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# Foliar Fe contents of dominant tree and water-extractable Fe of soil in forests in the Northeastern China

**XU Xiaoniu[1], CAI Tijiu[2] and SHIBATA Hideaki[3]**

[1] Department of Forestry, Anhui Agricultural University, Hefei 230036, China;
[2] Department of Forestry, Northeast Forestry University, Haerbin 150040, China;
[3] Field Science Center for Northern Biosphere, Hokkaido University, Nayoro 096-0071, Japan

## 1 INTRODUCTION

Forest communities are biological processors of terrestrial-aquatic interfaces. Forest plants directly take up and store nutrients. On the other hand, nutrients are also released with the decomposition of plant debris, contributing to the modification of runoff chemistry. The leaching of organic or mineral products at the surface of living vegetation provides potential additional effects on water chemistry. Therefore, the forest community is closely correlated with the nutrient biogeochemical processes in forested watershed.

Fe is an important nutrient for productivity of marine ecosystem. Terrestrial ecosystem is an important source of Fe transporting to the aquatic ecosystems. In relation to the impacts of forest vegetation on hydrological processes, it is clear that research is needed to reveal the soil-vegetation interaction. The objectives of this study are to determine the spatial pattern of Fe in soils and trees; and to reveal the tree-soil interaction controlling Fe biogeochemical cycling in forested watersheds within Amur Basin.

## 2 MATERIAL AND METHODS

### 2.1 Study site

This study was conducted at three sites, Liangshui (47°11'N, 128°53'E), Hanyue (47°15'N, 128°50'E) and Songling (50°54'N, 124°27'E), located in the northeastern China. Liangshui and Hanyue sites belong to the Xiaoxing'an Mountains, which native vegetation is typically warm-temperate mixed forest of *Pinus koraiensis*-deciduous broadleaved species. Because of forestry development, most of the primary forests were harvested during the past century. Except for a small area of the primary forest, most land was covered by secondary forests and plantations. The dominant tree species are *Pinus koraiensis*, *Picea koraiensis*, *Larix gmelini*, *Betulla* spp., *Fraxinus mandshurica* and *Juglans mandshurica*. At Hanyue site, most of the forests are plantations planted after 1950. The soil types at Liangshui and Hanyue sites are mainly brown forest soils at upland and peat soil on riparian area.

Songling site belongs to the Daxing'an Mountains, which native vegetation is the cool-temperate coniferous forest dominated by *Larix gmelini*. Most of the land was covered by secondary forests. The dominant tree species are *Larix gmelini*, *Betulla* spp., and *Alnus* spp.

Forest fires are frequent in this area, which become the most seriously natural disturbance on the forest. The dominant soil types are dark brown forest soils.

Table 1 Outline of the sampling forest stands

| Location | Position | Site conditions | Species and growth |
|---|---|---|---|
| Liangshui Site (Natural Reserve) | | | |
| LS1 | 47°10.956'N | 420m asl, upper slope 20° | korean pine old-growth, |
| | 128°58.690'E | loam | Hmax 30m, DBHmax 83cm |
| LS2 | 47°11.053'N | 410m asl, lower slope 9° | birch secondary forest, 52 yr |
| | 128°53.242'E | clay | 1300/ha, H 17m, D 18cm |
| LS3 | 47°11.043'N | 460m asl, upper slope 24° | larch plantation, 52 yr |
| | 128°53.461'E | clay-loan | 4400/ha, H 21m, D 25cm |
| LS4 | 47°11.053'N | 410m asl, lower slope 9° | natural spruce old-growth |
| | 128°53.242'E | clay | 1300/ha, H 17m, D 18cm |
| LS5 | 47°11.454'N | 363 m asl, riparian zone | natural spruce-birch mixture |
| | 128°53.738'E | peat 30 cm, lower sandy loan | 1300/ha, H 17m, D 18cm |
| Hanyue Site (Harvesting area) | | | |
| HY1 | 47°15.030'N | 376 m asl, riparian zone | birch-alder-larch secondary |
| | 128°49.975'E | sandy loan | H:10-12m; DBH:10 cm |
| HY2 | 47°15.738'N | 430m asl, slope 20°, loan | larch plantation, 50 yr |
| | 128°50.628'E | mid-slope | H: 18-20m; DBH: 23cm |
| HY3 | 47°14.008'N | 330m asl, flat valley | spruce-larch-birch secondary |
| | 128°50.336'E | sandy loan | H:12-20m; DBH:14cm |
| Dailing Site (Forest fire area) | | | |
| DL1 | 50°54.547'N | 630m asl, slope 6°, clay | H:8-10m, DBH: 6-12cm, 6000/ha |
| | 124°26.800'E | low-slope | larch-birch secondary, 40 yr |
| DL2 | 50°54.547'N | 654m asl, slope 16°, clay | larch-birch secondary, 60 yr |
| | 124°26.800'E | mid-slope | Mean H 14m, DBH 17cm |
| DL3 | 50°54.673'N | 590m asl, flat, peat | birch-larch secondary, 50 yr |
| | 124°26.552'E | riparian zone | burned in 2004 |
| DL4 | 50°54.400'N | 615m asl, slope 13°, | larch-birch secondary, 50 yr |
| | 124°26.605'E | low-slope, clay-loan | burned in 2004 |

