

JES

JOURNAL OF
ENVIRONMENTAL
SCIENCES

April 1, 2015 Volume 30
www.jesc.ac.cn

ISSN 1001-0742
CN 11-2629/X



MBR in Wastewater Reclamation



Sponsored by
Research Center for Eco-Environmental Sciences
Chinese Academy of Sciences

Highlight articles

- 129 Rice: Reducing arsenic content by controlling water irrigation
Ashley M. Newbigging, Rebecca E. Paliwoda and X. Chris Le
- 132 Apportioning aldehydes: Quantifying industrial sources of carbonyls
Sarah A. Styler

Review articles

- 30 Application of constructed wetlands for wastewater treatment in tropical and subtropical regions (2000-2013)
Dong-Qing Zhang, K.B.S.N. Jinadasa, Richard M. Gersberg, Yu Liu, Soon Keat Tan and Wun Jern Ng
- 47 Stepwise multiple regression method of greenhouse gas emission modeling in the energy sector in Poland
Alicja Kolasa-Wiecek
- 113 Mini-review on river eutrophication and bottom improvement techniques, with special emphasis on the Nakdong River
Andinet Tekile, Ilho Kim and Jisung Kim

Regular articles

- 1 Effects of temperature and composite alumina on pyrolysis of sewage sludge
Yu Sun, Baosheng Jin, Wei Wu, Wu Zuo, Ya Zhang, Yong Zhang and Yaji Huang
- 9 Numerical study of the effects of local atmospheric circulations on a pollution event over Beijing-Tianjin-Hebei, China
Yucong Miao, Shuhua Liu, Yijia Zheng, Shu Wang and Bicheng Chen, Hui Zheng and Jingchuan Zhao
- 21 Removal kinetics of phosphorus from synthetic wastewater using basic oxygen furnace slag
Chong Han, Zhen Wang, He Yang and Xiangxin Xue
- 55 Abatement of SO₂-NO_x binary gas mixtures using a ferruginous active absorbent: Part I. Synergistic effects and mechanism
Yinghui Han, Xiaolei Li, Maohong Fan, Armistead G. Russell, Yi Zhao, Chunmei Cao, Ning Zhang and Genshan Jiang
- 65 Adsorption of benzene, cyclohexane and hexane on ordered mesoporous carbon
Gang Wang, Baojuan Dou, Zhongshen Zhang, Junhui Wang, Haier Liu and Zhengping Hao
- 74 Flux characteristics of total dissolved iron and its species during extreme rainfall event in the midstream of the Heilongjiang River
Jiunian Guan, Baixing Yan, Hui Zhu, Lixia Wang, Duian Lu and Long Cheng
- 81 Sodium fluoride induces apoptosis through reactive oxygen species-mediated endoplasmic reticulum stress pathway in Sertoli cells
Yang Yang, Xinwei Lin, Hui Huang, Demin Feng, Yue Ba, Xuemin Cheng and Liuxin Cui
- 90 Roles of SO₂ oxidation in new particle formation events
He Meng, Yujiao Zhu, Greg J. Evans, Cheol-Heon Jeong and Xiaohong Yao
- 102 Biological treatment of fish processing wastewater: A case study from Sfax City (Southeastern Tunisia)
Meryem Jemli, Fatma Karray, Firas Feki, Slim Loukil, Najla Mhiri, Fathi Aloui and Sami Sayadi

