

## Research Article

### As, Cd, Cr, Hg, Ni and Pb in Soil from Eastern Slope of Mt. Gongga, Eastern Tibet, China

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**Abstract:** Concentrations of As, Cd, Cr, Hg, Ni and Pb were determined in soils from the eastern slope of Mt. Gongga at an altitude of 7,556 m above sea level. Mean concentrations of As, Hg and Pb in top soil were below the tolerance limit (the grade-1 standard) set in China for uncontaminated soils. Nevertheless, Pb was found in topsoil from the eastern slope of Mt. Gongga at mean concentrations of  $30.38 \pm 7.32$  mg/kg dw, which was close to the tolerance limit. At one site in surface layer of the Faber's fir mature forest, concentrations of Pb were all above the tolerance limit ( $35.7$ - $43.1$  mg/kg dw). Mean concentrations of Cd, Cr and Ni did exceed the tolerance limit (the grade-1 standard) set in China. Single-factor contaminant index data were calculated by taking into account the analytical information obtained from topsoil at each sampling site. Among heavy metals determined, the highest degree of topsoil pollution was found for Cd. The single-factor pollutant index values decreased in the order of  $P_{Cd} > P_{Cr} > P_{Ni} > P_{Pb} > P_{Hg} > P_{As}$ . Evidently, topsoil of the eastern slope of Mt. Gongga accumulated elevated levels of Cd and Cr and Ni. An integrated assessment of topsoil quality for six heavy metals analyzed indicated that the values of index  $P_N$  for all sites varied between 0.92 and 4.89 and all are considered as 'slight to pronounced impact' by heavy metals.

**Keywords:** China, forest, heavy metals, Mt. Gongga, Sichua, soil

## INTRODUCTION

Soil is the building block of basic materials that constitute the Earth's environment and it also provides a basis for the survival and development of living organisms, both plants and animals, including human beings. Heavy metals in soil can affect plant growth and have negative impacts on environmental conditions by contributing to air and water pollution. Soil can also be a source of heavy metals migration into animal and human food chains. An assessment of soil safety is to draw the boundary line for polluted soil through pre-determined methods or via other means to determine the extent of pollution. Determination of heavy metal pollution in soil can help in the assessment of risks of heavy metals (Wang *et al.*, 2009). Quite a number of studies associated with heavy metal contamination in agricultural soils, mine and urban soils have been carried out (Wei and Yang, 2010; Liu *et al.*, 2011; Manz *et al.*, 2009; Karczewska *et al.*, 2006; Moreno-Jiménez *et al.*, 2009; Bermea *et al.*, 2009; Manta *et al.*, 2002). However, there is a lack of information from scenic area.

Mt. Gongga at its highest peak of 7,556 m above mean sea level (a.s.l.), is situated at  $29^{\circ}20'$ - $30^{\circ}20'N$  and  $101^{\circ}30'$ - $102^{\circ}E$  on the eastern edge of the Qinghai-Tibet Plateau, which is in the mid-section of snowbound mountains of Hengduan (Daxue Shan mountain range). This mountain is approximately 60 km wide along the north-south direction and 30 km along the east-west direction. Mt. Gongga is located in the administrative counties of Kangding, Luding, Shimian and Jiulong of Sichuan Province in China. This mountain is characterized by glacier and forest growing region in the Asian maritime monsoon climate zone and is renowned for integrity of its natural geographical band. Dry and hot river valleys, agricultural fields, broad-leaved forest, coniferous forest, highland shrubs, alpine meadows and permafrost desert encompass the landscape of the region (Chen and Gao, 1993). Since the Quaternary Age, its geological tectonics has experienced violent activities. Mt. Gongga region was authorized by the State Council in 1997 to a status of the state-level nature protection area in China.

Hailuogou (Conch Valley) is a branch gully along the eastern slope of Mt. Gongga. Due to differences in

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hydrothermal conditions and vegetations, a structurally complex perpendicular band of soils have been formed, which changes with the elevation. From the foot to the peak of the mountain, these complex soils consist of yellow-brown earths below 1,700 m, brown earths at 1,700-2,500 m, dark-brown earths at 2,500-2,900 m, brown coniferous forest soils at 2,900-3,600 m, dark felty soils at 3,600-4,200 m, felty soils at 4,200-4,600 m and frigid frozen soils at 4,600-4,700 m.