## 2.2 Field survey

The field survey was conducted during August-October, 2007. At each site, different stands were selected to investigate the properties of the soils and foliar nutrients of dominant tree species. The sampling stands included the primary forests, secondary forests, and plantations, and secondary forests (at Songling) damaged by forest fire in 2006.

In each sampling stand, the soils were collected from the soil profile for different layers. The fresh leaves and needles were collected from 3 trees for each species in the growing season. The fresh litter was collected from forest floor for each species. The general conditions for the sampling stands were showed in Table 1.

## 2.3 Chemical analysis

Soil pH was measured in 1:2.5 soil : water by Horiba compact pH meter. Soil electronic conductivity was measured in 1:5 soil : water suspension by Horiba compact EC meter. Total N was determined by a Kjeldahl autoanalyzer. Subsamples of soils analyzed for available P were extracted using the Bray Ⅱ method. Subsamples equivalent to 20 g dry soil were extracted with 100 ml ultrapure water. The extractions filtered with GF/F glass-fiber filter were used for analysis of water-extractable components (P, K, Ca, Mg, Fe). The extracts were frozen until analysis. Plant materials were digested with $HNO_3$-$HClO_4$ reagent, and the digests were used for analyzing the contents of P, K, Ca, Mg, and Fe. K, Ca, Mg and Fe were measured by atomic absorption spectrometry (TAS-990AFG, Beijing). P was measured by Flow Injection Analyzer (FIAStar 5000, FOSS).

# 3 RESULS AND DISCUSSION

## 3.1 Soil chemical properties

Table 2 showed the general chemical properties of soils under the different stands at different sites. Soil pH was lower in the riparian stands than in the upland stands at all three sites. In larch plantations, soil pH was lower at Hanyue than at Liangshui. Soil ECs were highest at Hanyue and lowest at Songling. Among forest types, soils under larch plantation had rather higher EC than other stands except for the riparian alder-birch secondary forest at Hanyue (157 μS/cm in A horizon).

Table 2 Concentrations of water-extractable nutrients of soils in different forests

| Site & Plot | Soil depth | pH ($H_2O$) | EC μS/cm | TN g/kg | Avail P mg/kg | water soluble nutrient (mg/kg soil) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | P | K | Ca | Mg | Fe |
| Liangshui | | | | | | | | | | |
| LS1 | Natural pine old-growth stand (upper slope) | | | | | | | | | |
| | A | 5.65 | 82.6 | 7.472 | 19.338 | 3.829 | 0.471 | 1.713 | 0.372 | 0.127 |
| | AB | 5.75 | 34.3 | 3.611 | 16.026 | 3.398 | 0.416 | 1.524 | 0.349 | 0.113 |
| | B | 5.80 | 27.5 | 2.836 | 4.601 | 1.743 | 0.338 | 1.031 | 0.271 | 0.083 |
| | C | 6.05 | 21.5 | 2.522 | 2.814 | 0.916 | 0.211 | 0.767 | 0.166 | 0.049 |
| LS2 | Natural secondary birch stand (lower slope) | | | | | | | | | |
| | A | 5.75 | 87.2 | 4.824 | 13.316 | 2.692 | 0.372 | 1.331 | 0.301 | 0.091 |
| | AB | 5.80 | 38.6 | 3.309 | 12.561 | 2.213 | 0.299 | 1.154 | 0.257 | 0.085 |
| | B | 5.95 | 30.4 | 2.429 | 8.617 | 1.537 | 0.207 | 0.818 | 0.192 | 0.063 |
| | C | 6.00 | 19.6 | 1.713 | 5.225 | 1.126 | 0.132 | 0.673 | 0.138 | 0.034 |
| LS3 | Larch plantation stand (upper slope) | | | | | | | | | |
| | A | 5.95 | 103 | 5.301 | 8.736 | 2.572 | 0.309 | 1.426 | 0.257 | 0.086 |
| | B1 | 6.10 | 30.8 | 3.066 | 10.248 | 2.108 | 0.213 | 1.103 | 0.202 | 0.071 |
| | B2 | 5.90 | 25.3 | 1.848 | 5.003 | 1.369 | 0.134 | 0.633 | 0.112 | 0.033 |