CONTENTS

- 122 Bioreduction of vanadium (V) in groundwater by autohydrogentrophic bacteria: Mechanisms and microorganisms
Xiaoyin Xu, Siqing Xia, Lijie Zhou, Zhiqiang Zhang and Bruce E. Rittmann
- 135 Laccase-catalyzed bisphenol A oxidation in the presence of 10-propyl sulfonic acid phenoxazine
Rūta Ivanec-Goranina, Juozas Kulys, Irina Bachmatova, Liucija Marcinkevičienė and Rolandas Meškys
- 140 Spatial heterogeneity of lake eutrophication caused by physiogeographic conditions: An analysis of 143 lakes in China
Jingtao Ding, Jinling Cao, Qigong Xu, Beidou Xi, Jing Su, Rutai Gao, Shouliang Huo and Hongliang Liu
- 148 Anaerobic biodegradation of PAHs in mangrove sediment with amendment of NaHCO_3
Chun-Hua Li, Yuk-Shan Wong, Hong-Yuan Wang and Nora Fung-Yee Tam
- 157 Achieving nitrification at low temperatures using free ammonia inhibition on *Nitrobacter* and real-time control in an SBR treating landfill leachate
Hongwei Sun, Yongzhen Peng, Shuying Wang and Juan Ma
- 164 Kinetics of Solvent Blue and Reactive Yellow removal using microwave radiation in combination with nanoscale zero-valent iron
Yanpeng Mao, Zhenqian Xi, Wenlong Wang, Chunyuan Ma and Qinyan Yue
- 173 Environmental impacts of a large-scale incinerator with mixed MSW of high water content from a LCA perspective
Ziyang Lou, Bernd Bilitewski, Nanwen Zhu, Xiaoli Chai, Bing Li and Youcai Zhao
- 180 Quantitative structure-biodegradability relationships for biokinetic parameter of polycyclic aromatic hydrocarbons
Peng Xu, Wencheng Ma, Hongjun Han, Shengyong Jia and Baolin Hou
- 191 Chemical composition and physical properties of filter fly ashes from eight grate-fired biomass combustion plants
Christof Lanzerstorfer
- 198 Assessment of the sources and transformations of nitrogen in a plain river network region using a stable isotope approach
Jingtao Ding, Beidou Xi, Qigong Xu, Jing Su, Shouliang Huo, Hongliang Liu, Yijun Yu and Yanbo Zhang
- 207 The performance of a combined nitrification-anammox reactor treating anaerobic digestion supernatant under various C/N ratios
Jian Zhao, Jiane Zuo, Jia Lin and Peng Li
- 215 Coagulation behavior and floc properties of compound bioflocculant-polyaluminum chloride dual-coagulants and polymeric aluminum in low temperature surface water treatment
Xin Huang, Shenglei Sun, Baoyu Gao, Qinyan Yue, Yan Wang and Qian Li
- 223 Accumulation and elimination of iron oxide nanomaterials in zebrafish (*Danio rerio*) upon chronic aqueous exposure
Yang Zhang, Lin Zhu, Ya Zhou and Jimiao Chen
- 231 Impact of industrial effluent on growth and yield of rice (*Oryza sativa* L.) in silty clay loam soil
Mohammad Anwar Hossain, Golum Kibria Muhammad Mustafizur Rahman, Mohammad Mizanur Rahman, Abul Hossain Molla, Mohammad Mostafizur Rahman and Mohammad Khabir Uddin
- 241 Molecular characterization of microbial communities in bioaerosols of a coal mine by 454 pyrosequencing and real-time PCR
Min Wei, Zhisheng Yu and Hongxun Zhang
- 252 Risk assessment of *Giardia* from a full scale MBR sewage treatment plant caused by membrane integrity failure
Yu Zhang, Zhimin Chen, Wei An, Shumin Xiao, Hongying Yuan, Dongqing Zhang and Min Yang
- 186 Serious BTEX pollution in rural area of the North China Plain during winter season
Kankan Liu, Chenglong Zhang, Ye Cheng, Chengtang Liu, Hongxing Zhang, Gen Zhang, Xu Sun and Yujing Mu

Available online at www.sciencedirect.com

ScienceDirect

www.journals.elsevier.com/journal-of-environmental-sciences

Flux characteristics of total dissolved iron and its species during extreme rainfall event in the midstream of the Heilongjiang River

Jiunian Guan^{1,2}, Baixing Yan^{1,*}, Hui Zhu¹, Lixia Wang¹, Duian Lu^{1,2}, Long Cheng^{1,2}

1. Key Laboratory of Wetland Ecology and Environment, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130102, China. E-mail: jn.a.guan@gmail.com

2. University of Chinese Academy of Sciences, Beijing 100039, China

ARTICLE INFO

Article history:

Received 14 July 2014

Revised 25 November 2014

Accepted 2 December 2014

Available online 14 February 2015

Keywords:

Total dissolved iron

Extreme rainfall event

Midstream of the Heilongjiang River

Flux

ABSTRACT

The occurrence of extreme rainfall events and associated flooding has been enhanced due to climate changes, and is thought to influence the flux of total dissolved iron (TDI) in rivers considerably. Since TDI is a controlling factor in primary productivity in marine ecosystems, alteration of riverine TDI input to the ocean may lead to climate change via its effect on biological productivity. During an extreme rainfall event that arose in northeastern China in 2013, water samples were collected in the midstream of the Heilongjiang River to analyze the concentration and species of TDI as well as other basic parameters. The speciation of TDI was surveyed by filtration and ultrafiltration methods. Compared with data monitored from 2007 to 2012, the concentration of TDI increased significantly during this event, with an average concentration of 1.11 mg/L, and the estimated TDI flux reached 1.2×10^5 tons, equaling the average annual TDI flux level. Species analysis revealed that low-molecular-weight complexed iron was the dominant species, and the impulse of TDI flux could probably be attributed to the hydrological connection to riparian wetlands and iron-rich terrestrial runoff. Moreover, dissolved organic matter played a key role in the flux, species and bioavailability of TDI. In addition, there is a possibility that the rising TDI flux could further influence the transport and cycling of nutrients and related ecological processes in the river, estuary coupled with the coastal ecosystems, which merits closer attention in the future.

© 2015 The Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences.

Published by Elsevier B.V.

Introduction

Iron, a critical nutrient element in aquatic ecosystems, participates in most physiological processes of organisms (Zou et al., 2011). Reportedly, in comparison with balanced cell growth on the basis of fixed nitrogen, a 60- to 100-fold higher iron concentration was required in diazotrophy development in cells of planktonic diazotrophic cyanobacteria, such as *Trichodesmium*, the predominant autotrophic diazotroph in the pelagic marine environment

(Berman-Frank et al., 2001; Brand, 1991). The biogeochemical effects of total dissolved iron (TDI) rely on both its concentration and speciation, including ferrous (Fe(II)) and ferric (Fe(III)) iron, organically and inorganically complexed iron and colloidal iron (Stumm and Sulzberger, 1992). In rivers, the ionic iron largely involves Fe(II) since Fe(III) is extremely insoluble, but it can be dissolved by means of binding to dissolved organic matter (DOM) to enhance the overall solubility, and most (>99%) of the dissolved Fe(III) emerges in organic complexed form (Perdue et al., 1976;

* Corresponding author. E-mail: yanbx@neigae.ac.cn (Baixing Yan).

Meunier et al., 2005). Recently, the riverine input to the ocean, which is one of the primary sources of TDI in the ocean, has attracted increasing attention because of the likelihood that riverine input will generate climate changes, by virtue of its effect on primary biological production and the carbon sequestration rate in ocean regions (Blain et al., 2007; Chen et al., 2014).

Rainfall and subsequent territorial runoff are the chief driving forces of TDI transport (Vuori, 1995). On account of climate change, the occurrence of extreme rainfall events and associated flooding has been heightened worldwide in recent decades, especially in temperate areas at high latitudes (IPCC, 2012). This results in momentous changes of regional hydrology together with ecosystem processes and services, such as the biogeochemical cycles of nutrient elements (Knapp et al., 2008). Variations of DOM and nutrients have been studied intensively during an extreme rainfall event (Siemann et al., 2007); nevertheless, the transport and flux of TDI, the mobility of which can be impacted strongly by rainfall events, has rarely been documented.

The Heilongjiang River (also called the Amur River), located in northeastern China, flows into the Okhotsk Sea, which has a relatively high abundance of phytoplankton biomass because of the sufficient TDI transported from the Heilongjiang River (Yoshimura et al., 2010). A surge of TDI flux related to the flood in 1998 was documented during the late 1990s in the midstream of the Heilongjiang River (MHR) (Kulakov et al., 2010). A similar trend was also observed during intensive rainfall events in different studies, which might owe to the iron-rich runoff and large amounts of DOM inputs (Abesser et al., 2006; Jiann et al., 2013). An extreme rainfall event occurred in August, 2013 in northeastern China, causing severe flooding in the Heilongjiang River. Driven by the desire to understand the alteration of TDI flux resulting from this extreme event, this article presents the water quality data of MHR within the period of the extreme rainfall event as well as historical data from 2007 to 2012, (1) to study the characteristics of TDI flux and species during the extreme rainfall event, (2) to investigate the sources and critical decisive factors of this process, and (3) further to discuss the potential effects of an impulse flux of TDI to the aquatic ecosystem.

1. Materials and methods

1.1. Study area

The Heilongjiang River, stretching from western Manchuria to the Strait of Tartary, whose length is 2825 km (mainstream) with a catchment area about 1.85 million km², of which 48% is located in northeastern China, is the tenth largest watercourse in the world (Yan et al., 2013).