The aim of this study was to examine the status of heavy metal contamination (As, Cd, Cr, Hg, Ni and Pb) and assess environmental quality of soil of the major vegetation types along the eastern slope of Mt. Gongga in Sichuan Province (Eastern Tibet) of China. This was to provide scientific basis for sustainable tourism development, protection of ecological environment and reasonable utilization and management of soil resources. The degree of soil pollution with heavy metals was assessed by comparing with the quality assessment approach of soils using a single-factor and multiple-factor heavy metal indices method according to the "Quality Standard of Soil Environment" criterion of China.

## MATERIALS AND METHODS

**Collection and treatment of soil cores:** Soil cores were collected at three observation sites of Gongga Alpine Ecosystem Observation and Experiment Station in Hailuoguo along the eastern slope of Mt. Gongga (Fig. 1). The sampling site no. 1 is located in the middle

and bottom part of the steep slope (30-35°) of the Faber's Fir (*Abies fabri*) mature forest. This area is an 'observation site' at elevation of 3,100 m and the slope direction is southeast. The site no. 2 is located in the gentle-sloping (5-8°) valley of a 'Supporting observation site' in the Faber's Fir/Purdom Poplar (*Populus purdomii*) succession forest at elevation of 2,950 m and the slope direction is to the east. The site no. 3 is located at the gentle-sloping (7-10°) debris flow fan of the middle-aged Faber's Fir forest at elevation of 3,000 m and the slope direction is southeast.

At each of these three locations, three sampling points were selected depending on the topography at high, medium and low positions (Ou *et al.*, 2007) of the slope (Table 1).

The S-shape distribution of the soil core sampling points was adopted. The soil cores were taken using a core sampler (type XDB 0302, Soil Equipment Limited Company, New Earth Work, Beijing). The length of each core was 100 cm. Each core was sectioned at 0-10, 10-20, 20-40, 40-60 and 60-100 cm depth. Each layer of soil core sample was mixed evenly. Any visible roots and gravels and other impurities were removed. By quartering method, 1 kg of soil sample was packed in polyethylene bags and transported to the laboratory. In total, 9 soil profiles were collected and 45 soil core samples were prepared.

Soil samples were air dried under clean conditions, ground in agate mortar and impurities (small stones, plant debris etc.) were removed when sieving in

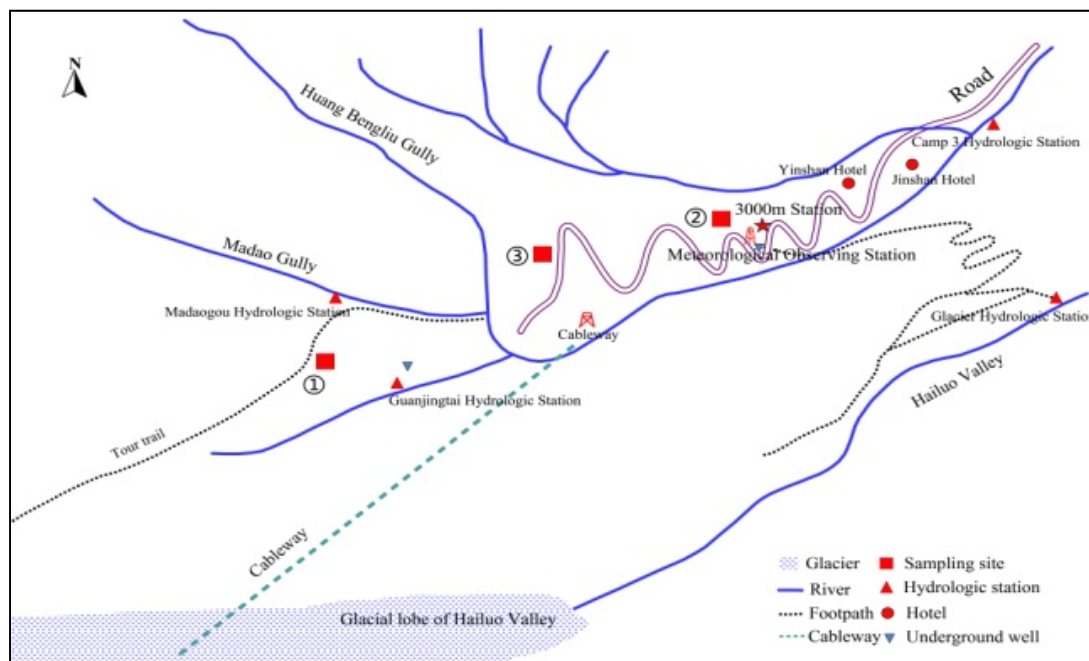


Fig. 1: Sampling sites of soil at the Mt. Gongga  
 (①Comprehensive observation field of *Abies fabri* mature forest, ②Supporting observation field of *Abies fabri*-*Populus purdomii* succession forest, ③Middle-aged *Abies fabri* Forest observation field)