Table 2 Continued

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| LS4 | Natural spruce stand (riparian) | | | | | | | | | |
| | A | 5.45 | 77.2 | 8.184 | 13.973 | 2.704 | 0.239 | 1.373 | 0.217 | 0.113 |
| | AB | 5.60 | 43.6 | 4.123 | 9.925 | 1.469 | 0.182 | 0.891 | 0.179 | 0.092 |
| | B1 | 5.65 | 41.4 | 2.734 | 5.116 | 1.036 | 0.155 | 0.664 | 0.119 | 0.069 |
| | B2 | 5.60 | 18.2 | 1.682 | 2.396 | 0.723 | 0.107 | 0.501 | 0.103 | 0.037 |
| LS5 | Natural spruce-birch mixed stand (riparian peat) | | | | | | | | | |
| | A | 5.35 | 31.8 | 10.024 | 5.837 | 2.352 | 0.247 | 0.934 | 0.207 | 0.122 |
| | B | 5.60 | 10.7 | 3.371 | 2.992 | 1.176 | 0.133 | 0.619 | 0.128 | 0.061 |
| Hanyue | | | | | | | | | | |
| HY1 | Secondary alder-birch stand (riparian) | | | | | | | | | |
| | A | 5.35 | 157 | 10.217 | 16.331 | 4.113 | 0.352 | 1.053 | 0.268 | 0.139 |
| | B1 | 5.30 | 110 | 6.359 | 10.502 | 3.606 | 0.282 | 0.734 | 0.223 | 0.112 |
| | B2 | 5.55 | 47.2 | 4.022 | 6.614 | 2.533 | 0.247 | 0.539 | 0.151 | 0.089 |
| HY2 | Larch plantation stand (upper slope) | | | | | | | | | |
| | A | 5.65 | 79.2 | 4.811 | 6.837 | 2.982 | 0.337 | 1.207 | 0.291 | 0.126 |
| | AB | 5.70 | 31.6 | 3.634 | 3.992 | 1.633 | 0.279 | 1.004 | 0.238 | 0.103 |
| | B | 5.70 | 23.7 | 2.036 | 3.608 | 1.117 | 0.153 | 0.825 | 0.201 | 0.079 |
| | C | 5.85 | 14.8 | 1.549 | 2.215 | 0.616 | 0.102 | 0.631 | 0.143 | 0.053 |
| HY3 | Secondary spruce-alder-birch stand (riparian) | | | | | | | | | |
| | A | 5.45 | 97.4 | 8.231 | 8.913 | 2.673 | 0.281 | 1.036 | 0.255 | 0.103 |
| | B1 | 5.55 | 67.6 | 4.167 | 5.336 | 1.779 | 0.236 | 0.839 | 0.203 | 0.116 |
| | B2 | 5.80 | 32.2 | 1.759 | 3.282 | 0.904 | 0.137 | 0.712 | 0.156 | 0.081 |
| Songling | | | | | | | | | | |
| DL1 | Natural larch-birch secondary stand (mid-slope) | | | | | | | | | |
| | A | 5.80 | 37.6 | 3.864 | 21.035 | 3.617 | 0.341 | 1.558 | 0.311 | 0.091 |
| | B1 | 5.95 | 21.2 | 2.336 | 17.104 | 3.234 | 0.259 | 1.312 | 0.293 | 0.086 |
| | B2 | 5.90 | 13.6 | 1.520 | 7.226 | 2.479 | 0.163 | 0.861 | 0.226 | 0.061 |
| | C | 6.10 | 10.3 | 0.963 | 3.652 | 1.051 | 0.117 | 0.657 | 0.177 | 0.041 |
| DL2 | Natural larch-birch secondary stand (low-slope) | | | | | | | | | |
| | A | 5.70 | 41.1 | 4.344 | 25.114 | 3.771 | 0.375 | 1.476 | 0.334 | 0.113 |
| | B1 | 5.85 | 23.3 | 3.031 | 16.566 | 3.106 | 0.303 | 1.393 | 0.298 | 0.101 |
| | B2 | 5.90 | 17.5 | 2.008 | 8.612 | 2.394 | 0.224 | 0.745 | 0.219 | 0.076 |
| | C | 5.90 | 11.7 | 1.106 | 4.407 | 1.773 | 0.139 | 0.572 | 0.166 | 0.052 |
| DL3 | Natural larch-birch secondary stands damaged by forest fire (low-slope) | | | | | | | | | |
| | A | 5.65 | 48.3 | 3.623 | 9.338 | 3.219 | 0.336 | 1.802 | 0.323 | 0.083 |
| | B1 | 5.60 | 26.1 | 2.176 | 11.513 | 2.631 | 0.271 | 1.426 | 0.254 | 0.102 |
| | B2 | 5.80 | 15.8 | 2.014 | 5.802 | 2.008 | 0.219 | 0.861 | 0.207 | 0.079 |
| | C | 5.95 | 12.5 | 1.038 | 3.136 | 1.106 | 0.144 | 0.663 | 0.173 | 0.047 |
| DL4 | Natural larch-bircch-alder seondary stands damaged by forest fire (riparian) | | | | | | | | | |
| | A | 5.45 | 43.7 | 6.026 | 7.494 | 2.731 | 0.237 | 1.737 | 0.272 | 0.107 |
| | B1 | 5.65 | 18.4 | 3.409 | 12.291 | 3.594 | 0.249 | 1.352 | 0.230 | 0.106 |
| | B2 | 5.90 | 13.6 | 2.132 | 4.227 | 1.034 | 0.109 | 0.973 | 0.201 | 0.083 |

