The effects of the Qinghai–Tibet railway on heavy metals enrichment in soils

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HIGHLIGHTS

► Levels of Zn, Cd and Pb in soils are affected by railway transportation.
► Cadmium enrichment is especially high.
► The affected area for these pollutants was within 20 m of the railway.
► The distributions of metal presented different characteristics in different sites.

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ABSTRACT

The impact of land transportation on local soil environments is an important topic in environmental and ecological sciences. The rapid development of transportation infrastructure lends increasing importance to studies that identify and evaluate related heavy metal pollution. This paper discusses the effects of railways on soil heavy metal enrichments in the Tibetan plateau. At a representative area along the Haergai–Delingha railway, lead, cadmium, copper, zinc, chromium, nickel, cobalt, and vanadium were measured in 127 topsoil samples (0–10 cm depth).

The results indicate that railway transport has a significant effect on the concentration of Zn, Cd and Pb in the soil, with levels of enrichment ranging from no pollution to significant pollution. The affected area was within 20 m of the railway. The soil at Delingha was the most contaminated soil with heavy metals, and the enrichment level of Cd in the soil was the highest along the Qinghai–Tibet railway. The horizontal distributions of the three heavy metals present different characteristics at different sampling sites, which may be due to discrepancies in terrain and vegetation types. Alkaline soils and guardrails along the railway might reduce the effect of soil pollution on local people and animals.

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1. Introduction

While certain heavy metals are essential for the proper function of biological systems, at elevated levels, they can be detrimental to human health and the environment (Suiter et al., 1999; Dai et al., 2004; Morra et al., 2009; Chen et al., 2010; Özcan and Al Juhaimi, 2012). Accompanying rapid economic development, pollution has become a growing problem, resulting in a higher volume of pollutants, including an increased amount of heavy metals discharged into the environment. Along with industry, transportation has been one of the most significant sources of heavy metal pollution (Pagotto et al., 2001; Liu et al., 2009). Particles containing metals are released into the air from liquid fuel combustion (Chen et al., 2010), vehicular abrasion and road/track material abrasion (Blok, 2005; Suzuki et al., 2009). Heavy metal particulate matter ultimately settles in soils and vegetation through dry and wet deposition. Due to their low degradability, heavy metals can reside in soil for long periods of time. Moreover, they have the potential to damage microbiota, flora and fauna, and to threaten human health as pollutants flow via the food chain.

Since the 1970s, numerous studies have addressed heavy metal pollution in roadside environments (Motto et al., 1970; Davies, 1989; Koeleman, 1999; Fakayode and Olu-Owolabi, 2003; Khan et al., 2011; Mikalajūnė and Jakučionytė, 2011). However, most research has focused on environmental pollution surrounding highways, with relatively little attention to the pollution resulting from railways. For example, research has found that road transport affects levels of numerous heavy metals, including Pb, Cd, Cu, Zn, Cr, Ni, Fe, Mn, Al, Co, V, Sb, Ba, Pt, Mo, Hg, Se and As (Ho and Tai, 1988; Sansalone and Buchberger, 1997; Blake and Goulding, 2002; Zechmeister et al., 2005; Lia et al., 2007). By contrast, researchers have only examined the relationship between railways and heavy metals for a limited number of elements, i.e., Ni, Pb, Mn, Cr, Zn, Cu and Cd (Malawska and Wiołkowska, 2001; Liu et al., 2009; Ma et al., 2009). Over the last decade, scientists have directed greater attention to the soil

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environment near railways. Their research has shown that railway transportation can affect the surrounding environment, especially in urban areas (Bukowiecki et al., 2007; Davila et al., 2006; Gehrig et al., 2007; Lorenzo et al., 2006). With respect to the soil environment along railways, recent studies have primarily shown: (1) the differences of soil heavy metals across different sites (Langmi and Watt, 2003; Malawska and Wiołkomierski, 2001), (2) the horizontal distribution of soil heavy metals (Baltrénas et al., 2009; Ma et al., 2009), and (3) the influence of terrains on soil heavy metal distribution (Liu et al., 2009). However, these studies were mainly conducted in transportation junctions, urban regions, or agricultural areas, with frequent social activity, where other inputs may have affected the ability to access the influence of railways.