Table 1: Characterization of the sampling area and soil

Site	Point	Slope position	Soil classification <sup>*</sup> ; Soil parent material	Forest type
Faber's fir ( <i>A. fabri</i> ) mature forest at 3,100 m a.s.l.	1-1	High	Podzolic brown coniferous forest soil <sup>†</sup>	Faber's fir mature forest
	1-2	Middle	wash	
	1-3	Low		
Faber's fir ( <i>A. fabri</i> )/Purdum poplar ( <i>P. purdomii</i> ) succession forest at 2,950 m a.s.l.	2-1	High	Acidic debris flow skeleton soil	Mixed broad-leaved and conifer forest
	2-2	Middle	Deposits and alluvial of debris flow	
	2-3	Low		
Faber's fir ( <i>A. fabri</i> ) middle-aged forest at 3,000 m a.s.l.	3-1	High	Debris flow skeleton soil <sup>**</sup>	Faber's fir middle-aged forest
	3-2	Middle	Deposits of debris flow	
	3-3	Low		

\* GB/T 17296-2000 (2000); #the profile is characterized by acidic ashes and has the characteristics of embedded soil layer; \*\* there is no soil category known as debris flow parent material soil in the China's scheme of soil classification (GB/T 17296-2000, 2000); †Information above from the Mt. Gongga observatory station

laboratory using a plastic sieve of 20 mesh followed by 100 mesh. Dried and sieved soil samples were packed in polyethylene bags and stored in capped polyethylene bottles.

**Heavy metal determination:** To determine Cd content, each soil sample was hot digested using a mixture of hydrochloric (HCl), nitric (HNO<sub>3</sub>), hydrofluoric (HF) and perchloric acids (HClO<sub>4</sub>); Cd was quantified using graphite furnace atomic absorption spectroscopy (GB/T 17141-1997, 1997). To determine Hg and As content, each soil sample was hot digested in aqua regia (1+1) and was quantified by Atomic Fluorescence Spectrometry (AFS). To determine Pb, Cr and Ni content, each soil sample was hot digested using a mixture of HCl, HNO<sub>3</sub>, HF and HClO<sub>4</sub> acids and were quantified with the aid of Inductively-Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) according to the Chinese standard method (Ou *et al.*, 2007). All acids used were of analytical grade (Merck).

Analytical quality control and quality assurance were achieved by the analyses of fortified samples and a blank sample with each set of samples.

**Soil quality assessment:** In order to assess the degree of soil pollution with heavy metals, single-factor and multiple-factor indices approaches were used (Ding, 2001). The use of single-factor approach is related to the degree of soil pollution by a particular compound from which the single soil quality criterion will be obtained. The single factor index method is the basis for multiple factor method. The single-factor index assessment is one of the most popular methods of soil quality assessment widely adopted in China (Ding, 2001; Xia, 1996). The calculation of the single factor index method can be expressed as:

$$P_i = C_i/S_i \quad (1)$$

where,

- P<sub>i</sub>(dimensionless) = The environmental quality index for pollutant "i"
- C<sub>i</sub>(mg/kg) = The actual measured value for pollutant "i"
- S<sub>i</sub>(mg/kg) = The assessment standard of pollutant

According to the National Environmental Quality Standards of China adopted by the National Department of Environmental Protection, Mt. Gongga region is a nature reserve. Hence, the soils in the region fall under the standard "Category I and grade-1" which should be used in "Environmental Quality Standard of Soil" (GB 15618-1995, 1995).