MHR is defined as the river section between the embouchures of the Zeya River (Blagoveshchensk City) and Ussuri River (Khabarovsk City), with a length of approximately 950 km. Not only snowmelt in spring but also monsoonal rain in the course of summer to autumn, which accounts for 15%–20% and 65%–80% of total runoff supply, respectively, comprises the main sources of the flow (Yan et al., 2013). Extensive lowland wetlands exist widely in the basin of MHR, which serves as vital parts in buffering floods and biogeochemical processes in the river ecosystem. In the junction of the Heilongjiang River, the Songhua River and the Ussuri River lie along Tongjiang City and Fuyuan City (Fig. 1), where the annual average temperature is 2–3°C, precipitation around 600 mm per year, of which nearly 80% occurs from June to September, and frost period about 180 days per year, lasting from late October to April of the next year.

The average annual discharge of MHR is 8260 m³/sec, which has fluctuated from 4290 (in 1979) to 14,000 (in 1897) m³/sec, with maximum flow of 39,200 m³/sec recorded in 1897 at Khabarovsk. The MHR has a water catchment area of 1.63 million km², accounting for 87.9% of the total basin area of the Heilongjiang River, with the main control station situated in Khabarovsk City after the convergence of the Rivers of Zeya, Bureya, Songhua and Ussuri (Yan et al., 2013).

1.2. The extreme rainfall event

An extreme rainfall event in this study is defined as rainfall with precipitation over 20 mm with a high frequency (average frequency 3.78 times per year) within a gap of 1–5 days (Yang et al., 2008). In 2013, four intensive rainfall events with precipitation over 20 mm were monitored from August 14th to 22nd in the research area (Fig. 2), which could be defined as “extreme rainfall event”. The water level in MHR peaked around September 1st during the event and ebbed away to the normal level on September 22nd. No extreme rainfall event was observed during 2007–2012 in this area. The runoff depth during the extreme rainfall event was calculated according to the Soil Conservation Service Curve Number (SCS-CN) method (Mishra and Singh, 2003).

1.3. Sample collection and analysis

Water samples were taken from the depth of 50 cm below the water surface at Tongjiang City and Fuyuan City (Fig. 1) in the flood period (July and August) after the rainfall and normal flow period (May, June, September and October) from 2007 to 2012, as well as in the period of the extreme rainfall event from August to September in 2013. After collection, all samples were then stored in a portable refrigerator (4°C)

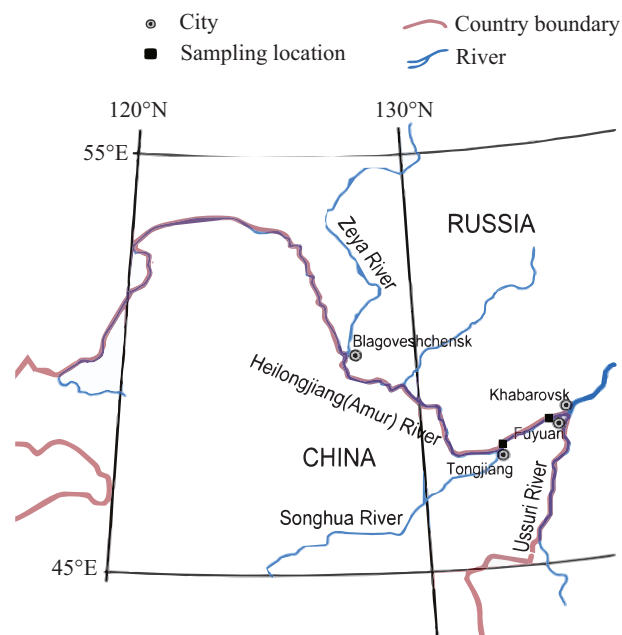


Fig. 1 – Location of sampling sites in the midstream of the Heilongjiang River (MHR).

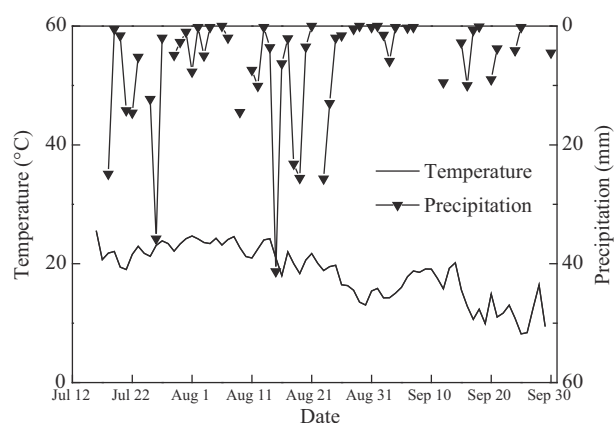


Fig. 2 – Air temperature and precipitation during the extreme rainfall event in midstream of the Heilongjiang River (MHR) (data source: The Sanjiang Experimental Station of Wetland Ecology, Chinese Academy of Sciences).

immediately for further treatment and analysis. Three replicate samples were collected during each sampling event.

