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Monsoon rain chemistry and source apportionment using receptor modeling in and around National Capital Region (NCR) of Delhi, India

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Abstract

Studies on monsoon precipitation chemistry were carried out to understand the nature of rainwater and sources of pollution at eight different locations in and around the National Capital Region (NCR) of Delhi during southwest monsoon in the years 2003–2005. These sites were Bulandshahr (BUL), Garhmuktesar (GAR), Muradnagar (MUR), Sardhana (SAR), Panipat (PAN), Charkhi Dadri (CHA), Hodal (HOD) and Bahror (BAH). The rainwater samples, collected at these locations, were analyzed for major anions, cations and pH. The data were assessed for its quality. In general, the order of concentrations of major ions was observed to be: $Ca^{2+} > SO_4^{2-} > HCO_3^- > NH_4^+ > Cl^- > NO_3^- > Na^+ > Mg^{2+} > K^+ > F^-$. The average pH of rainwater at these stations was observed to be 6.39, ranging from 5.77 to 6.62, indicating alkaline nature. However, a few rain events, 31% at Panipat, 12% at Muradnagar and 29% at Sardhana, were observed to be acidic (pH < 5.6). Acidity observed at Panipat and Muradnagar is attributed to industrial influence but at Sardhana to weak organic acids contributed by surrounding vegetation. No definite trends are found for most of the components at all the sites. However, concentrations of Cl^- at Bulandshahr; NO_3^- at Muradnagar and Hodal; F^- at Panipat and Bahror; Na^+ at Bulandshahr; K^+ at Bahror and Bulandshahr; Ca^{2+} at Bulandshahr, Muradnagar, Charkhi Dadri and Sardhana; Mg^{2+} at Panipat, Bahror, Bulandshahr, Hodal and Sardhana have increased from 2003 to 2005. For source identification, principal component analysis (PCA) was made, which showed that in general, at all the sites; suspended soil–dust and sea salts which are natural sources, were identified as the most dominating. Sources like agriculture including cattle, brick kilns and industries were reflected in third or fourth PC indicating moderate influence of anthropogenic activities in this region.
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Keywords: Precipitation chemistry; Soil–dust interference; Alkaline pH; Monsoon rain; Receptor modeling

1. Introduction

The study of precipitation chemistry was initially developed in response to the adverse effects of acidic rain phenomenon on vegetation, human beings, animals, soil, water, fish and buildings (Raddum and Skjelkvale, 2001). Currently, studies

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of atmospheric pollutants mainly in urban areas have been considered of greater importance due to their harmful effects on human health (Hontoria et al., 2003). Precipitation chemistry provides important information by which the deposition of water-soluble gases and aerosol-bound constituents on the earth's surface can be estimated. Such estimates are fundamental in many studies of terrestrial and marine ecology. These also provide the data for testing of regional and global transport models (Rodhe et al., 1995). Further, the study of precipitation chemistry enables us to understand the effects of urban, industrial and agricultural emissions and the biogeochemical factors. These factors regulate the chemistry of precipitation and provide an understanding of the processes controlling the chemical composition of the atmosphere in remote areas and natural biogeochemical cycle (Galloway and Gaudry, 1984).

Precipitation chemistry has been of immense interest in East Asia, Western Europe and northern US for the last 30 years (Balestrini et al., 2000; Dikaiakos et al., 1990; Fornaro and Gutz, 2003; Fujita et al., 2000; Galloway et al., 1987; Granat et al., 1996; Khwaja and Husain, 1990; Lee et al., 2000; Likens et al., 1987; Manoli et al., 2002; Migliavacca et al., 2004; Raper and Lee, 1996; Sanusi et al., 1996; Seto et al., 2000; Singer et al., 1993; Sequeira and Lai, 1998; Tanner, 1999; Zunckel et al., 2003; etc.). In India, a number of studies on precipitation chemistry have been carried out at urban locations such as Bombay, Delhi, Calcutta, Pune, Hyderabad (Ali et al., 2004; Jain et al., 2000; Khemani et al., 1989, 1995; Kulshrestha et al., 1996, 2003a, 2005; Mukherjee, 1957; Safai et al., 2004; Ravichandran and Padmanabhamurty, 1994, etc.). However, very few studies based on one or two locations have been reported for rural environment in India (Kumar et al., 1993; Mahadevan et al., 1989; Momin et al., 2005; Rao et al., 1990; Satsangi et al., 1998, etc.). But the present study is an attempt to understand the precipitation chemistry and to identify the pollutant sources at a larger number of locations (seven rural and one industrial) in and around National Capital Region (NCR) of Delhi.

2. Experimental

2.1. Site description

Delhi (28°37′N, 77°12′E, 217 m a.s.l.), the capital of India situated on the banks of Yamuna River and covering an area of approximately 1500 km^2, is about 1100 km away from the nearest coast of Arabian Sea. It is the fourth most polluted city in the world with respect to suspended particulate matter with 14 million inhabitants (Goyal and Sidhartha, 2002). The main sources of pollution in Delhi are thermal power plants, road transport, small-scale industries and domestic cooking/heating. Delhi is located at the border between the rich rain-washed Gangetic plains in the east and semi-arid tracts of Rajasthan to the southwest.

Some parts of the neighboring three states (Uttar Pradesh, Rajasthan and Haryana) were taken by the Government of India under Central Administration for infrastructure improvement and relocation of industries in designated areas outside Delhi along with laying national highway for diverting the heavy surface transport from within the city to outside during day and night. This region is called the National Capital Region (NCR) of Delhi. In this study, eight sampling locations were selected viz. Bulandshahr, Garhmuktesar, Muradnagar, Sardhana in Uttar Pradesh (UP); Panipat, Charkhi Dadri, Hodal in Haryana; and Bahror in Rajasthan. These locations are shown in Fig. 1. The site description is given below:

1. *Bahror (BAH, 27.51N, 76.20E)*: It is located at about 150 km away from Delhi on Delhi–Jaipur highway in Alwar district of Rajasthan. It has dry climate with hot summer, cold winter and a short monsoon season. The normal annual rainfall in the district is approximately 58 cm. It is deemed as background location compared to others. It is highly sandy/dusty region without any industrial pollution.
2. *Bulandshahr (BUL, 28.24N, 77.54E)*: It is situated at about 130 km southeast of Delhi. It is a typical rural location where cultivation is the major activity.
3. *Panipat (PAN, 29.25N, 77.02E)*: It is a highly industrialized and urbanized location at about 90 km north of Delhi where thermal power plant, fertilizer plant, textile, chemicals, paper and dyeing industries are located.
4. *Sardhana (SAR, 29.9N, 77.37E)*: It is situated 95 km northeast of Delhi on the border of Uttaranchal and Uttar Pradesh states. It represents a rural area where sugar cane is cultivated as the main crop.
5. *Charkhi Dadri (CHA, 28.37N, 76.17E)*: It is situated around 107 km west of Delhi in the

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