The Qinghai–Tibet railway provides favorable conditions for exploring the effects of railways on soil heavy metal enrichment. Most of the area surrounding the Qinghai–Tibet railway is in well-preserved ecosystem, where the environment is sensitive to outside influences. Even small-scale human activities can result in significant environmental changes. Aside from transportation, other anthropogenic disturbances are relatively low in this area. Moreover, the Qinghai–Tibet railway traverses several distinct landscapes with different climate, soil and vegetation types. All of these factors can affect the enrichments and distributions of soil heavy metals (Blok, 2005; Saedi et al., 2009; Sezgin et al., 2004; Zhao et al., 2007).

This paper quantifies the impact of railway transport on soils in the Tibetan plateau. Based on findings from a large-scale field investigation, we identify possible heavy metal pollutants using statistical analysis and assess heavy metal contamination levels in soils along the Qinghai–Tibet railway.

2. Material and methods

2.1. Study area

The Qinghai–Tibet railway traverses several natural zones with different environmental characteristics; the landscapes along the railway include alpine shrub, alpine meadow, alpine steppe, and alpine desert. The section from Xining to Golmud comprises the first part of the Qinghai–Tibet railway. It has a length of 846 km and an average altitude of 3018 m. This section was built in 1956 and opened in 1984. It carries 5 million tons of cargo every year and runs 18 passenger trains daily. The trains are pulled by two diesel locomotives, which operate at a speed of 120 km/h. This section belongs to a temperate continental zone characterized by strong winds during the long-cold winter, low rainfall in summer and short spring and autumn seasons. This section crosses the Qinghai–Tibet railway provides favorable conditions for exploring the effects of railways on soil heavy metal enrichment. Most of the area surrounding the Qinghai–Tibet railway is in well-preserved ecosystem, where the environment is sensitive to outside influences. Even small-scale human activities can result in significant environmental changes. Aside from transportation, other anthropogenic disturbances are relatively low in this area. Moreover, the Qinghai–Tibet railway traverses several distinct landscapes with different climate, soil and vegetation types. All of these factors can affect the enrichments and distributions of soil heavy metals (Blok, 2005; Saedi et al., 2009; Sezgin et al., 2004; Zhao et al., 2007).

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2.2. Soil sampling strategy

To probe the enrichments and distributions of heavy metals in the soil along the Qinghai–Tibet railway, sampling sites adhered to the following criteria: (1) relatively flat terrain, (2) uniform vegetation and soil type associated with the regional landscape and (3) dominant landscapes in the Tibetan plateau. Moreover, to avoid the influence of the highway to the extent possible, samples were drawn from sites where the railway was at least 2 km away from highways. Taking these factors into consideration, the study area was separated into three sites: Delingha (DLH), Tianjun (TJ), and Haergai (HEG) (Fig. 1).

At the DLH site, soil samples were collected at 2, 5, 10, 20, 30, 50, 60, 70, 80, 100, and 150 m from the railway in August 2008 (there was a mountain in the distance at 180 m). At TJ and HEG, soil was sampled at 2, 5, 10, 20, 30, 50, 60, 70, 80, 100, 150 and 200 m from the railway in August 2009. Three (at TJ and HEG) or five (at DLH) surface soil samples (10 cm depth) were obtained at each distance with a wooden shovel. Each soil sample was packed into a polyethylene bag and taken to the laboratory. A total of 127 soil samples were collected.

2.3. Sample preparation and analysis for the measurement of total metal concentrations

The soil samples were dried indoors at room temperature then passed through a 2 mm nylon sieve to remove root debris and stones.

The method extracting total metal concentrations is based on Liang et al. (2000). Some steps of this method were improved according to experimental requirements. Specific steps were as follows: A quarter of the 2-mm sieved sample was further ground to pass through a 0.15-mm sieve. A small portion of each sample (20–30 mg) was transferred into a PTFE (Polytetrafluoroethylene) bomb, moisturized with 2 or 3 drops of Milli-Q water (18.2 MΩ cm) and subjected to total digestion. To each bomb we added 1 ml HNO₃ (68%) and 1 ml HF (38%). The bombs were then moved to a hot plate at 150 °C and the solution evaporated to almost dryness to remove most of the silica. Subsequently, 1 ml HNO₃ and 1 ml HF were added to each bomb, which was placed in a stainless steel seal pot and heated in an electric oven to 190 °C for more than 24 h. After cooling, the bombs were placed on the hot plate and reheated at 150 °C to almost dryness. Then, 1 ml HNO₃ was added twice and evaporated at 150 °C to almost dryness. The final residue was re-digested by adding 2 ml HNO₃ and 3 ml Milli-Q water, resealing the bombs and placing them into the electric oven at 150 °C for more than 30 h. After cooling, the digestate was transferred to a volumetric polypropylene tube and diluted to approximately 2000 times its original concentration. The total concentrations of V, Cr, Co, Ni, Cu, Zn, Cd and Pb were determined by inductively coupled plasma mass spectrometry (ICP-MS).

