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Rainwater characteristics and interaction with atmospheric particle matter transportation analyzed by remote sensing around Beijing

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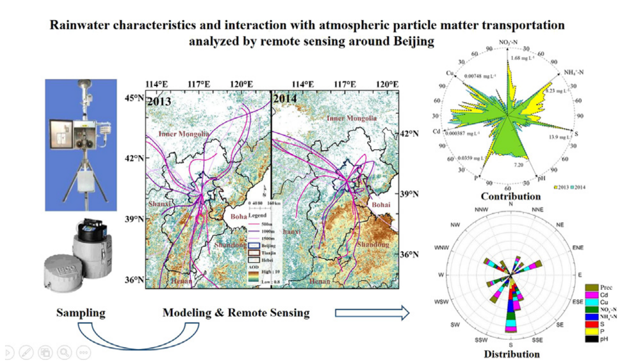
HIGHLIGHTS

- AOD and HYSPLIT model presented transformation patterns pollution in rainfall water.
- Rainfall water quality revealed a positive development of air quality around Beijing.
- Rainfall water quality is influenced by air mass transmission mainly from south.
- NO_3^--N concentration in rainfall water is best indicator for pollution control assessment.

GRAPHICAL ABSTRACT



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ABSTRACT

Air pollution in Beijing has attracted much more attentions, and multiple regulations have been enacted since 2013. Based on the close link between the atmospheric particle matter concentration and the deposited load in rainwater, 336 rainwater samplings with seven parameters (pH, NH_4^+-N, NO_3^--N, P, S, Cu and Cd) at five-minute intervals in 2013 and 2014 were compared. The field monitoring and the temporal patterns analysis revealed a positive development of air quality. The lesser composition of coal in the energy consumption and the effective control of traffic emission were found. The average Aerosol Optical Depth (AOD) value around the sampling point during the 7 sampling rainfall events in 2014 was 2.855, which was higher than that in 2013 (1.807). It reflected the washing effect of rain on atmospheric particulates and highlighted the urban non-point source pollution effected by atmospheric deposition. AOD was demonstrated to perform well in reflecting regional air quality. A trajectory analysis conducted by HYSPLIT model in conjunction with the spatial distribution of AOD in the Beijing-Tian-Hebei (BTH) region depicted paths of air pollutants from long-range transport. The dominant trace was to the south of region. Cities around BTH were provided with different emission-reducing targets. Both Inner Mongolia and Henan province were suggested to control agricultural emissions. Shanxi, Shandong and cities around Bohai Bay should supervise the energy consuming industries. Furthermore, NO_3^--N was introduced to be an indicator of effect of the regional joint prevention and control in the future.

1. Introduction

Urban air pollution is one of the top 15 causes of public health issues worldwide (Bechle et al., 2011) and is also a priority issue for

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sustainable urbanization. To some extent, air quality can intensify the challenge of urban environmental management and industry planning. Air pollution in Beijing, which has a population of more than 20 million and contains 5.6 million vehicles (Beijing Transport Institute data, http://www.bjtrc.org.cn), has accompanied rapid urbanization and industrialization (Wu et al., 2011). The summit concentration of $PM_{2.5}$ in 2013 was greater than 450 μg m^{-3} (Ouyang et al., 2015), followed by accumulating haze events. Increased PM concentrations and increasing public concern about health have resulted in global attention on the issue of the city (Rao et al., 2016), and several regulations and rules were publicized by the Ministry of Environmental Protection (MEP) in the latter part of 2013 to control PM emission (Wang et al., 2010; Tie et al., 2015). Therefore, PM analysis and source identification are both of great demand.

Since ground-based monitoring has drawbacks in reflecting spatial characteristics adequately, remote sensing optics has been using in air quality studies and proved effective for large scale observation (Chu et al., 2003). It has been demonstrated that Aerosol Optical Depth (AOD) retrieved from satellite data has a significant correlation with PM concentration in many regions around the world (Zhao et al., 2017). Thus the AOD value has been used to represent overall air quality (Provençal et al., 2017). The existing two main kinds of NASA AOD products obtained from Moderate Resolution Image Spectroradiometer Sensor (MODIS) are operated with the dense dark vegetation (DDV) and the deep blue (DB) algorithm. While DDV is designed mostly for clear-sky aerosol properties and is not useful when there is heavy loading of PM (haze days), products retrieved by DB perform poorly in resolution and have problems in data accuracy at a small scale (Ma et al., 2016). Therefore, this research retrieved AOD by optics from CCD equipped in China's HJ-1 satellites using DB algorithm to obtain aerosol distribution image at a higher spatial resolution to represent PM condition in polluted days.