The comprehensive multiple factor index method is one of the principal methods used for recognizing integrated environmental quality status. The Nemerow's integrated approach for soil quality assessment is the most popular method adopted to calculate pollution index in China and also in other countries (Gong *et al.*, 2008). It takes into account both the average value and maximum value of a single-factor pollutant index and emphasizes the influence of relatively important agent on the environmental quality (Xia, 1996). This index is calculated by using formula (2):

$$PN = \{0.5[(C_i/S_i)_{\max} + (C_i/S_i)_{\text{av}}]\} \quad (2)$$

where,

- PN = Multi-factor index
- (C<sub>i</sub>/S<sub>i</sub>)<sub>max</sub> = The maximum value of the pollution index of pollutant in soil
- (C<sub>i</sub>/S<sub>i</sub>)<sub>av</sub> = The average value of pollution index of pollutant in soil.

Assessment criterion of soil pollution indices used in China for a single-factor and the Nemerow's integrated approach by a multiple-factor index is given in Table 2.

## RESULTS AND DISCUSSION

**Concentrations of six heavy metals:** The heavy metal concentrations in soil samples were done through statistical analyses with Microsoft Excel and SPSS 17.0 software and the descriptive statistics of heavy metal concentrations in the studied area are summarized in Table 3. Comparing the results with standards range (GB 15618-1995, 1995), showed that the concentrations of Pb, Hg and As in this area are lower than standard

Table 2: Assessment criterion of soil pollution indices (HJ/T 166-2004, 2004)

Classification	Single-factor pollution index		Multiply-factor pollution index	
	Pollution index	Pollution grade	Pollution index	Pollution grade
I	$P_i \leq 1.0$	Clean (safe)	$P_N \leq 0.7$	Clean (safe)
II	$1.0 < P_i \leq 2.0$	Slightly polluted	$0.7 < P_N \leq 1.0$	Relatively clean (warning limit)
III	$2.0 < P_i \leq 4.0$	Moderately polluted	$1.0 < P_N \leq 2.0$	Slightly polluted
IV	$4.0 < P_i \leq 6.0$	Heavily polluted	$2.0 < P_N \leq 3.0$	Moderately polluted
V	$P_i > 6.0$	Extremely polluted	$P_N > 3.0$	Heavily polluted

Table 3: Descriptive statistics parameters of heavy metal concentrations in topsoil

Metallic element (mg/kg dw)	Mean	S.D.	Median	Max	Min	C.V.
Cd	0.38	0.34	0.27	1.33	0.17	0.91
Pb	30.38	7.32	26.70	43.10	22.80	0.24
Cr	103.40	31.02	97.50	156.30	69.50	0.30
Ni	42.27	16.50	40.40	63.80	15.80	0.39
Hg	0.07	0.05	0.04	0.14	0.03	0.71
As	3.83	2.31	2.39	8.04	2.12	0.60

(Pb<35 mg/kg, Hg<0.15 mg/k, As<15 mg/kg). However concentrations of Cd, Cr, Ni in our study are higher than standard range (Cd>0.2 mg/kg, Cr>35 mg/kg, Ni>40 mg/kg). Soil of the eastern slope of Mt. Gongga was enriched with Cr (103.4 mg/kg dw) when compared to soil from Mt. Fenghuang Park near the city of Chengdu in Sichuan with a concentration of 82 mg/kg dw (Jia *et al.*, 2009). However, soils from Mt. Fenghuang Park were more contaminated with Cd at 0.45, Pb at 45, Hg at 0.89 and As at 14 mg/kg dw, but Ni level was similar at 40 mg/kg dw (Jia *et al.*, 2009).

The Coefficient of Variation (C.V.) values of six heavy metals in the study ranged from 0.24 to 0.91 indicating that they had moderate variations. The C.V. of Cd was 0.91, which was the highest of the 6 heavy metals, suggesting that Cd has the highest variation among the soil samples. The lowest C.V. was for Pb with a value of 0.24, suggesting that Pb has the least variation. The order of the coefficient of variation for the six heavy metals was Cd>Hg>As>Ni>Cr>Pb.

**Comparison of heavy metal concentrations of the three sites:**

The arithmetic mean concentrations of six major heavy metals in top soil layer from the three sites along the eastern slope of Mt. Gongga were: Cd 0.62±0.51 mg/kg, Pb 40.20±3.23 mg/kg, Cr 85.57±15.18 mg/kg, Ni 23.27±9.32 mg/kg, Hg 0.14±0.01 mg/kg, As 7.02±0.85 mg/kg for the Faber's Fir mature forest site; Cd 0.27±0.03 mg/kg, Pb 23.97±1.03 mg/kg, Cr 143.17±11.74 mg/kg, Ni 60.77±3.05 mg/kg, Hg 0.04±0.01 mg/kg, As 2.14±0.02 mg/kg for the Faber's Fir/Purdom Poplar succession forest site; and Cd 0.24±0.02 mg/kg, Pb 26.97±0.38 mg/kg, Cr 81.47±11.79 mg/kg, Ni 42.77±4.15 mg/kg, Hg 0.03±0.00 mg/kg, As 2.34±0.07 mg/kg for the Faber's Fir middle-aged forest site.