The quality assurance and quality control (QA/QC) procedures were conducted by using standard reference materials: GSS-1, GSS-3, GSS-5, GSS-6 and GSS-8 (Geochemical Standard Soil). Recoveries of the eight heavy metals were 96–108% for V, 98–112% for Cr, 93–104% for Co, 96–116% for Ni, 99–115% for Cu, 93–102% for Zn, 88–104% for Cd and 96–109% for Pb. Duplicated samples were analyzed simultaneously for 15% of the soil samples and the standard deviation was within 5%. Two blank samples and forty samples were

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Haergai (HEG)</th>
<th>Tianjun (TJ)</th>
<th>Delingha (DLH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
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<td>37°13′</td>
<td>37°20′</td>
</tr>
<tr>
<td>Longitude</td>
<td>100°18′</td>
<td>98°56′</td>
<td>97°03′</td>
</tr>
<tr>
<td>Elevation</td>
<td>3240</td>
<td>3420</td>
<td>2910</td>
</tr>
<tr>
<td>Soil type</td>
<td>Typic Haploboroll</td>
<td>Pachic Haploboroll</td>
<td>Haplocalcid</td>
</tr>
<tr>
<td>Dominant species</td>
<td>Achnatherum splendens</td>
<td>Stipa purpurea</td>
<td>Ceratoides latens</td>
</tr>
<tr>
<td>Vegetation cover (%)</td>
<td>70–80</td>
<td>90–95</td>
<td>10–15</td>
</tr>
<tr>
<td>Zonea</td>
<td>Alpine grassland</td>
<td>Alpine grassland</td>
<td>Alpine desert</td>
</tr>
<tr>
<td>AATb</td>
<td>−1.6 °C</td>
<td>−3.8 °C</td>
<td>0.03 °C</td>
</tr>
<tr>
<td>AAPc</td>
<td>475 mm</td>
<td>378.98 mm</td>
<td>244.07 mm</td>
</tr>
<tr>
<td>Soil pH</td>
<td>8.3</td>
<td>8.2</td>
<td>8.3</td>
</tr>
<tr>
<td>Rail bed</td>
<td>Flat</td>
<td>Flat</td>
<td>Slope</td>
</tr>
</tbody>
</table>


Table 1: Location and physical features of the three study sites.
Fig. 1. Study area and sampling sites on the Xining–Golmud section of the Qinghai–Tibet railway, China.
Table 2
Descriptive statistics of metal concentrations (mg kg\(^{-1}\)) in soils.