Chemical speciation of TDI was analyzed by filtration and ultrafiltration methods that were established in previous research by our team (Pan et al., 2010). First and foremost, the samples were filtered by acid-cleaned Whatman GF/F membranes (Whatman International Ltd., Kent, England) to analyze TDI concentration. Then, by cross-flow ultrafiltration, TDI was severally split into low-molecular-weight iron (LMWI), medium-molecular weight iron (MMWI) and high-molecular-weight iron (HMWI) with the sizes of $<0.01\ \mu\text{m}$ (10 kDa MWCO PES), $0.01\text{--}0.05\ \mu\text{m}$ (50 kDa MWCO PES), and $0.05\text{--}0.7\ \mu\text{m}$ (Whatman GF/F), respectively. In the present study, the colloidal iron fraction is defined as the sum of HMWI and MMWI. LMWI contains ionic and complexed iron, which separately refers to Fe(II) and Fe(III). The difference between LMWI and ionic iron is calculated as complexed iron. The cross-flow ultrafiltration setup, cleaning procedure and quality control were implemented on the basis of the processes that were already established in previous research (Pan et al., 2010). In addition, the recovery rate was 95.4%–103.5% and the detection limit was $0.002\ \text{mg/L}$.

Fe(II) concentrations were measured using a Fe Concentration Tester (ET7406 Lovibond, Tintometer GmbH, Dortmund, Germany) with o-phenanthroline spectrophotometry; the concentrations of Fe and Mn, an atomic absorption spectrophotometer (GBC 932, GBC Scientific Equipment Pty, Ltd, Braeside, Australia); the pH values, a portable pH electrode (Rex, INESA Scientific Instrument, Shanghai, China); dissolved organic carbon (DOC), a TOC- $V_{\text{C}_{\text{PH}}}$ analyzer (TOC- $V_{\text{C}_{\text{PH}}}$, SHIMADZU, Kyoto, Japan); and $\text{NH}_4^+\text{-N}$, $\text{NO}_3^+\text{-N}$, and $\text{PO}_4^{3-}\text{-P}$ concentrations in each sample, an automatic chemical analyzer (Mode Smartchem 200, AMS, Rome, Italy).

1.4. Estimation of TDI flux

Considering that the majority of the river sections of MHR are lines of demarcation between China and Russia, the recent hydrological information is classified. Thereby, the discharge of MHR was estimated based on historical discharge information recorded at the Khabarovsk Hydrological Station by the

Heilongjiang River from 1897 to 2005 (Yan et al., 2013). The historic maximum discharge recorded is $39,200\ \text{m}^3/\text{sec}$. The water level in 2013 reached 808 cm, exceeding the historical maximum water level (642 cm) for nearly one month – the monitored period in current studies is also within this time interval – from mid-August to mid-September at Khabarovsk. Since the historical data are comparable to that in the current study, TDI flux during the extreme rainfall event was estimated using the average TDI concentration and historic maximum discharge ($39,200\ \text{m}^3/\text{sec}$) within a period of 30 days.

1.5. Statistical analysis

All statistical analysis was conducted by SPSS 20.0 statistical software (SPSS Inc., Chicago, USA). Spearman correlation analysis was performed to analyze the relationship between iron concentrations and the other analyzed parameters, since the data did not fit a normal distribution pattern tested by Q–Q probability plot analysis. One-way analysis of variance (ANOVA) was executed to compare the differences between concentrations monitored in different periods; differences were considered significant if $p < 0.05$.

2. Results

2.1. Aquatic parameter set in MHR

The statistics of water quality in MHR in the normal flow period (2007–2012), flood period (2007–2012) and extreme rainfall event (2013) are displayed in Fig. 3. Most of these parameters showed a variation trend among different periods, except pH, which remained relatively stable (on average around 7.40) in all periods. Dissolved Mn in the flood period reached a maximum of $64\ \mu\text{g/L}$, while the concentration averaged $34\ \mu\text{g/L}$ during both the normal flow period and extreme rainfall event. The mean contents of DOC, $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^+\text{-N}$ peaked during the extreme rainfall event and displayed minimum levels during the normal flow period. Taking $\text{NH}_4^+\text{-N}$ as an example, the mean concentration was $0.05\ \text{mg/L}$ during the normal flow period, but it rose to $0.12\ \text{mg/L}$ during the flood period, and climbed up to more than $0.20\ \text{mg/L}$ during the extreme rainfall period. Contents of $\text{PO}_4^{3-}\text{-P}$ showed a similar pattern; however, its concentration decreased from $0.04\ \text{mg/L}$ in the normal flow period to $0.02\ \text{mg/L}$ in the flood period.