In the three different forest types, mean concentrations of Cd, Pb, Hg and As in surface layer of

the Faber's fir mature forest were higher than the Faber's Fir/Purdom Poplar succession forest and the Faber's Fir middle-aged forest and it was found that there were significant differences in Pb, Hg and As, but not in Cd (p<0.05; Student t-test; Fig. 2). Meanwhile the mean concentrations of Cr and Ni in surface layer of the Faber's Fir/Purdom Poplar succession forest were significantly higher than the other two (Fig. 2). This phenomenon may be due to different soil parent bedrock geochemical composition and the processes of soil formation and so on Yin and Chen (2000) and Fu *et al.* (1992). Usually, soils having more clay minerals and organic matters can enrich higher heavy metals, they have apparent characteristic of combined with metallic elements (Chen *et al.*, 2011).

In forest ecosystem, heavy metals in soil can be transported as a result of erosion and leaching (Zeng and Zhang, 2001). For aged forests, the amount of heavy metals lost due to soil erosion is much lower but leaching plays a more decisive role. Leaching is closely related to the soil acidity and complexation of organic matters like humic acids, while heavy metal mobility in soil horizon is mainly elevated from highland to lowland (Zeng and Zhang, 2001). This could have resulted in the enrichment of heavy metals in the soils of Faber's fir mature forest site which is in a low lying areas.

Concentration values of a particular metallic element in soils varied highly between layers of cores and between the cores. For the Faber's Fir mature forest site, at low slope section at 3,100 m soil contained Cd at 1.33 mg/kg dw and in this site's high slope section Cd was at 0.17 mg/kg dw., which were the highest and lowest content, a difference of nearly 7 times. But for two other gentle-sloping sites of the Faber's Fir/Purdom Poplar succession forest at elevation 2,950 m and of the Faber's Fir middle-aged forest at 3,000 m, the elemental concentrations did not vary obviously with the slope/altitude.

