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An evaluation of atmospheric N_r pollution and deposition in North China after the Beijing Olympics

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HIGHLIGHTS

- Atmospheric N_r concentration and deposition were reported at six sites in North China.
- High N_r concentrations in the air were found in North China several years after the Beijing Olympics.
- Annual N dry and total deposition was 35.2–60.0 and 54.4–102.3 kg N ha^{-1} in North China, respectively.
- Concentration and deposition of N_r were much higher at urban than at rural sites in North China.

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ABSTRACT

North China is known for its large population densities and rapid development of industry and agriculture. Air quality around Beijing improved substantially during the 2008 Summer Olympics. We measured atmospheric concentrations of various N_r compounds at three urban sites and three rural sites in North China from 2010 to 2012 and estimated N dry and wet deposition by inferential models and the rain gauge method to determine current air conditions with respect to reactive nitrogen (N_r) compounds and nitrogen (N) deposition in Beijing and the surrounding area. NH_3, NO_2, and HNO_3 and particulate NH_4^+ and NO_3^-, and NH_4^+–N and NO_3^-–N in precipitation averaged 8.2, 11.5, 1.6, 8.2 and 4.6 μg N m^{-3}, and 2.9 and 1.9 mg N L^{-1}, respectively, with large seasonal and spatial variability. Atmospheric N_r (especially oxidized N) concentrations were highest at urban sites. Dry deposition of N_r ranged from 35.2 to 60.0 kg N ha^{-1} yr^{-1}, with wet deposition of N_r of 16.3 to 43.2 kg N ha^{-1} yr^{-1} and total deposition of 54.4–103.2 kg N ha^{-1} yr^{-1}. The rates of N_r dry and wet deposition were 36.4 and 33.2% higher, respectively, at the urban sites than at the rural sites. These high levels reflect the occurrence of a wide range of N_r pollution in North China and suggest that further strict air pollution control measures are required.

1. Introduction

Reactive nitrogen (N_r) in the environment produced by human activities has increased more than ten-fold over the past 150 years since the industrial revolution (1860) and will continue to increase because of the increasing demand for food and energy worldwide (Galloway et al., 2008). Global application of N fertilizers produced using the Haber–Bosch process has fed nearly 50% of the newly increased world population (Erisman et al., 2008). Additionally, fossil fuel combustion has facilitated the development of industry and transportation and improved the quality of life of people in developed countries (Compton et al., 2011). Unfortunately, atmospheric emissions of N_r such as NH_3 and NO_x (sum of NO and NO_2) can also promote the formation of small particles which lower air quality and damage human health (Tainio et al., 2009). Increases in

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atmospheric N_r emissions will also lead to elevated N_r dry and wet deposition to the land surface, leading to series of negative effects on ecosystems such as loss of biodiversity in grasslands (Stevens et al., 2004; Song et al., 2012) and forests (Rattray and Sievering, 2001), soil acidification and eutrophication (Erisman and Pul, 1994), and increased N_2O emission which impacts the global greenhouse gas budget (Sutton et al., 2011). Therefore atmospheric N_r pollution and deposition induced by excessive anthropogenic N_r emissions have become an environmental concern worldwide (Compton et al., 2011).

Rapid socioeconomic development in China has led to large N fertilizer consumption and energy consumption over the past 30 years. For example, synthetic N fertilizer consumption, from 12.1 Tg N in 1980 to >30 Tg N in 2010 (Liu et al., 2013), and total energy consumption was equivalent to 3.25 billion tons of standard coal in 2010, about 5 times more than in 1978 (China Statistical Yearbook, 2011). These intensive human activities stimulate the huge N_r emission over China. However, the impacts of such high anthropogenic N_r emissions on atmospheric N deposition and their subsequent implications have not been evaluated systematically to date (Liu et al., 2011).

Cities in North China such as Beijing and Tianjin, and provinces such as Hebei, Henan, Shanxi and Shandong have large population densities, intensive agriculture and highly developed industries and transport systems. Previous studies (Zhang et al., 2008; Shen et al., 2009; He et al., 2010) have demonstrated high levels of N_r pollution and N deposition in rural regions. Substantial air pollution by particulate matter (e.g. PM_{10} and $PM_{2.5}$) has also been found in the megacity of Beijing (Chan and Yao, 2008). The policy of the national government has been to reduce air pollution (Fang et al., 2009). The 2008 Beijing Summer Olympics provided a unique opportunity to check the effects of the pollution control measures, including motor vehicle restrictions, reducing the output from the most polluting factories, and limiting pollutant emissions from coal combustion facilities in Beijing and surrounding areas (Zhou et al., 2010). Air quality in terms of PM_{10} and $PM_{2.5}$, NH_3 and NO_2 improved substantially in Beijing during the Olympics (Wang et al., 2010; Shen et al., 2011a) but air pollution (as indicated by PM_{10}, $PM_{2.5}$, NH_3, NO_2, SO_2, and the particulate ions) recovered quickly almost to previous levels within two months following the Olympics (Shen et al., 2011a). During the three years since the Olympics (2009–2011) the central government encouraged high-quality economic growth with a target of 40–45% less GHG emission per unit GDP by 2020 and also the concept of 'green GDP' (referring to less environmental cost per unit GDP), but there is still a challenge for air quality especially in Beijing, the megacity of North China (Zhang et al., 2012). Moreover, there have been many uncertainties associated with previous studies on N deposition in this area. These include the separate evaluation of dry and wet deposition and uncertainties in the estimation of dry N deposition (Zhang et al., 2008; Shen et al., 2009).