<table>
<thead>
<tr>
<th></th>
<th>V</th>
<th>Cr</th>
<th>Co</th>
<th>Ni</th>
<th>Cu</th>
<th>Zn</th>
<th>Cd</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLH, n=55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean±SD</td>
<td>45.2±4.0a</td>
<td>31.5±5.3a</td>
<td>7.9±0.6a</td>
<td>16.2±2.9a</td>
<td>14.8±1.5a</td>
<td>41.1±11.9a</td>
<td>0.133±0.086a</td>
<td>21.4±6.5a</td>
</tr>
<tr>
<td>Min</td>
<td>35.4</td>
<td>18.5</td>
<td>6.8</td>
<td>10.1</td>
<td>11.3</td>
<td>28.0</td>
<td>0.047</td>
<td>16.6</td>
</tr>
<tr>
<td>Max</td>
<td>58.4</td>
<td>46.5</td>
<td>9.7</td>
<td>24.8</td>
<td>20.5</td>
<td>77.32</td>
<td>0.417</td>
<td>41.85</td>
</tr>
<tr>
<td>CV (%)</td>
<td>8.8</td>
<td>16.83</td>
<td>7.59</td>
<td>17.9</td>
<td>10.14</td>
<td>28.95</td>
<td>64.66</td>
<td>30.37</td>
</tr>
<tr>
<td>TJ, n=36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean±SD</td>
<td>87.8±4.7b</td>
<td>71.2±4.1b</td>
<td>11.4±0.7b</td>
<td>33.6±2.6b</td>
<td>31.1±1.8b</td>
<td>81.8±7.6b</td>
<td>0.185±0.046b</td>
<td>26.1±2.7b</td>
</tr>
<tr>
<td>Min</td>
<td>79.2</td>
<td>62.4</td>
<td>12.1</td>
<td>28.4</td>
<td>27.7</td>
<td>63.9</td>
<td>0.123</td>
<td>22.1</td>
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<tr>
<td>Max</td>
<td>102.0</td>
<td>79.9</td>
<td>15.8</td>
<td>39.5</td>
<td>36.4</td>
<td>91.40</td>
<td>0.253</td>
<td>29.58</td>
</tr>
<tr>
<td>CV (%)</td>
<td>5.35</td>
<td>5.76</td>
<td>5.22</td>
<td>6.85</td>
<td>5.79</td>
<td>9.29</td>
<td>24.86</td>
<td>10.34</td>
</tr>
<tr>
<td>HEG, n=36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean±SD</td>
<td>84.4±5.4c</td>
<td>70.6±6.2b</td>
<td>11.3±0.9b</td>
<td>32.8±2.8b</td>
<td>24.1±1.9c</td>
<td>78.8±8.7b</td>
<td>0.201±0.090b</td>
<td>25.6±3.1b</td>
</tr>
<tr>
<td>Min</td>
<td>65.5</td>
<td>50.9</td>
<td>10.6</td>
<td>24.1</td>
<td>22.5</td>
<td>53.0</td>
<td>0.115</td>
<td>19.7</td>
</tr>
<tr>
<td>Max</td>
<td>93.8</td>
<td>81.3</td>
<td>15.4</td>
<td>39.3</td>
<td>33.5</td>
<td>87.57</td>
<td>0.445</td>
<td>29.51</td>
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<tr>
<td>CV (%)</td>
<td>6.40</td>
<td>8.78</td>
<td>6.77</td>
<td>8.54</td>
<td>6.76</td>
<td>11.04</td>
<td>44.78</td>
<td>12.11</td>
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<tr>
<td>ACV (%)</td>
<td>6.85</td>
<td>10.46</td>
<td>6.53</td>
<td>11.10</td>
<td>7.56</td>
<td>16.43</td>
<td>44.77</td>
<td>17.61</td>
</tr>
<tr>
<td>Continental crustd</td>
<td>135</td>
<td>100</td>
<td>25</td>
<td>75</td>
<td>55</td>
<td>70</td>
<td>0.2</td>
<td>12.5</td>
</tr>
<tr>
<td>Background of United Statese</td>
<td>80</td>
<td>54</td>
<td>9.1</td>
<td>19</td>
<td>25</td>
<td>60</td>
<td>–</td>
<td>19</td>
</tr>
<tr>
<td>Background of mainland Chinaf</td>
<td>82.4</td>
<td>61.0</td>
<td>12.7</td>
<td>23.4</td>
<td>22.6</td>
<td>74.2</td>
<td>0.097</td>
<td>26.0</td>
</tr>
</tbody>
</table>

CV, coefficient of variation; ACV, average coefficient of variation; DLH, Delingha sites; TJ, Tianjun sites; HEG, Haergai sites. The data with different lowercase letters have significant differences in columns d, Taylor and McLennan (1995); e, Shacklette and Boerngen (1984); and f, CNEMC (1990).

analyzed in each experiment. All of the samples were analyzed by four separate experiments.

2.4. Enrichment factor (EF)

Enrichment factor (EF) can be used to assess the degree of heavy metal contamination in soils. It is calculated using the following formula (Atiemo et al., 2012):

\[
EF_x = \frac{X_s/C_{138}}{X_r/C_{138}} = \frac{X_s}{X_r} \times \frac{C_{138}}{C_{138}}
\]

where EF\(_x\) is the enrichment factor for the metal X; X\(_s\) is the metal concentration in the sample; X\(_r\) is the concentration of the reference metal used for normalization in the sample; X\(_r\) is the metal concentration in the crust; and C\(_{138}\) is the concentration of the reference metal used for normalization. The crustal elemental concentration used in this study is replaced by soil background values in China that remove the effect of natural geochemical variability (CNEMC, 1990).

