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Distribution of fluorine in the surface dust of Wuda coal base, Inner Mongolia of Northern China

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A R T I C L E I N F O

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A B S T R A C T

Wuda coalfield in Inner Mongolia is one of China's typical old coal bases and has a coal fire history of over 50 years. Many studies have been carried out on fluorine pollution caused by high-temperature processing industries such as those related to the production of steel, aluminum, glass, brick, and tile. However, few studies have focused on fluorine pollution caused by coal-fired industrial parks or coal fires. For the present study, 224 dust samples were collected from Wuda district in Inner Mongolia and its surrounding zones, covering a total area of ~270 km^2. Subsequently, fluorine concentrations in the samples were analyzed using the combustion–hydrolysis/fluoride-ion selective electrode method. Results showed that the average fluorine concentration of dust is 848 $\mu g \cdot g^{-1}$ (430–1504 $\mu g \cdot g^{-1}$) in Wuda coalfield and 1016 $\mu g \cdot g^{-1}$ (237–2830 $\mu g \cdot g^{-1}$) in industrial parks, which are more than four times the background value. The average fluorine concentration in the adjoining downwind urban area of Wuda is 488 $\mu g \cdot g^{-1}$, which is twice the background value. The results indicate that long-term fluorine release from the coal fire and industrial parks leads to significantly elevated fluorine concentration levels in the dust around the study area. The scenario of urban areas in close proximity to coal seam fires and industrial parks is not particular to Wuda; it is relatively common in northern China and elsewhere. Thus, the influence of coal seam fire and industrial parks on other cities merits further investigation.

1. Introduction

Fluorine is important for animals and humans and is particularly essential for bone and tooth growth (Bellomo et al., 2003). However, an overdose of fluorine can negatively affect environmental quality and animal health and is known to contribute to dental fluorosis, skeletal fluorosis, impaired thyroid function, and lower intelligence in children (Gao et al., 2016). Fluorine enters the atmosphere via both natural and anthropogenic sources (Bellomo et al., 2003, 2007; Codling et al., 2014; D'Alessandro et al., 2008; Jayarathne et al., 2014). Natural sources of fluorine include marine aerosols, volcanic eruptions, soluble fluoride in rocks, and resuspension of soil dust (Barnard and Nordstrom, 1982; Gao et al., 2016). Additionally, anthropogenic activities resulting from high-temperature processing industries, such as steel production, aluminum smelting, brick and ceramic firing, as well as coal burning, emit fluorinated compounds and further raise the concentration of atmospheric fluorine well above the natural levels in many areas (Almeida et al., 2005; Feng et al., 2016; Jayarathne et al., 2014; Monfort et al., 2008; Zhao and Luo, 2017). The fine fluorine-containing particles, in some cases, may get deposited in environments, resulting in contamination of air, underground water, food, and plants (Egli et al., 2004; Farooqi et al., 2007, Finkelman, 2004; Finkelman et al., 2002; Udeigwe et al., 2011; Zhu et al., 2013).

Fluorine pollution is usually caused by fine fluorine-containing smoke dust particles (Zheng, 1994), which could lead to disease or even death in animals. For example, chronic animal fluorosis in northern China caused by high-fluorine smoke dust particles has been reported in many studies. In the process of metal smelting, such as steelmaking and aluminum smelting, fluorine is mainly released with smoke dust particles, and then deposited locally, causing high fluorine content in surface dust and soil, thereby leading to excessive fluoride intake in cattle and sheep. Yi et al. (2012) reported that fluorine poisoning in livestock in the city of Baotou, Inner Mongolia, China is extremely serious, with nearly one million goats affected annually owing to the high-fluorine smoke dust released from industries such as rare earth metal smelting. Yun et al. (2005) showed that chronic fluorosis of sheep in Haiyan County, Qinghai province, China is also caused by smoke dust with high fluorine content emitted from local aluminum manufacturers.

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Coal combustion also contributes significantly to anthropogenic high-fluorine smoke emissions (Liu et al., 2013). Fluorine pollution caused by coal has been reported widely, including in studies on fluorine emission inventory of the coal-fired industry (Chen et al., 2013; Luo et al., 2002), on domestic coal (Ando et al., 2001; Liang et al., 2011; Liu et al., 2013; Luo et al., 2010, 2011), and on the environmental pollution caused by coal-washing by-products (Gao et al., 2016; Li et al., 2013; Wang et al., 2016). However, little is known about fluorine pollution from underground coal fires and industrial parks. Among the many cities adjacent to coal fires and affiliated industrial parks in northern China, this study focused on a typical coal-based city, i.e., Wuda in Inner Mongolia, which is located near a prominent coalfield—Wuda coalfield, which has a coal fire history of nearly 50 years. This study was conducted to investigate fluorine concentrations in the dust of Wuda District and adjacent areas (covering an area of 270 km^2), with an aim of assessing the environmental impacts of the underground coal fire and industrial parks.