2.2. TDI flux and its species during the extreme rainfall event in MHR

Similar to $\text{PO}_4^{3-}\text{-P}$, average TDI concentrations varied significantly ($p < 0.01$) in these three periods (Fig. 4). TDI was $0.43\ \text{mg/L}$ in the normal flow period while $0.28\ \text{mg/L}$ in the flood period, and these TDI levels were comparable with research findings in a similar area of the Heilongjiang River (Levshina, 2012). Yet, a sharp increase of TDI concentration was observed during the extreme rainfall event ($p < 0.01$), with mean value of $1.11\ \text{mg/L}$. Most TDI was in the form of LMWI, and the ionic and complexed iron was the main species during the regular period in MHR (Fig. 5). Even though LMWI

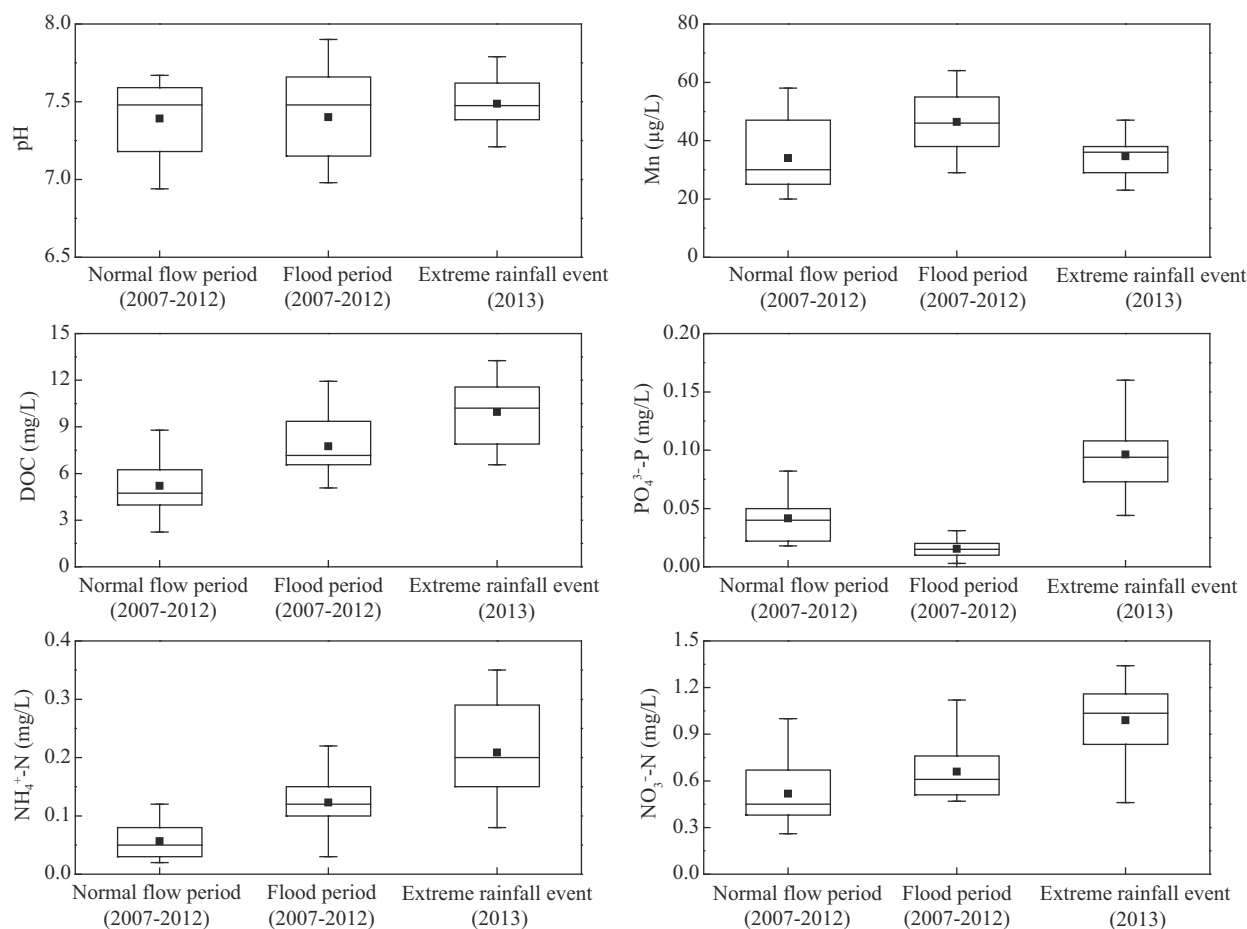


Fig. 3 – Aquatic parameter in different periods in midstream of the Heilongjiang River (MHR). Box-and-square plot representing the maximum, mean, median, 25th to 75th percentiles, and minimum.

was still the main form of TDI, complexed iron became the dominant species, with the relative proportions of iron species varying in the sequence of complexed iron > colloidal iron > ionic iron.

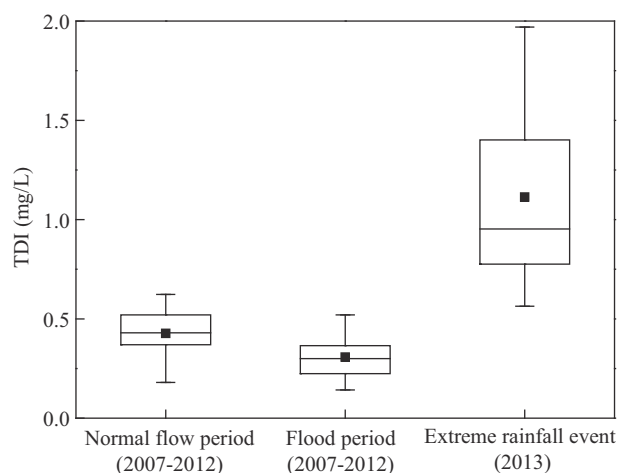


Fig. 4 – Concentrations of total dissolved iron (TDI) in different periods in midstream of the Heilongjiang River (MHR). Box-and-square plot representing the maximum, mean, median, 25th to 75th percentiles, and minimum.