Based on the enrichment factors, five pollution levels were proposed by Sutherland (2000): EF<2 represents depletion to minimal enrichment, suggestive of no or minimal pollution; 2≤EF<5 indicates moderate pollution; 5≤EF<20, significant pollution; 20≤EF<40, strong pollution and EF≥40 indicates extreme pollution.

2.5. Statistical analysis

The concentrations of eight metals were compiled to form a multi-element database using PASW (SPSS Inc., Chicago, USA). Factor analysis (FA), cluster analysis (CA), ANOVA, multiple comparisons, and Pearson correlation analysis were performed using PASW 18.0. In the FA, factors with eigenvalues over 1 were extracted and an orthogonal varimax rotation was used to rotate the axes for a better fit through the variable cluster (Lu, 2010). In the CA, the raw data were first standardized to a mean of 0 and a standard variation of 1 (Z score) then classified using between-group linkages with the Pearson correlation as the similarity measurement. The Pearson product–moment correlation coefficient was applied to explore the linear relationships between the concentrations of heavy metals and the distance from the railway. ANOVA was used to observe significant differences in metal concentrations among the different sampling sites and to assess the significant impact of sampling sites on the enrichment of metals in soils. Multiple comparisons were used to show significant differences in metals concentrations and enrichment factor between soils from different sampling sites.

3. Results and discussion

3.1. Concentration of soil heavy metals

Descriptive statistics of the heavy metal concentrations in the investigated soil samples are listed in Table 2. The % CVs of V, Co, Cr, Ni and Cu in each sampling site were smaller than those of Zn, Cd and Pb. This finding indicates that the concentrations of V, Co, Cr, Ni and Cu showed relatively little variability in each sampling site, while the concentrations of Zn, Cd and Pb greatly changed. The % CVs of elements at DLH were much higher than those at TJ and HEG, most likely because of different sample numbers (Table 2). To remove regional differences, the average coefficient of variations (ACV) of these elements was calculated and listed in Table 2. The results showed that ACV followed the sequence Cd>Pb>Zn>Ni>Cr>Cu>V>Co. This finding revealed that concentrations of Zn, Cd and Pb in
the soil varied greatly along the railway. This result leads us to speculate that concentrations of Zn, Cd and Pb in the soil were most likely related to human activities along the Qinghai–Tibet railway.

The results of ANOVA in Table 2 show that Cr, Co, Ni, Zn, Cd and Pb at HEG and TJ are significantly higher compared with those at DLH. V and Cu have the highest concentrations at TJ and the lowest at DLH. Some metals in soils were the optimal indicators for climate (Gallet et al., 1996; Fairchild and Treble, 2009). Humid climate and low temperature were made for high soil enrichment of some metals i.e. Zn, Cd and Pb (Pang et al., 2001). There is a corresponding relationship between the average concentrations of Cr, Co, Ni, Zn, Cd, Pb and the AAP, between V, Cu and the AAT (Table 1). This finding leads us to deduce that the differences in rainfall and temperature may be likely to cause the differences in metal concentrations in soils along the railway.

As shown in Table 2, concentrations of most metals in soils are lower than that in continental crust with the exception of Zn and Pb at TJ and HEG (Taylor and McLennan, 1995). Zn and Pb concentrations in soils at TJ and HEG are slightly higher than they are in continental crust, which may be due to the higher background concentrations of Zn and Cu in the soils of China (74.2 mg kg$^{-1}$, 22.6 mg kg$^{-1}$). The levels of all metals at DLH are lower than their background concentrations in soils in the United States, while the levels of all metal at TH and HEG are higher (Shacklette and Boerngen, 1984). The concentrations of V, Cr, Co, Ni, Cu, Zn and Pb in soils at DLH are lower than their background concentration in Mainland China, while the level of Cd is

Fig. 2. Scatter plots and cluster tree of elements showing interrelationships among metals.
higher. The concentration of most metals in soils at TJ and HEG is higher than their background concentrations in China, with the exception of Pb at HEG.

3.2. Interrelationships among heavy metal in soils along the railway

Metals in soil can be geogenic and also originate from anthropogenic inputs (Zaharescu et al., 2009). To determine the source of metal in soils along Xining–Golmud railway, factor analysis (FA) was applied on the relationship among metals. A total of two factors (F1 and F2) were extracted at all three sampling sites. The two factors were applied on the relationship among metals. A total of two factors was applied on the relationship among metals. A total of two factors (corresponding to Zn, Cd, and Pb) and the distance to the railway in each group at HEG had a closer relationship. As a whole, the metal classification according to cluster analysis was totally consistent with the results from factor analysis.