Aerosol is also known to be condensation of clouds so that is an important factor affecting precipitation (Khain et al., 2005). It has been proved that increasing urban aerosol can result in rising precipitation depending on air humidity rate (Sherpherd and Burian, 2003; Lin et al., 2006). Since urban aquatic environment is increasingly affected by deposited nutrients, trace heavy metals and the organic pollution from atmospheric deposition (Xu et al., 2015; Naik and Hammerschmidt, 2011), and the non-point pollution is intense especially in rainfall events. Many simulations have aimed to describe the impact of atmospheric deposition on urban water quality throughout the world since the 1970s, and several studies have evaluated the air pollution dynamics with a rainwater chemistry analysis (Peirson et al., 1973; Vicente et al., 2014). The atmospheric PM is washed down by rain during the rainfall process, so the deposited pollutant concentrations represent the air quality (Sherman et al., 2015) which is probably reluctant because the air quality normally gets better after rain. With the advances of source analyses, the pollutant characteristics in rainwater can also indicate the atmospheric PM dynamics.

The major sources for PM in Beijing include coal power-generating plants, industrial activity, and traffic (Kauhaniemi et al., 2008; Shi et al., 2016). Based on the primary PM and rainwater pollution characteristics in Beijing (Guo et al., 2012), seven rainwater quality parameters are selected in this study. The water pH value is an effective indicator for the acid matter in the water. The nitrogen (NH_4^+-N and NO_3^--N), sulfur and phosphorus are included in the regular composition of PM and are effective indicators for energy combustion (Lindberg et al., 1990). Cadmium (Cd) is a hazardous anthropogenic metal and has been identified as an indicator for brake/tire abrasion particles and is employed to assess traffic emissions (Demiray et al., 2012). Copper (Cu) is a reliable indicator for coal combustion (Vallero, 2014). These elements are the regular parameters for a PM composition analysis and are also common indices for urban water management (Adams, 2003). Since the precipitation in Beijing is mainly concentrated in the summer when the stormwater runoff pollution is also serious, the experiments have been designed to carry out mainly in summer (from June to October).

In addition to local pollution sources, the long-range transport of air particles is an important factor as well (Inomata et al., 2017). The Air Pollution Prevention and Control Action Plan (Action Plan) was promulgated by MEP on September 10th, 2013, which was followed by requirements of joint prevention and control for three key regions including Beijing-Tianjin-Hebei region (BTH) (Chai et al., 2013). According to the Implementation Rules of the Action Plan, the analysis of source and spatial transport of PM has become one of the key tasks. It has been proved in some studies that PM from other cities significantly contributes to local air quality (Fu et al., 2008; Wang et al., 2014). With a Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model, the backward trajectories of air mass can be simulated, and then PM derived from long range transmission can be identified (Yan et al., 2015).

Since the 2000s, various air pollution studies have been conducted around Beijing and provide conclusions for the atmospheric deposition and source identifications of PM (Johansson et al., 2008; Singh et al., 2016). In this study, rainwater quality at five-minute intervals obtained from 336 rainwater samples is employed to assess the PM deposition difference under the new air pollution control policies. By using satellite measurements of aerosol dynamics in conjunction with backward trajectory analyses of air mass before the start of rainfall events, the impact of air mass migration on the rainwater chemical composition is analyzed. The detailed purpose of the study is to (1) differentiate the rainwater variance over two years using seven water quality parameters, (2) recognize the spatial sources of specific elements in rainwater and provide guidance for regional joint prevention and control.

2. Materials and methods

2.1. Bulk rainwater sample collection and treatment

The monitoring location was on the campus of Beijing Normal University (116.37E, 39.97N), which was located in downtown Beijing and did not experience direct disturbance from PM emissions. Rainwater samples from 2013 to 2014 were collected with ISCO (ISCO 6712, TELEDYNE ISCO, Nebraska, USA), which could automatically collect water samples with a set time or volume. There were 24 polyethylene plastic bottles (1 L) in the ISCO, and the time interval was set at 5 min. To collect rainwater during the precipitation process without the impact of the underlying type, polyethylene boards (2 m × 4 m) were set on the building roof to guide the flow to the ISCO equipment (Ouyang et al., 2015). Sampling data was used to calculate the Event Mean Concentration (EMC) of the rainfall events and to identify the washing effect of precipitation to PM, further indicating the impact of PM to surface water.

The rainwater samples were taken from the ISCO system to the lab immediately. The pH was analyzed with a pH meter (METTLER TOLEDO, Switzerland). The determination of NH_4^+-N was performed with Nessler's reagent using an Orbeco-Hellige 975 MP colorimeter. The NO_3^--N was determined with ultraviolet spectrophotometric method (UV-2550, SHIMADZU, Japan). The samples were then filtered with a 0.45 μm membrane to remove the suspended particulate matter. Acid digestion treatment was conducted to acidify and digest the organic oxide compounds in the water samples into the form of ions. To make sure the addition of the acid does not produce interference, 0.5 mL of concentrated nitric acid was added to 10 mL of the water samples. The rainwater sample solution, blank solution and standard solution were all subjected to the same operation procedure (Chen et al., 2015). The surface dishes were covered, and the water samples were heated with an electric heating board in the ventilation cabinet for 2 h at 105 °C. After the samples had cooled, the solution was diluted to 10 mL. After a series of pretreatment, the concentrations of Cd, Cu, P and S were measured by inductively coupled plasma atomic emission spectrometry (SPECTRO ARCOS EOP, SPECTRO Analytical Instruments GmbH, Germany) (Lekkas et al., 2004).