2.3. Dynamic of TDI during the extreme rainfall event in MHR

The dynamics of all species during this extreme rainfall are illustrated in Fig. 6. The results indicated that ionic iron decreased with the augmentation of complexed iron as well as colloidal iron. TDI concentration kept increasing from 0.43 mg/L (before the event) and rose up to a peak of 1.97 mg/L on September 1st, when the water level reached the maximum in MHR, and declined gradually to 0.65 mg/L with the abated water level after that. The complexed and colloidal iron followed a similar pattern as TDI. Export of TDI during the extreme rainfall event in 2013 yielded 1.2×10^5 tons.

3. Discussion

3.1. Water quality variation and potential causes in MHR

The nitrogen and phosphorus concentrations rose significantly during the extreme rainfall event ($p < 0.01$) due to excessive fertilizer application, which is the principal source in this area. The consumption of chemical fertilizers was 1.58×10^6 tons (converting the gross weight into weight containing 100% efficacious components) in the basin of MHR in China in 2012, of which nitrogen fertilizer was 5.70×10^5 tons

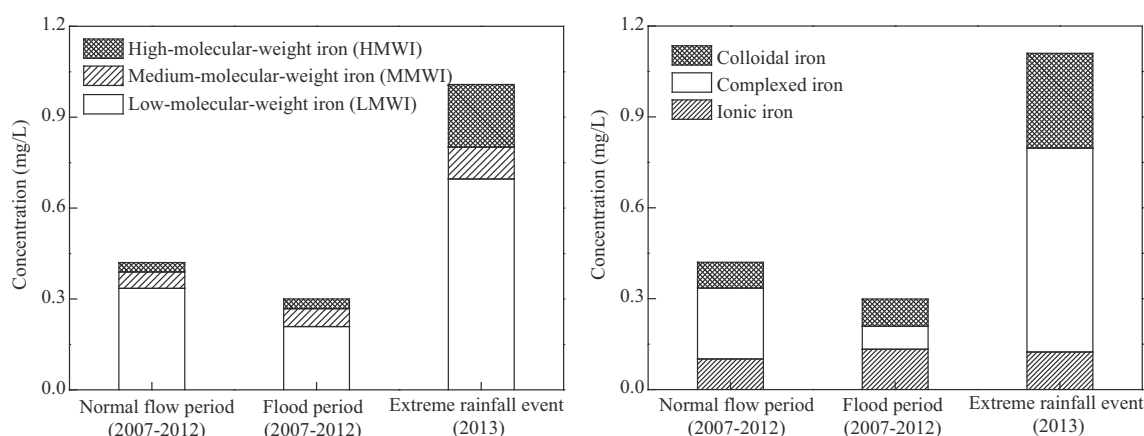


Fig. 5 – Characteristics of iron species in different periods in midstream of the Heilongjiang River (MHR).