In general, the total N in soil was higher at Hanyue and Liangshui than at Songling. However, the available P in soil was greater at Liangshui and Songling than at Hanyue (Table 2). Soil water-extractable P was higher at Songling than the other sites. However, soil water-extractable Fe was higher at Hanyue than the other sites. At Liangshui, soil water-extractable Fe was somewhat great in old-growth pine-broadleaf mixed forest. In addition, soil of riparian stands usually had relatively higher content of water-extractable Fe.

At Songling, the contents of water-extractable Fe were greater in riparian and low-slope zones than in the upper-land zone whether disturbed by fire or not. However, the fire-disturbed site had significant low content of water-extractable Fe in the surface soil layer.

Table 3 Nutrient concentrations in leaf of the major tree species

| Tree species | Leaf | N | P | K | Ca | Mg | Fe |
|---|---|---|---|---|---|---|---|
| | | (g/kg) | | | | | (mg/kg) |
| Liangshui | | | | | | | |
| *Larix gmelinii* Rupr. | Fresh | 14.57 | 0.307 | 3.61 | 4.07 | 3.23 | 203.6 |
| | Fallen | 11.13 | 0.155 | 2.88 | 4.51 | 2.11 | 227.2 |
| *Picea koraiensis* Nakai | Fresh | 8.82 | 0.201 | 3.25 | 5.33 | 2.09 | 157.4 |
| | Fallen | 7.29 | 0.088 | 2.62 | 5.84 | 1.76 | 178.7 |
| *Pinus koraiensis* S. et Z. | Fresh | 11.26 | 0.215 | 3.67 | 4.59 | 3.13 | 157.4 |
| | Fallen | 8.92 | 0.093 | 3.06 | 4.71 | 2.07 | 173.1 |
| *Betulla platyphylla* Suk. | Fresh | 20.12 | 0.273 | 5.71 | 7.17 | 3.79 | 151.2 |
| | Fallen | 17.08 | 0.117 | 4.46 | 7.29 | 3.13 | 159.4 |
| *Alnus hirsuta* Turcz. | Fresh | 31.17 | 0.346 | 3.46 | 8.58 | 2.79 | 133.6 |
| | Fallen | 26.59 | 0.182 | 3.07 | 8.46 | 2.37 | 141.7 |
| *Tilia amurensis* Rupr. | Fresh | 19.59 | 0.331 | 6.34 | 6.97 | 3.48 | 213.6 |
| | Fallen | 15.77 | 0.178 | 4.78 | 7.34 | 2.81 | 216.7 |
| Hanyue | | | | | | | |
| *Larix gmelinii* Rupr. | Fresh | 13.27 | 0.294 | 3.01 | 4.57 | 3.02 | 224.7 |
| | Fallen | 9.82 | 0.133 | 2.33 | 4.43 | 2.16 | 239.5 |
| *Betulla platyphylla* Suk. | Fresh | 21.27 | 0.227 | 4.67 | 6.79 | 3.54 | 164.3 |
| | Fallen | 17.82 | 0.136 | 3.95 | 6.82 | 3.03 | 170.2 |
| *Alnus hirsuta* Turcz. | Fresh | 29.33 | 0.318 | 3.24 | 9.37 | 2.93 | 141.9 |
