distance over the Hexi corridor and elevated concentrations of Ca$^{2+}$, Na$^+$ and Mg$^{2+}$ in PM$_{10}$ during a typical sand-dust day. Meteorological data and concentrations
of \( \text{NH}_4^+ \), \( \text{SO}_4^{2-} \), \( \text{NO}_3^- \) and \( \text{SO}_2 \) were analyzed to reveal the formation mechanism of secondary aerosol pollution. SOR was derived from the concentration of \( \text{SO}_4^{2-} \) and \( \text{SO}_2 \); it had strong positive correlation with relative humidity, indicating that the processes of gas-to-particle transformation were mainly influenced by the relative humidity in the Lanzhou early summer. Moreover, \( \text{NH}_4\text{NO}_3 \), \( \text{NH}_3\text{SO}_4/\text{NH}_4\text{HSO}_4 \) and \( \text{NH}_4\text{Cl} \) were common salts in secondary aerosols.

Acknowledgments

The authors are grateful to Liang Hu and Fang Wang of the College of Atmospheric Science, Lanzhou University, for routine maintenance of experimental instruments, and we also thank anonymous reviewers for their constructive comments. This work was supported by the National Natural Science Foundation of China (No. 20307005), the Technological Project of Gansu (No. 0804GKCA029), and Gansu Province science and technology research funded projects (No. 2GS057-A52-001-02).

References


\text{HNO}_3 \), \( \text{HCl} \), \( \text{SO}_2 \) and \( \text{H}_2\text{O}_2 \) in ambient air by a wet annular denuder system. Atmos. Environ. (1967) 22, 2541–2548.


Yao, X. H., Chan, C. K., Fang, M., Cadle, S., Chan, T., Mulawa, P., et al., 2002. The Water-soluble Ionic Composition of PM$_{2.5}$ in Shanghai and Beijing, China. Atmos. Environ. 36, 4223–4234.


Editorial Board of Journal of Environmental Sciences

Editor-in-Chief
Hongxiao Tang
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China

Associate Editors-in-Chief
Jiuhui Qu
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Shu Tao
Peking University, China
Nigel Bell
Imperial College London, United Kingdom
Po-Keung Wong
The Chinese University of Hong Kong, Hong Kong, China

Editorial Board

Aquatic environment
Baoyu Gao
Shandong University, China
Maosheng Fan
University of Wyoming, USA
Chhipin Huang
National Chiao Tung University, Taiwan, China
Ng Wun Jern
Nanyang Environment & Water Research Institute, Singapore
Clark C. K. Liu
University of Hawaii at Manoa, USA
Hokyong Shon
University of Technology, Sydney, Australia
Zhiwu Wang
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China

Terrestrial environment
Christopher Anderson
Massey University, New Zealand
Zucong Cai
Nanjing Normal University, China
Xinbin Feng
Institute of Geochemistry, Chinese Academy of Sciences, China
Hongjing Hu
Huazhong Agricultural University, China
Qun-Ying Li
The Chinese University of Hong Kong, Hong Kong, China
Erwin Klumpp
Research Centre Juelsich, Agroscope Institute, Germany
Peijun Li
Institute of Applied Ecology, Chinese Academy of Sciences, China
Michael Scholter
German Research Center for Environmental Health, Germany
Xuejun Wang
Peking University, China
Liizhong Zhu
Zhejiang University, China
Jiannin Chen
Fudan University, China
Abdelwahid Mellouki
Centre National de la Recherche Scientifique, France
Yueying Mu
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Min Shao
Peking University, China
James Jay Schauer
University of Wisconsin-Madison, USA
Yuesi Wang
Institute of Atmospheric Physics, Chinese Academy of Sciences, China
Xin Yang
University of Cambridge, UK
Environmental biology
Yang Cai
Florida International University, USA
Henner Hollett
RWTH Aachen University, Germany
Jae-Seong Lee
Hanyang University, South Korea
Christopher Rensing
University of Copenhagen, Denmark
Bojan Sedmak
National Institute of Biology, Ljubljana
Liorgin Song
Institute of Hydrobiology, Chinese Academy of Sciences, China
Zhongxiang Wang
National Natural Science Foundation of China
Heng Wei
Northwest A & F University, China
Daqiang Yin
Tongji University, China
Zhongtang Yu
The Ohio State University, USA

Environmental toxicology and health
Jingwen Chen
Dalian University of Technology, China
Jianying Hu
Peking University, China
Guibin Jiang
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Sijin Liu
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Tsuysoshi Nakanishi
Gifu Pharmaceutical University, Japan
Willie Peijnenburg
University of Leiden, The Netherlands
Bingsheng Zhou
Institute of Hydrobiology, Chinese Academy of Sciences, China

Environmental catalysis and materials
Hong He
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Junhua Li
Tsinghua University, China
Wenfeng Shangguan
Shanghai Jiao Tong University, China
Yasutake Teraoka
Kyushu University, Japan
Ralph T. Yang
University of Michigan, USA

Environmental analysis and method
Zongwei Cai
Hong Kong Baptist University, Hong Kong, China
Jiping Chen
Dalian Institute of Chemical Physics, Chinese Academy of Sciences, China
Minghui Zheng
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China

Municipal solid waste and green chemistry
Pinjing He
Tongji University, China

Environmental ecology
Ruoxing Wang
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China

Copyright © Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. Published by Elsevier B.V. and Science Press. All rights reserved.
Aims and scope

*Journal of Environmental Sciences* is an international academic journal supervised by Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. The journal publishes original, peer-reviewed innovative research and valuable findings in environmental sciences. The types of articles published are research article, critical review, rapid communications, and special issues.

The scope of the journal embraces the treatment processes for natural groundwater, municipal, agricultural and industrial water and wastewaters; physical and chemical methods for limitation of pollutants emission into the atmospheric environment; chemical and biological and phytoremediation of contaminated soil; fate and transport of pollutants in environments; toxicological effects of terrorist chemical release on the natural environment and human health; development of environmental catalysts and materials.

**For subscription to electronic edition**

Elsevier is responsible for subscription of the journal. Please subscribe to the journal via http://www.elsevier.com/locate/jes.

**For subscription to print edition**

China: Please contact the customer service, Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China. Tel: +86-10-64017032; E-mail: journal@mail.sciencep.com, or the local post office throughout China (domestic postcode: 2-580).

Outside China: Please order the journal from the Elsevier Customer Service Department at the Regional Sales Office nearest you.

**Submission declaration**

Submission of an article implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The submission should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

**Submission declaration**

Submission of the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The publication should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

**Editorial**

Authors should submit manuscript online at http://www.jesc.ac.cn. In case of queries, please contact editorial office, Tel: +86-10-62920553, E-mail: jesc@263.net, jesc@rcees.ac.cn. Instruction to authors is available at http://www.jesc.ac.cn.