Many studies have proven that Zn, Cd and Pb are indicator metals in contaminated soils near highways (Hasselbach, 2005; Chen et al., 2010; Wang et al., 2011). Only few studies have shown that levels of Zn, Cd and Pb in soils along railways were influenced by railway transport (Ma et al., 2009; Malawska and Wiółkomirski, 2001). Although factor and cluster analyses were inadequate to conclude that the pollutants originated from railway transport, the Zn, Cd and Pb appear to have derived from a similar source, which may be related to rail traffic.

3.3. Relationship between soil metal concentrations and distance

There were significant negative correlations between factor 2 scores (corresponding to Zn, Cd, and Pb) and the distance to the railway in the three sampling sites (DLH, −0.38, p<0.01; TJ, −0.39, P=0.05; HEG, −0.54, p=0.01). Some authors have shown that heavy metal pollutants derived from traffic had significant negative correlation with distance to the road (Liu et al., 2009; Nabulo et al., 2006; Zehetner et al., 2009). The further analysis shows that Zn concentrations at DLH and TJ are significantly correlated with distance from the railway, while Cd and Pb concentrations at DLH and HEG are significantly related to the distance from the railway. The corresponding correlation coefficients are −0.31 (p<0.05), −0.41 (p<0.05), −0.36 (p<0.01), −0.38 (p<0.05), −0.37 (p<0.01) and −0.34 (p<0.05). After the combination of % CVs of metals, factor analysis and cluster analysis, our result suggests that the enrichment of Zn, Cd and Pb in surface soils along the railway is related to the locomotive traffic along the Xining–Golmud section of the Qinghai–Tibet railway.

3.4. Soil enrichment of Zn, Cd and Pb along the railway

3.4.1. The distributions of Zn, Cd and Pb with distance from the railway

The concentrations of Zn, Cd and Pb at each distance from the railway are presented in Fig. 3. The concentrations of Zn, Cd and Pb decreased with increasing distance from the railway at DLH. The maximum concentrations of Zn, Cd and Pb were 68.11, 0.35 and

Table 4

<table>
<thead>
<tr>
<th>Metal</th>
<th>1st criterion (mg kg⁻¹)</th>
<th>2nd criterion (mg kg⁻¹)</th>
<th>pH&gt;7.5</th>
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</thead>
<tbody>
<tr>
<td>Zn</td>
<td>100</td>
<td>300</td>
<td>0.2</td>
</tr>
<tr>
<td>Cd</td>
<td>0.2</td>
<td>0.6</td>
<td>35</td>
</tr>
<tr>
<td>Pb</td>
<td>35</td>
<td>350</td>
<td>7.27</td>
</tr>
</tbody>
</table>

The concentrations of Zn, Cd, and Pb were compared with the first and second criteria index of the Chinese Environmental Quality Standard for Soils (CEPA, 1995; Table 4), in which the first criterion was suitable to keep natural background values, while the second could be used to establish the threshold values for protecting human health (Bai et al., 2011). The Cd concentrations at DLH, TJ and HEG exceed the first criterion of the environmental quality standards by 9.09%, 25% and 36.11%, respectively. The results indicate that Cd pollution exists in surface soils along the Qinghai–Tibet railway.

### 3.4.2. The enrichment of Zn, Cd and Pb along railway soils

In formula (1), Mn, Fe, Si and Al were generally used as reference metal E to assess heavy metal contamination levels (Atiemo et al., 2012; Liu et al., 2009; Sutherland, 2000). In this paper, Co was used as the reference metal E because of its low % CV (Table 2) and significantly different statistical relationship with metals of traffic origin (Fig. 2). The value of Es is derived from the Co concentration from Table 1 and Er was 12.7 mg kg\(^{-1}\) based on the soil Co background values of China (CNEMC, 1990).

The EFs of Zn, Cd and Pb at different sites are presented in Table 5. The EFs of these metals ranged from 0.67 to 6.85, indicating a scope from no pollution to significant pollution. The results of ANOVA and multiple comparisons show that the EFs of Cd are significantly higher than the EFs of Zn and Pb, and the EFs of metals at DLH are significantly higher than those at TJ and HEG. This finding indicates that soil at DLH is the most heavily contaminated, with heavy metals and the enrichment level of Cd in soil being the highest along the railway. These results are similar to this study’s comparison between metal concentrations and to the Chinese Environmental Quality Standard for Soils (Table 4).