| | Fallen | 26.61 | 0.146 | 2.88 | 9.49 | 2.34 | 152.5 |
| Dailing | | | | | | | |
| *Larix gmelinii* Rupr. | Fresh | 11.67 | 0.231 | 3.24 | 5.11 | 2.82 | 173.3 |
| | Fallen | 7.29 | 0.086 | 2.51 | 5.34 | 2.07 | 185.9 |
| *Betulla platyphylla* Suk. | Fresh | 17.59 | 0.205 | 3.66 | 6.91 | 3.38 | 145.6 |
| | Fallen | 13.24 | 0.083 | 2.91 | 6.84 | 2.91 | 151.1 |
| *Alnus hirsuta* Turcz. | Fresh | 25.45 | 0.281 | 3.16 | 8.06 | 2.96 | 133.8 |
| | Fallen | 21.38 | 0.147 | 2.59 | 8.37 | 2.14 | 138.4 |

### 3.2 Fe contents in leaves and needles

Table 3 showed the chemical composition of leaves and needles of the dominant trees at different sites. The concentration of Fe in fresh needles and litter of larch (*Larix gmelinii* Rupr.) was lowest at Songling and was greatest at Hanyue. At Songling and Hanyue, larch had the greatest concentration of Fe compared to the other tree species. At Liangshui, Amur linden (*Tilia amurensis* Rupr.) had the greatest concentration of Fe in fresh leaves. However, the highest concentration of Fe was found in foliage litter of larch. Alder (*Alnus hirsuta* Turcz.) had low concentration of Fe in both leaf and litter at all three sites compared to the other trees.

The total N was greatest in alder and lowest in Korean spruce (*Picea koraiensis* Nakai). For the same tree species (e.g. larch, alder and birch), the highest N concentration was found at Liangshui and the lowest at Songling.

### 3.3 Tree-soil interaction and its impact on Fe biogeochemical cycling

In order to reveal the relationships between water-extractable Fe and other soil chemical properties, linear regression was used. The result demonstrated that the concentration of water-extractable Fe was significantly and positively correlated with soil total N (Fig. 1) and water-extractable OC (Fig. 2), which indicates that DOC-fixation may be the dominant form in the extractable Fe. In addition, soil total N content was significantly correlated to soil extractable OC (Fig. 3). This suggests that Fe leaching can be controlled by DOC in forest ecosystems.

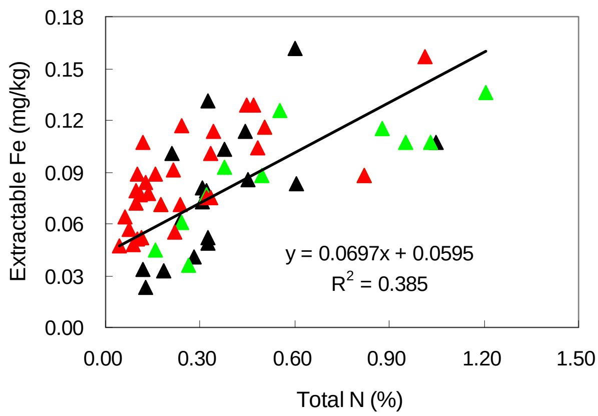


Fig. 1 Relationship between soil extractable Fe and total N in different sites (▲: Liangshui; ▲: Hanyue; ▲: Songling).

