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Traffic-related metal(loid) status and uptake by dominant plants growing naturally in roadside soils in the Tibetan plateau, China

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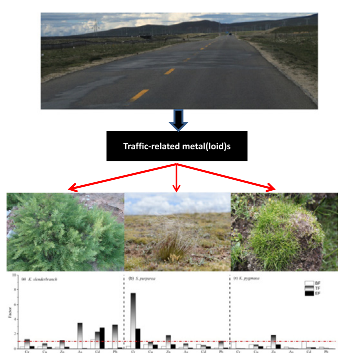
HIGHLIGHTS

- Metal(loid) concentrations in plants varied as the exponential function of proximity.
- The uptake styles of plant vary with species and metal(loid) types.
- The studied plant presented limited BF and high TF.

GRAPHICAL ABSTRACT



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ABSTRACT

To understand traffic-related metal(loid) status and uptake by dominant plants growing naturally in roadside soils in the Tibetan plateau, China, aboveground parts and root samples of three dominant plant species (*Kalidium slenderbranch*, *Stipa purpurea*, *Kobresia pygmaea*) were collected along the Qinghai–Tibet highway, and were analyzed for concentrations of traffic-related metal(loid)s such as chromium (Cr), zinc (Zn), copper (Cu), cadmium (Cd), arsenic (As), and lead (Pb). The results indicated that concentrations of metal(loid)s in plant tissues varied greatly among plant species and sites. Tissue distribution of metal(loid)s was significantly related to distance and demonstrated variability as an exponential function of traffic proximity. It was deduced that Cd in *Kalidium slenderbranch* and Cu and Zn in *S. purpurea* were mainly derived from soil; *Kalidium slenderbranch* and *Kobresia pygmaea* absorbed Zn, and *S. purpurea* absorbed Cd, mainly through stomata, from atmospheric deposition; enrichments of Pb and As in *S. purpurea* presented similar characteristics to those of Cd and Pb in *Kobresia pygmaea* and were affected by both soil and atmospheric deposition. After excluding the effects of the traffic, the highest value obtained for metal(loid)-translocation capacity (7.51 for translocation factor, TF) was observed for *S. purpurea* collected from Tuotuohe, while the lowest value for metal(loid)-uptake capacity (0.015 for bioaccumulation factor, BF) was for *Kalidium slenderbranch* collected from Golmud. The three plant species showed limited soil-to-root transfer of metal(loid)s, possibly due to the high soil pH along the Qinghai–Tibet highway, but demonstrated great potential for metal(loid) transfer from roots to aboveground parts.

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1. Introduction

Traffic and road construction can produce different kinds of contaminants and results in ecological imbalance in sensitive environments nearby (Bermejo-Orduna et al., 2014). These contaminants contain road salts, polycyclic aromatic hydrocarbons, and heavy metals, which spread in both dissolved and particulate forms. Particularly, heavy metals are of great concern due to their low degradability, and persistent poison to plants, animals and humans (Werkenthin et al., 2014). Metal(loid)s including Cr, Cd, Cu, Zn, Ni, Pb, As, and the platinum group elements have been identified as traffic-related metal(loid)s in roadside environments (Schäfer et al., 1998; Viard et al., 2004; Wiseman et al., 2014, 2016; Zhang et al., 2012, 2015). These metal(loid)s derive from many different sources, e.g., tire abrasion, brake linings, wear of individual vehicular components, incomplete fuel combustion, oil leaks, road abrasion, pavement leaching, and road maintenance (Werkenthin et al., 2014). Once separated from the vehicles or road, these pollutants are transported into the roadside environment through aerial spread or infiltration of spray water and road runoff (Legret and Pagotto, 2006; Bakirdere and Yaman, 2008).

Roadside soil and plants are recognized to be major sinks for traffic-related heavy metals. It has been proven that concentrations in soils are significantly affected by road construction and traffic, and are inversely proportional to the distance from the highway (Zhang et al., 2015; De Silva et al., 2016). The traffic-related metal(loid)s arise in soil through dry and wet deposition. The distributions of metal(loid)s in plant tissues also show variability as a function of traffic proximity (Wiseman et al., 2014). Unlike soils, plant tissues uptake heavy metals not only via soil-to-root transfer, but also by absorption from wet and dry particles deposited on aerial parts of the plant (McBride et al., 2013; Sánchez-López et al., 2015). This characteristic may complicate the migration and transformation of metal(loid)s in roadside environments, especially in urban regions or agricultural areas with frequent human activities and multiple pollutant sources (Li et al., 2007; Wiseman et al., 2013, 2014; Galal and Shehata, 2015; Morse et al., 2016; Sánchez-Chardi, 2016). The multiple pollutant sources and wet-dry deposition hamper the ability to assess the influence of the traffic and may lead to incorrect or incomplete conclusions.

