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Concentrations of trace elements in wet deposition over the central Himalayas, Nepal

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HIGHLIGHTS

- Over 1-year dataset of trace elements in wet deposition is presented.
- The difference between monsoon and non-monsoon seasons was not clear at urban site.
- Sources of trace elements in precipitation were from anthropogenic and crustal.

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ABSTRACT

Atmospheric pollutants transported from south Asia may impose a serious impact on human and ecosystem health in the central Himalayan region, Nepal. In order to investigate trace elements in atmospheric wet deposition in the southern slope of the Himalayas, precipitation samples were collected for over a year from four stations: Kathmandu (1314 m.a.s.l), Dhunche (2065 m.a.s.l), Dimsa (3078 m.a.s.l) and Gosainkunda (4417 m.a.s.l) characterized as urban, semi-urban, rural or remote site, respectively. A total of 221 samples were collected and concentrations of 10 trace elements (Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, and Pb) were examined. The highest concentrations of elements were found at urban site (Kathmandu) and lowest at remote site (Gosainkunda). The seasonal differences of elemental concentrations in Kathmandu was not clear between monsoon and non-monsoon seasons as local sources predominated over regional sources. On the contrary, the other three sites showed a distinct seasonal variation with higher loadings of trace elements during non-monsoon and lower during monsoon. EFs calculations at all sites showed that most of elements (Cr, Co, Ni, Cu, Zn, Cd and Pb) were from anthropogenic sources and some (Al, Fe and Mn) were originated from crustal sources. Furthermore, principal component analysis (PCA) also indicated that the precipitation chemistry was mostly influenced by crustal and anthropogenic sources in Nepalese Himalayas. The result from the present study is an indication that long-range transport of pollutants has a significant impact on the high altitude remote areas in the central Himalayan regions.

1. Introduction

Trace elements and metals are increasingly introduced into the environment as pollutants (Nriagu and Pacyna, 1988). Wet deposition, by scavenging the emitted trace element pollutants, delivers them to the terrestrial surface. Due to the differences in the sources, transport pathways, and residence time of trace elements in the atmosphere, the composition and concentration of elements may

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vary greatly from region to region. Moreover, trace elements can also be long-range transported through the atmosphere and deposited in remote regions far away from urban areas (Kyllonen et al., 2009). Therefore, wet depositions of trace elements are important as their long-term excessive inputs may impress adverse impact on the ecosystems and human health through various biogeochemical cycles. This has increased the research interest in the atmospheric contribution of anthropogenic trace elements in the environment over the past few decades around the world.

Since the early 1970s, extensive research on trace elements in precipitation has been undertaken (Peirson et al., 1973). The concentrations of trace elements in the atmosphere have increased since 19th century mainly due to the human activities (Galloway et al., 1982). During the past few decades, studies on wet deposition of trace elements focused on the concentrations, wet deposition fluxes, spatial and temporal variations, source identification and the long-range transport (Al-Momani, 2003; Conko et al., 2004; Gabrielli et al., 2008; Kyllonen et al., 2009; Zhou et al., 2012). To find out the extent of anthropogenic contribution of trace elements, the studies were mainly conducted in cities, industrial areas, and remote regions; however very few studies were carried out at remote high mountain regions (Lee et al., 2008; Cong et al., 2010; Liu et al., 2013). Nevertheless, some studies have been conducted on snow chemistry in northern and southern slope of the Himalayas (Valsecchi et al., 1999; Marinoni et al., 2001; Shrestha et al., 2002; Kang et al., 2004), concentrating mainly on the ionic chemistry. These studies indicated low pollutant concentrations in the Himalayan atmosphere. Deposition of trace elements has been studied in the northern slope of Himalayas in snow and ice (Kang et al., 2007; Huang et al., 2013a) but such studies are lacking in the southern slope. Some research estimated that Asia is a very important emitter of trace metal pollutants to the atmosphere (Pacyna and Pacyna, 2001), so this continent is suffering from the consequences of heavy atmospheric contamination of trace elements (Zhou et al., 2012; Liu et al., 2013). Asian monsoon and Westerlies are accountable for the distribution and transport of the anthropogenic pollutants and airborne dusts from South Asia and central Asia (Cong et al., 2007; Huang et al., 2007; Ming et al., 2008), resulting in potential threats to the ecosystems of continental Asia.