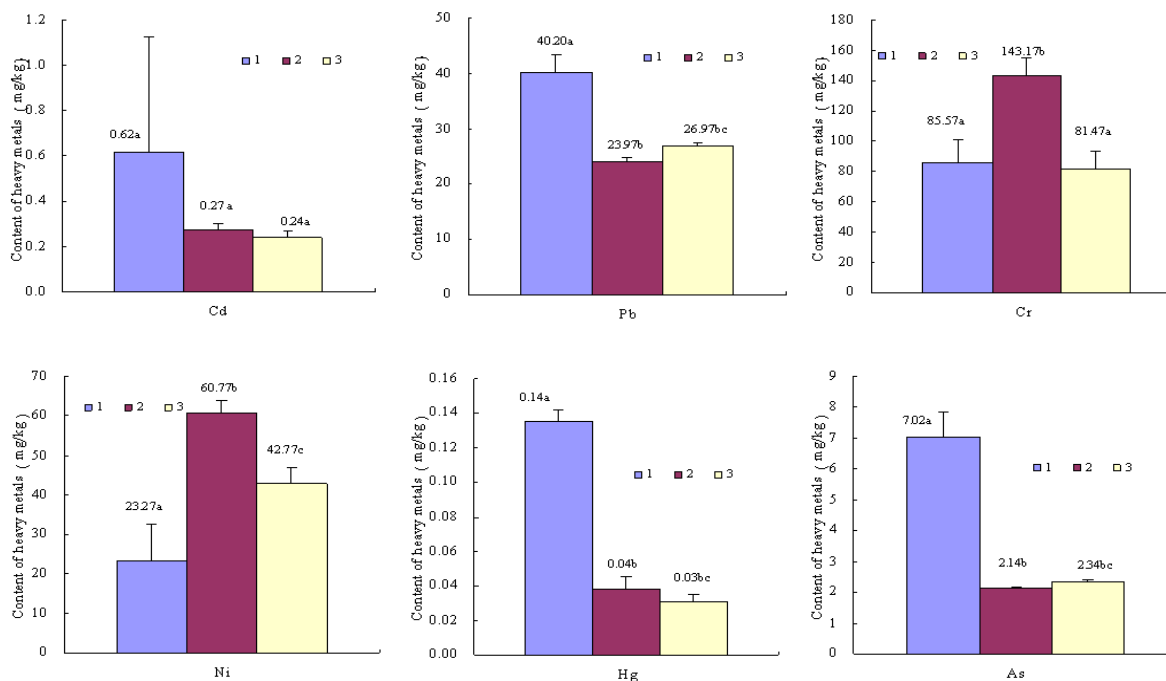


Fig. 2: Concentrations of heavy metals in different site

1. Faber's fir (*A. fabri*) mature forest
2. Faber's fir (*A. fabri*) /Purdom poplar (*P. purdomii*) succession forest
3. Faber's fir (*A. fabri*) middle-aged forest

Values of the same parameters followed by different letters are significantly different ( $p < 0.05$ )

The coefficient of variation values of such heavy metal in the Faber's Fir mature forest site ranged from 0.05 to 0.83, much higher than that of the other two sites (0.01-0.19 and 0.01-0.14). This is due to steep topography of the Faber's Fir mature forest, because topography and landforms are the most important factors affecting the spatial variation of soil which in complex topography area.

**Heavy metals distribution in soil profiles:** Element distribution in soil can be affected by several factors (Du *et al.*, 2007). Soil of the Faber's Fir mature forest site was characterized by high Pb accumulation in the upper horizon at 0-10 cm (topsoil), while for As, Cd, Cr and Ni there were no significant differences in the different soil layers and Hg in particular is largely enriched in the 10-20 cm layer (Fig. 3).

For the Faber's Fir/Purdom Poplar succession forest soil, Cr was mainly concentrated in 10-20 cm layer similar to that of the Faber's Fir mature forest site while As, Ni, Pb were evenly distributed from top to 100 cm depth and Hg accumulated in topsoil (Fig. 3).

For the Faber's Fir middle-aged forest soil, concentration of Cd was lowest in the 10-20 cm layer; Ni was lowest in 0-10 cm layer, while Hg is largely enriched in 10-20 cm layer, which is similar to that of the Faber's Fir mature forest site. As, Cr, Pb were no significant differences in different soil layer (Fig. 3).

The distributions of heavy metals in soil layers at each of the three sites surveyed were diverse due to several factors. This observation was not consistent with the phenomenon that all the heavy metals accumulate in the upper layer because certain heavy metals in soil are less soluble in water and therefore less mobile. The results of this study are consistent with the results of a survey performed by Ren *et al.* (2009).

Each type of soil has its unique characteristics resulting from the process of the soil formation. This process releases minerals at different levels of vertical movement, especially in soils of forest zones, where the process of soil formation is largely affected by climate, parent rock's geochemistry, topography, biology and time and thus the spatial heterogeneity is more evident. Nevertheless, some anthropogenic processes relating to remote sources of heavy metals released by atmospheric transport can also with varying degree, contribute to surface soil heavy metal enrichment.

Elemental Hg easily vaporizes and natural thermal (volcanic activity, forest fires) and anthropogenic processes (fossil fuels combustion, waste incineration) contribute to ambient air pollution with mercury. Hg is therefore transportable by global atmospheric diffusion (Fitzgerald *et al.*, 1998). Mercury in its elemental form has a long-life in air. Deposition by aerial fallout can enrich the uppermost layer of soils especially humus abundant forest soils (Falandysz *et al.*, 1996, 2003).