Six monitoring sites representing urban and rural regions in North China were selected for this study. Atmospheric N_r concentrations were measured and N dry and wet deposition rates were evaluated using a DELTA system combined with inferential modeling (dry) and the rain gauge method (bulk). The objectives were to verify whether there is still higher atmospheric N_r pollution in north China (including a comparison of urban and rural N_r levels after the Beijing Olympics) and to provide improved estimates of N dry and wet deposition in this region.

2. Materials and methods

2.1. Sampling sites

Sampling was conducted at six sites located in Beijing and in Hebei, Shanxi, and Henan provinces (Fig. 1). The three urban sites are CAU, BD, and ZZ. CAU, located at the west campus of China Agricultural University (40°01′N, 116°17′E), is near the fifth ring road in Beijing. The BD site is in Baoding city in Hebei province and

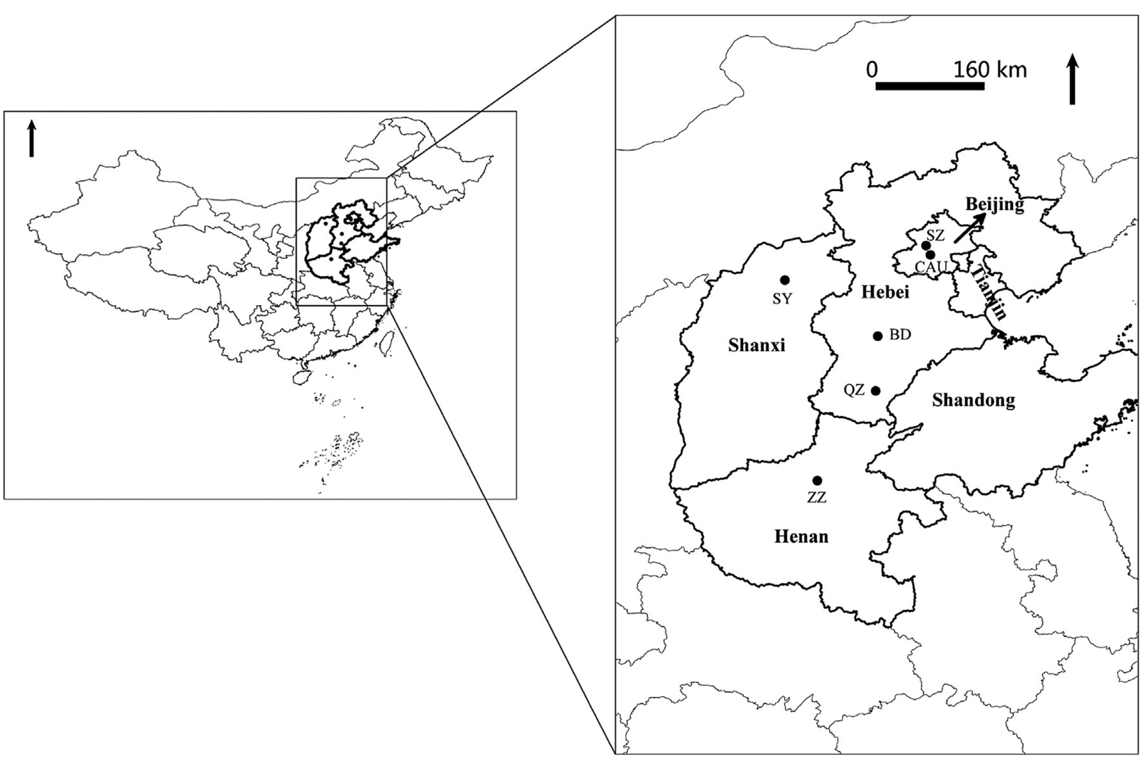

Fig. 1. Geographical distribution of the six monitoring sites in North China. Urban sites (CAU, BD, ZZ); Rural sites (SZ, SY, QZ).