The data of trace elements in wet deposition in the southern slope of the Himalayas, Nepal is limited since this environment is very challenging for continuous sampling mainly due to high altitude, remoteness and harsh weather conditions. Recently, data on major ions in wet precipitation in Nepal has been reported (Tripathee et al., 2014), however data on trace elements have not been published yet. Therefore, different locations on the southern slope of Himalayas, Nepal including urban, semi-urban, rural and remote sites with different elevations were selected for evaluating trace elements in wet deposition. Thus, this study can provide a valuable database on trace elements and pave the way for future studies in the region. The main objectives of this study are to: 1) measure the concentrations of trace elements in wet precipitation sampled at four different sites for over one year period and compare the data with other regions, 2) understand the spatial and temporal (seasonal) variations of elemental composition in precipitation, and 3) investigate their possible sources in the region.

2. Sampling and analysis

2.1. Sampling site description

Nepal is a land locked country between India in the South and China in the North located between the latitudes of 26°22′ and 30°27′ N and longitudes of 80°04′ and 88°12′ E. The altitude ranges from about 57 m to 8,848 m above sea level. The climate of Nepal is dominated by the south–west summer monsoon (or Indian Monsoon) which brings most of the precipitation (Mid-June–September). On the other hand, westerlies brings the rain and the snowfall as the major synoptic weather systems moving eastwards across the Himalayas during the pre-monsoon months and winter (Shrestha and Aryal, 2011).

Detailed information on sampling sites is shown on Table 1 and Fig. 1. The wet deposition samples were collected at Kathmandu (1314 m.a.s.l), Dhunche (2065 m.a.s.l), Dimsa (3078 m.a.s.l) and Gosainkunda (4417 m.a.s.l) on the southern slope of central Himalayas, Nepal. This can lead to a remarkable dataset of trace element concentrations in precipitation from low to high altitude. Kathmandu valley is the largest urbanized city in Nepal located in the middle hills. It has experienced rapid increase in population, urbanization and industries in the recent years with increased vehicles (Dhital et al., 2013). The major pollution sources around Kathmandu are vehicles emission, industries and brick Kilns, unmanaged urbanization, unmanaged solid and liquid wastes. Intensified agricultural activities is the another significant pollution source around the valley. The other three sites (Dhunche, Dimsa and Gosainkunda) are situated in the Langtang National Park in Rusuwa district, which is about 50 km north of Kathmandu and 14 km south of China border. Dhunche is a semi-urban small town which is the head-quarter of Rusuwa district, Nepal. The major sources for pollution are biomass burning for cooking, vehicle emission, tourism and agricultural activities around the town. Dimsa is forested area along the trekking route with a few hotels. Gosainkunda is a famous religious place on the southwest of the national park with high number of people flow during August for a famous Hindu festival *Janai Purnima*. In the latter two sites the major human activities are tourism and limited agricultural activities; thus, local emissions are due to biomass combustion for cooking and heating. The monthly average precipitation in Kathmandu and Dhunche has been shown by Tripathee et al. (2014). The average annual precipitation (1972–2009) at Kathmandu and Dhunche are 1445 and 1884 mm respectively, of which 78% and 74% respectively occurs in the monsoon season. The average monthly highest temperature occurs in July and August and the average monthly lowest temperature during December and January at these two sites. The air masses at these sites are defined by the mountain valley wind system. The zone has a temperate climate. At other two sites, Dimsa and Gosainkunda, relatively low precipitation occurs and precipitation in the form of snow is common during winter. In these regions, a monsoonal weather system move from south to north into the high mountains and comprises sub-alpine and alpine climatic zones. These two sites have no meteorological stations due to remoteness and high altitude that make a continuous monitoring very difficult.

2.2. Sampling and laboratory analysis

In order to understand the atmospheric trace metal chemistry in the Himalayas, precipitation samples were collected from April 2011 to September 2012 at Kathmandu and Dhunche and from May 2011 to July 2012 at Dimsa and Gosainkunda. A total of 221 precipitation samples were collected from four sampling locations. Since the number of snowfall samples was few, they were considered as precipitation samples as explained earlier by Tripathee et al. (2014). Pre-cleaned high-density polyethylene (HDPE) bucket with inner removable HDPE plastic bag was used for the sample collection and then samples were transferred to the HDPE bottle immediately after the precipitation event. The sampling bucket was placed 1.5 m above the ground. All samples were acidified with ultra-pure nitric acid (0.5% V/V) to dissolve the trace elements