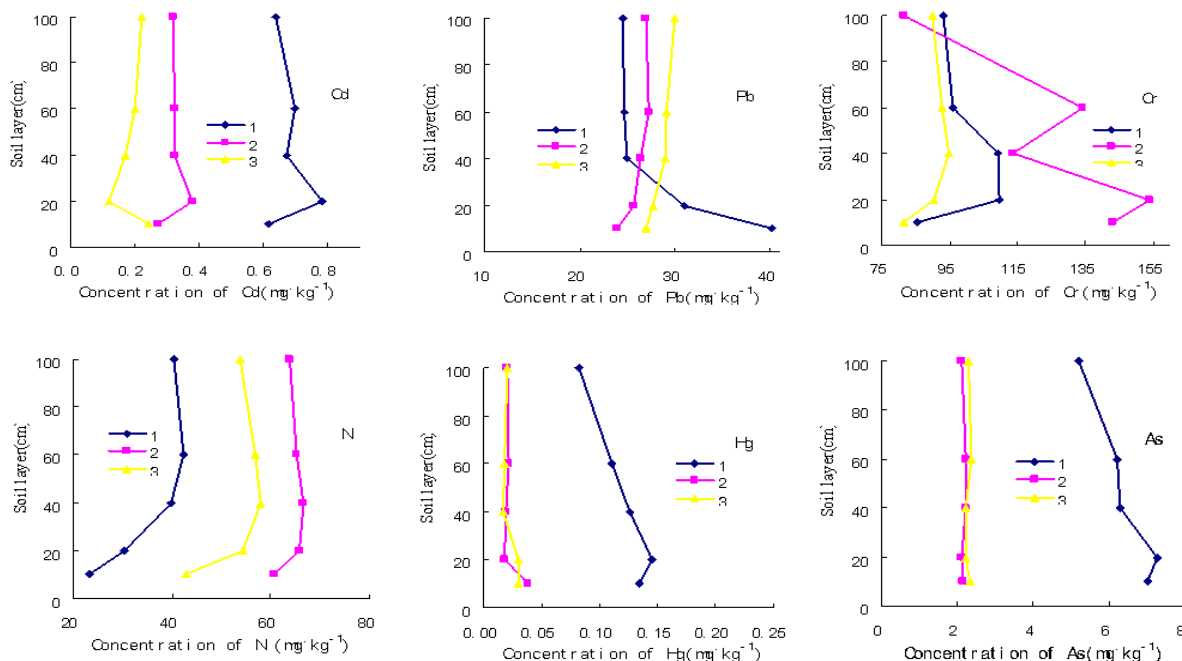


Fig. 3: Concentrations of heavy metal in soil vertical profiles  
 1. Comprehensive observation field of Abies fabri mature forest  
 2. Supporting observation field of Abies fabri-Populus purdomii succession forest  
 3. Middle-aged Abies fabri Forest observation field

Table 4: Assessment results of soil quality at the east slope of Gongga Mountain by single factor contaminant index (P<sub>i</sub>)

Point No.	Cd	Pb	Cr	Ni	Hg	As
1-1	0.86	1.23	0.78	0.44	0.89	0.54
1-2	1.72	1.19	0.89	0.40	0.96	0.47
1-3	6.66	1.02	1.18	0.91	0.85	0.40
Mean value of the site	3.08	1.15	0.95	0.58	0.90	0.47
2-1	1.34	0.65	1.42	1.60	0.19	0.14
2-2	1.20	0.68	1.74	1.55	0.27	0.14
2-3	1.55	0.72	1.62	1.42	0.30	0.14
Mean value of the site	1.36	0.68	1.59	1.52	0.25	0.14
3-1	1.11	0.79	0.86	1.01	0.19	0.16
3-2	1.37	0.76	0.77	1.22	0.17	0.15
3-3	1.13	0.76	1.08	0.98	0.24	0.16
Mean value of the site	1.20	0.77	0.90	1.07	0.20	0.16
Mean value	1.88	0.87	1.15	1.06	0.45	0.26

Anthropogenic thermal processes (combustion, incineration) also contribute to release and subsequent deposition of Pb and Cd. Nevertheless, atmospheric residence time and therefore long-range transport of atmospheric particles rich in Pb and Cd is lower than Hg (Sturges and Harrison, 1986; Tasić *et al.*, 2006).

**Soil quality:**

**Single-factor pollutant index assessment:** The single-factor contaminant index (Table 4) was calculated by taking into account the analytical data obtained from topsoil at each sampling site. Among the heavy metals examined, the highest degree of pollution along the eastern slope of Mt. Gongga was for Cd (Table 4). For this element, 89% of top soils analyzed were considered polluted and the mean value of P<sub>i</sub> pollution index for Cd was 1.88. Hence, soils in that region can be assigned a pollution index category of 1 < P<sub>i</sub> ≤ 2, as can be

described as “slightly polluted” with Cd. An exception was the sampling point no. 1-3, where P<sub>i</sub> index value for Cd reached 6.66 (Table 4). This location is classified as ‘very severely polluted’ (P<sub>i</sub> > 6) category.