The Tibetan plateau provides good conditions for studying the influence of traffic on heavy metal accumulation in soil–plant systems. It bestrides a longitude of 31 degrees with a length of 2945 km from west to east, and a latitude of 13 degrees with a length of 1532 km from north to south (Zhang et al., 2002). The majority of the area close to the Qinghai–Tibet highway is well preserved, but constitutes a fragile ecosystem that is very sensitive to global climate changes and anthropogenic activities (Yu and Lv, 2011). Even limited influences of anthropogenic activities can result in remarkable environmental reaction (Klein et al., 2004). Traffic and grazing are exclusively human activities. The roadside environment, especially soil–plant systems, is suffering increasing pressure with increasing tourism and freight transport. The Qinghai–Tibet highway spans several different landscapes with distinct climates, types of vegetation, and soils, including steppe and alpine meadow ecosystems. Continuous monitoring of the accumulation of traffic-related metal(loid)s in roadside soil–plant systems is necessary to safeguard these fragile ecosystems. These otherwise-pristine environments also help us to effectively understand the mechanisms of traffic influence on roadside soil–plant systems.

This study was designed to evaluate the status and distributions of traffic-related metal(loid)s in soils and dominant plants growing naturally in roadside environments in the Tibetan plateau, China. The specific purposes of the study were: (1) to measure concentrations of traffic-related metal(loid)s in plants growing naturally at different sites; (2) to examine the distribution pattern of traffic-related metal(loid)s in plant tissues and soils in order to distinguish the uptake styles of traffic-related metal(loid)s in different plants; (3) to understand the metal(loid) assimilation and transfer potentials of three dominant plants.

2. Materials and methods

2.1. Study area

For specific information on the study area, please refer to Zhang et al. (2015). Large areas of natural pasture distributed along the Qinghai–Tibet highway are a food source for domesticated and wild animals. These natural pastures are characteristic of different landscapes: alpine shrub, alpine steppe, alpine meadow, and alpine desert. *Kobresia pygmaea*, *Stipa purpurea*, and *Kalidium slenderbranch* are dominant plant species in alpine steppe, alpine meadow, and alpine desert, respectively.

2.2. Sampling strategy

The environmental characteristics of Nagqu (NQ) and Damxung (DX) are extremely similar, i.e., same soil type, dominant plant species, and soil texture, and similar vegetation cover and average annual wind speed. Therefore, we selected only Golmud (GM), Tuotuohe (TTH), and Nagqu (NQ) as study areas, and dispensed with Damxung (DX) (Fig. 1). In determining the distribution and accumulation of traffic-related metal(loid)s in plants along the Qinghai–Tibet highway, the choice of plant species was controlled by two main factors: (1) how representative the plants were of those growing naturally in the Tibetan plateau, and (2) dominant plant species as indicators of regional environmental conditions. Based on these two criteria, three plant species were chosen: *Kalidium slenderbranch* (GM), *S. purpurea* (TTH), and *Kobresia pygmaea* (NQ) (Fig. 1).

The detailed sampling strategy of soil at three typical sites can be found in the Supplementary Information. Whole plants were sampled from the three sites at locations corresponding to soil sampling at the same distances from the highway (0, 1, 2, 4, 5, 7, 10, 20, 30, 50, 60, 80, 100, 150, 200 and 300 m). The plants collected were separated into aboveground parts (including leaves and shoots) and belowground roots. Three plants of the same species were collected at each distance and mixed together to create a composite sample. All samples were then packed into polyethylene bags and taken to the laboratory. In total, 48 separate root and shoot samples were collected, respectively.

2.3. Sample pretreatment and detection of total heavy metal(loid) concentrations

Methods of sample preparation for heavy metal determination have been described fully by Zhang et al. (2015). Briefly, prior to analysis, a 20–30 mg ground soil sample in a 15 mL Teflon vessel was repeatedly digested on a hotplate and in a drying oven. The concentrations of V, Cr, Co, Ni, Cu, As, Zn, Rb, Cd, Pb and Tl were detected by inductively coupled plasma mass spectrometry (ICP-MS; Thermofisher X2, Thermo Fisher Scientific, Massachusetts, USA) after dilution.

Plant samples were cleaned five times with distilled water and dried at 80 °C, and then ground to a powder with a metal-free plastic mill. The method for extracting total metals from plant samples was as follows: a 0.2 g sample of dried, ground plant was transferred into a 15 mL Teflon bomb. Next, 1 mL HNO_3, 1 mL H_2O_2, and 1 mL HF were added to the sample and let stand overnight in a dust-free environment. The sample was then put in a hermetic stainless-steel container and heated in a drying oven at 160 °C for about 4–5 h before being put on a hotplate and concentrated almost to dryness at 150 °C. The remnant was then dissolved in 1 mL HNO_3 and again concentrated almost to dryness at 150 °C, and this was repeated twice. The remnant was dissolved once more by adding 1 mL HNO_3 and 1 mL H_2O_2, and then put in a hermetic stainless-steel container and dried in a drying oven at 150 °C for about 4–5 h. A clean solution was obtained and then diluted. The concentrations of Cr, Cu, Zn, As, Cd, and Pb were detected by ICP-MS, on account of these metal(loid)s being identified as traffic-related (Zhang et al., 2015).