The EFs of Zn, Cd and Pb at different distances from the railway are presented in Fig. 4. Among metals, the enrichment degree of Cd indicated significant pollution at 2 m from DLH railway and sharply decreased to no pollution; the EF of Pb at 2 m indicated moderate pollution and decreased to no pollution level after 5 m. At TJ and

### Table 5

<table>
<thead>
<tr>
<th></th>
<th>Zn</th>
<th>Cd</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>0.89± 0.24</td>
<td>2.22 ± 1.32</td>
<td>1.33 ± 0.39</td>
</tr>
<tr>
<td>Max</td>
<td>1.66</td>
<td>6.85</td>
<td>2.84</td>
</tr>
<tr>
<td>Min</td>
<td>0.67</td>
<td>1.14</td>
<td>1.08</td>
</tr>
<tr>
<td>TJ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>1.01 ± 0.07</td>
<td>1.80 ± 0.26</td>
<td>0.95 ± 0.06</td>
</tr>
<tr>
<td>Max</td>
<td>1.20</td>
<td>2.50</td>
<td>1.15</td>
</tr>
<tr>
<td>Min</td>
<td>0.94</td>
<td>1.29</td>
<td>0.88</td>
</tr>
<tr>
<td>HEG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>0.97 ± 0.07</td>
<td>1.96 ± 0.58</td>
<td>0.94 ± 0.08</td>
</tr>
<tr>
<td>Max</td>
<td>1.12</td>
<td>4.33</td>
<td>1.17</td>
</tr>
<tr>
<td>Min</td>
<td>0.83</td>
<td>1.35</td>
<td>0.73</td>
</tr>
</tbody>
</table>

The data with different capital letters have significant differences in rows and data with lowercase letters have significant differences in columns.

38.10 mgkg\(^{-1}\), respectively (2 m from railway) and decreased rapidly to stable until 10 m. The concentrations of these pollutants at TJ and HEG did not display an obvious trend with increasing distance from railway and sharply fluctuated within 80 m of the railway.

Numerous factors can lead to different distributions of soil Zn, Cd and Pb along railway. The terrain is the most likely reason for the differences in heavy metal concentrations observed. At DLH, the railway was built on high rail bed (Table 1). The heavy metal particles from exhaust gas and friction are easily deposited on the shoulder of the rail line and enrich the topsoil (Blok, 2005). During rainfall, these particles can be readily transported to the bottom of the slope (Ma et al., 2009; Liu et al., 2009). This may be the reason that the maximum values of metals peak at 2 m from the railway. Vegetation coverage may be another factor affecting the distribution patterns of soil metal. Vegetation coverage is higher at TJ and HEG than at DLH (Table 1), and the relatively denser vegetation may have helped filter the atmospheric particles by adsorption and absorption (Zhao et al., 2007; Hagler et al., 2012).
HEG, only the EF of Cd indicated moderate pollution within 20 m from the railway. Although concentrations of Zn, Cd, and Pb sharply fluctuated within 80 m from the railway (Fig. 3), the majority of heavy metal enrichment was within 20 m.

Along the Qinghai–Tibet railway, the guardrails were set within 20 to 30 m from the railway to keep local people and animals away from the tracks. These guardrails also keep local people and animals away from the polluted soil. The soil pH ranged from 8.2 to 8.3 along the Xining–Golmud railway (Table 1). This alkaline soil can decrease the migration and availability of metals (Huang et al., 2004; Blake and Goulding, 2002). Therefore, the enrichment of these metals in soils along the Qinghai–Tibet railway may have little effect on local people and animals.

4. Conclusion

The results indicate that, of the eight metals measured in this study, soil concentrations of Zn, Cd and Pb were the most affected soil concentrations by railway transport along the Xining–Golmud railway. The difference in horizontal distribution of soil metals at different sampling sites may be due to terrain and vegetation coverage. The enrichment of the three metals ranged from no pollution to significant pollution, affecting an area ~20 m from the railway. The enrichment of these pollutants in the soil likely had little effect on the local people and animals because of soil alkalinity and the positioning of guardrails. Given the sensitive and vulnerable environment of the Tibetan plateau, long-term monitoring of soil pollution along railways is important.

Acknowledgments

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Motto HL, SPSS statistical analysis.
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