In case of Cr, 56% of the sites were slightly polluted (1 < P<sub>i</sub> ≤ 2) with a mean value of pollution index of 1.15. In the Wutai Mountain soils, a positive correlation between Cr and organic matter content was found but a negative correlation between Cr and soil pH or soil sand content (Fan and Chen, 1999). The high concentration of Cr in soils of the studied area may be related to the high percentage of forest cover, biological activity, acidic pH and high organic matter content. Moreover, rainfalls in the area and high leaching contribute to Cr enrichment.

The proportion of soils with the category of ‘slightly polluted’ (1 < P<sub>i</sub> ≤ 2) with Ni was 56 % and mean

Table 5: Assessment results of soil quality at the east slope of Gongga Mountain by multi-factor contaminant index ( $P_N$ )

Point No.	$P_N$	Pollution grade
1-1	1.03	Slightly polluted
1-2	1.38	Slightly polluted
1-3	4.89	Heavily polluted
2-1	1.29	Slightly polluted
2-2	1.39	Slightly polluted
2-3	1.33	Slightly polluted
3-1	0.92	Relatively clean (warning limit)
3-2	1.10	Slightly polluted
3-3	0.95	Relatively clean (warning limit)

value of pollution index was 1.06 (Table 4). For Pb, mean value of a single-factor pollution index was 0.87. Nevertheless, 33 % of topsoil in the area and all of the Faber's Fir mature forest area can be characterized as 'slightly polluted' ( $1 < P_i \leq 2$ ) with Pb (Table 4). An explanation for enrichment of Pb in surface layer of soil at this site can be its proximity to the nearby parking lots. Pb contained in leaded gasoline exhaust of vehicles and in atmospheric particles (mainly as sulfates and halides), accumulate at the surface-largely as PbS and to a lesser extent as PbCO<sub>3</sub>, PbSO<sub>4</sub>, PbCrO<sub>4</sub> and Pb-organic chelates (Panayotowa, 2000; Xu and Liao, 2004). This deposition was both firmly confined to surface soil because of lead's immobile nature in soil horizon.

The single-factor pollutant index values for heavy metals in topsoil decreased in the following order as  $P_{Cd} > P_{Cr} > P_{Ni} > P_{Pb} > P_{Hg} > P_{As}$ . Evidently, topsoil of the eastern slope of Mt. Gongga accumulated Cd and Cr and less amount of Ni.

In light of these results, soil contamination with Cd was the most serious issue along the eastern slope of Mt. Gongga, followed by Cr. Soil at each sampling site suffered from Cd contamination. Enrichment was most evident in the Faber's Fir mature forests, which may be attributed to acidity of the coniferous forest soil and its location in wet climatic regions. The adequate supply of rainfall and thriving vegetation were favorable to accumulation of organic matter in the soil, which further supported Cd enrichment.

**Multi-factor pollutant index assessment:** An integrated assessment of topsoil quality for six heavy metals assessed will provide a more comprehensive picture than a single-factor approach. Since the values of index  $P_N$  for all sites varied between 0.92 and 4.89, all these values should be considered as slight to pronounced impact with heavy metals (Table 5).

For 22 % of the topsoil's, the multi-factor pollution index was  $0.7 < P_N < 1$  which implied lack of pollution but warning of a problem. For 67 % of the topsoil analyzed, the integrated index was  $1 < P_N < 2$ , which suggested 'slightly polluted' nature of soils (Table 5). Topsoil at Faber's mature forest site showed a  $P_N$  index value of 4.89 which indicates heavy pollution. This particular site has already attained the level of 'serious'

pollution. The minimum  $P_N$  index value was observed at the Faber's Fir middle-aged forest area. At this area a relatively clean to slightly polluted soils were found and this site needs further attention too.

As discussed above, increasing traffic in the region due to increasing tourist attractiveness of Mt. Gongga and the booming tourism and some manufacturing activities contributed to soil environment contamination with heavy metals. Nevertheless, this region was also affected by natural factors such as the parent rock geochemistry, climate and soil erosion.

## CONCLUSION

Mt. Gongga region is among the areas of the world with unique nature and biodiversity and is relatively remote to industrial and urban areas. The results of this study implied that heavy metal content of soils along the eastern slope of Mt. Gongga may be affected by natural factors such as the parent rock geochemistry, climate and soil erosion but also by anthropogenic factors such as traffic, which resulted in the accumulation of heavy metals in the environment.

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