Fig. 4 showed the relationship between soil water-extractable Fe and dissolved Fe of stream water in the three sampling sites. The concentrations of dissolved Fe in stream water were somewhat low, particularly at Songling site (ranged from 0.102~0.186 mg/L at Liangshui; 0.176~0.277 mg/L at Hanyue; 0.057~0.067 mg/L at Songling). Similarly, the concentrations of water-extractable Fe of the surface soil under the dominant forests were lower at Songling than at Liangshui and Hanyue. The content of dissolved Fe of stream water was significantly and positively correlated with the soil water-extractable Fe (Fig. 4).

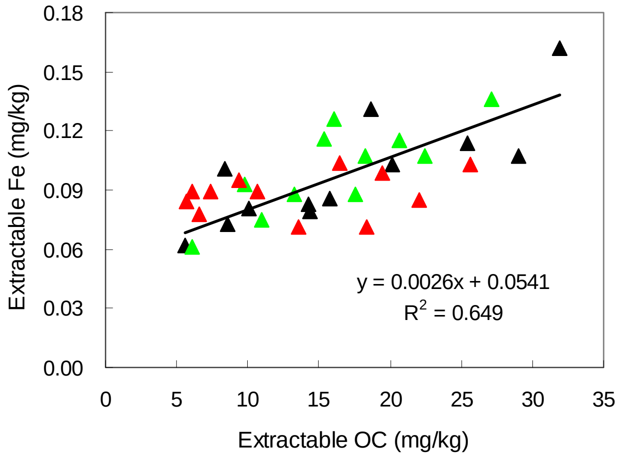


Fig. 2 Relationship between soil extractable Fe and extractable OC in different sites (▲: Liangshui; ▲: Hanyue; ▲: Songling).

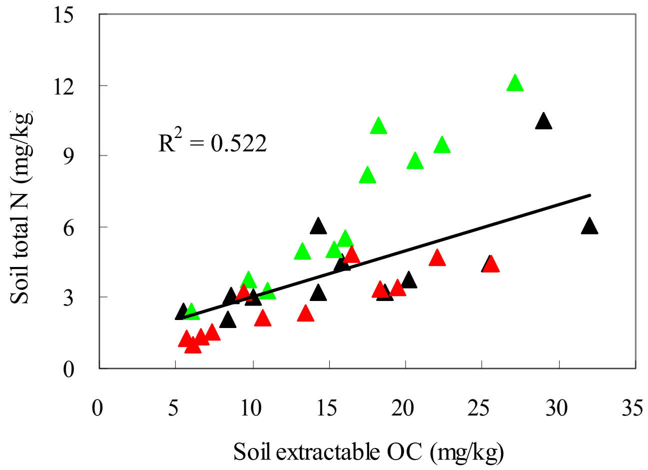


Fig. 3 Relationship between soil total N and extractable OC in different sites (▲: Liangshui; ▲: Hanyue; ▲: Songling).

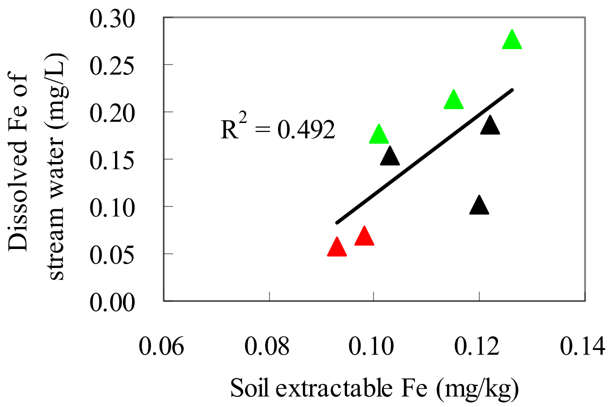


Fig. 4 Relationship between soil extractable Fe and the Dissolved Fe of stream water in different sites (▲: Liangshui; ▲: Hanyue; ▲: Songling).

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