2. Materials and methods

2.1. Site description

Wuda District in the city of Wuhai (39° 29′N, 106° 42′E) is located in central Inner Mongolia, northern China (Fig. 1), at the northern end of the Helan Mountains, southern edge of Ulan Buh Desert, and adjacent to the Ningxia Hui Autonomous Region, with the Yellow River crossing through it from south to north at its eastern edge (Liang et al., 2014). Wuda District covers an area of ~220 km^2 and has a population of about 130,000 (2013). The Wuda coalfield, a 35-km^2 north-south striking syncline, is sited 5 km west of Wuda District. As seen in Fig. 2, there are remains of former sandstone in the middle of the coalfield. A limestone mountain is located at the southeastern border of the coalfield. The climate is characterized by a strongly continental, fully arid climate, with annual evaporation of 3500 mm and precipitation of 168 mm (Jiang et al., 2011; Kuenzer et al., 2012). In this region, northwesterly winds prevail and the annual average wind speed is 4.8 m s^{-1}. Because of the semiarid to arid climate, influenced mainly by the East Asian Monsoon, the land surface cover in Wuda is dominated by bare rocks and soils as well as sparse dry desert shrubs with partially sclerophyllous leaves (Kuenzer et al., 2007, 2012). The Wuda coalfield is bordered by Badain Jaran Desert to the northeast, west, and northwest, but to the east and on both sides of the Yellow River are integral farming and pastoral areas of the Hexi Corridor (Bayan Raul to Yinchuan).

The coal base in Wuda coalfield was initiated in 1958. This coal base produces coking coal, which was once mainly supplied to the Baotou Steel Group (Xue, 2014). The first coal seam fire in this area was reported in 1961, and then intensified in the following years. Many coal seams have ignited here, leading to heavy smog in the near-surface air (Fig. 1A, B). Surface vents (Fig. 1E, F) and cracks (Fig. 1G) with or without fumes are scattered throughout the central area, along with several small-scale open-flame sites (Fig. 1C, D). By the beginning of this century, it had drawn wide concern from the international community (Jiang et al., 2017; Kuenzer et al., 2012; Liang et al., 2015; Prakasha and Vekerdy, 2004; Wang et al., 2011; Zhang et al., 2008). Previous studies have shown that this coal mining area has both coal fire and gangue problems (Ao, 2005; Li et al., 2016). Recent studies have verified that not only local underground coal fires emit gaseous mercury (Liang et al., 2014), but coal gangue gas also contains mercury (Liang et al., 2016). There are also indications that the mercury emissions from the Wuda coalfield and industrial parks have intensified the accumulation of mercury in the surface dust of this area (Li et al., 2017).

There are two industrial parks near Wuda coalfield: Wuda industrial park in the east and Wusitai industrial park in the west, both of which are located in the main zone that is downwind from the fire. The industrial parks were established in the 1980s. After more than 30 years of development, these parks have formed a circular pattern of development of large-scale power plants, coking plants (coke production), metal smelters, coal plants, calcium carbide plants, PVC plants, other heavy chemical plants, etc. The roads in the industrial parks are mainly used for heavy-duty diesel trucks, which carry coal for coal enterprises such as power plants. Almost no other industries besides the coalmines, coal washers, and power plants are located within 20 km of the parks.

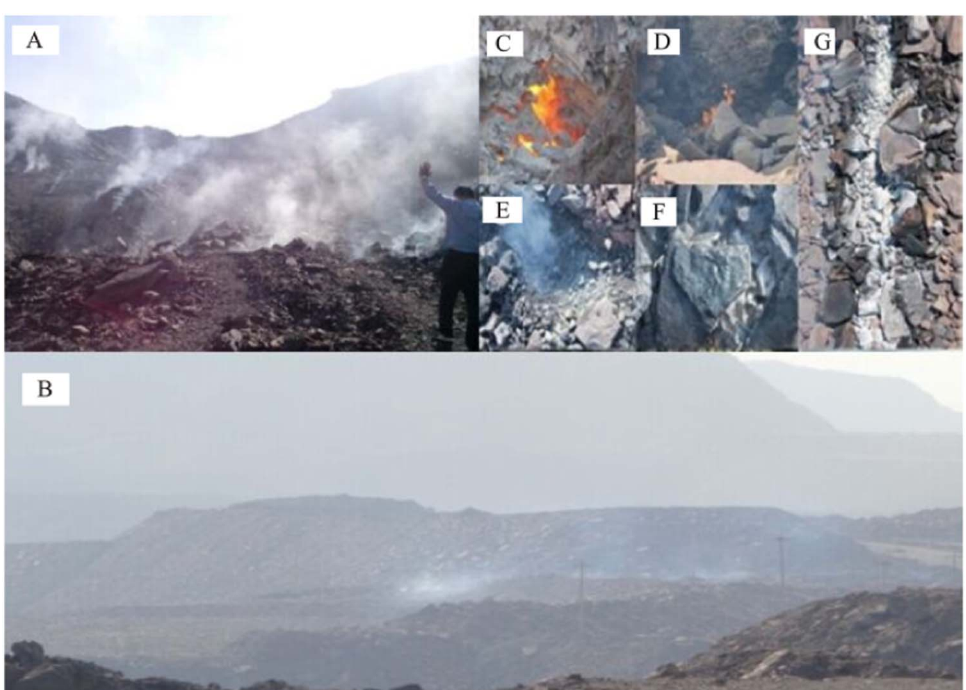

Fig. 1. Landscape and appearance of the coal fire in the Wuda coalfield (A, B: landscape of the Wuda coalfield; C, D: open-flame site; E, F: surface vents with and without smoke, respectively; G: surface cracks).

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