while phosphorus fertilizer was 3.47×10^5 tons (Heilongjiang Bureau of Statistics and National Bureau of Statistics Survey Office in Heilongjiang, 2013). Phosphorus could be easily leached by runoff, and then flow into receiving water bodies, giving rise to freshwater eutrophication and/or biodiversity loss in the aquatic ecosystem (Yang et al., 2010). Compared with the regular flood period, DOC values increased considerably as well ($p < 0.01$) during the extreme rainfall event, which was in agreement with other studies, suggesting that the majority of annual DOC export occurred during intensive rainfall events

(Clark et al., 2007). It was also observed that the concentration of TDI increased during the rainfall events, dominated by species in the organic complexed form, and indicated that the maximum contribution from iron sources occurred at peak discharge (Lorieri and Elsenbeer, 1997; Gaiero et al., 2003).

High TDI contents during the extreme rainfall event can be attributed to iron output from wetlands induced by high water level. During the event, the river buffered more widely, resulting in effective hydrological connection to the wetlands and, according to remote sensing monitoring within the research area, over 50% of the total inundated area was swamp wetlands previously. Moreover, the finding that the iron species in the surface water of wetlands were in the order of $LMWI > HMWI > MMWI$, dominated by the species of complexed iron (Pan et al., 2010), was the same as what was found in this study. Hence, the riparian wetlands were the main source of TDI in MHR, which was probably the territorial runoff during the extreme rainfall event (Chi et al., 2010).

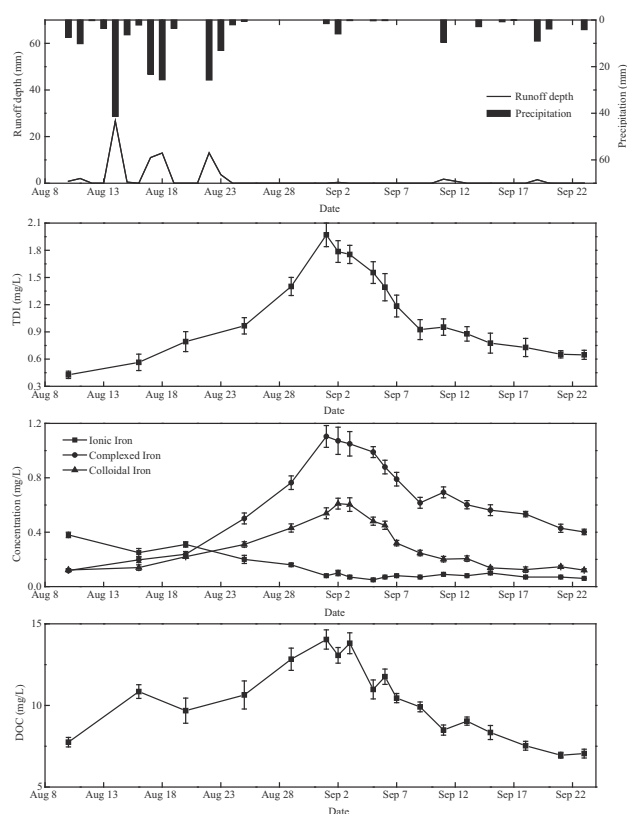


Fig. 6 – Dynamic of total dissolved iron (TDI) and dissolved organic carbon (DOC) during the extreme rainfall event in midstream of the Heilongjiang River (MHR).

3.2. Analysis of factors controlling TDI flux and species during the extreme rainfall event in MHR

In order to identify the critical controlling factor, Spearman correlation was conducted to analyze the relationship between different iron species and water quality parameters monitored during the extreme rainfall event. A significantly positive correlation was observed between the pairs complexed iron-DOC, colloidal iron-DOC, TDI-DOC (Table 1). Thus, DOM may exert great influence upon the concentrations and species of TDI in MHR. In rivers, Fe(II) can be rapidly oxidized to Fe(III) and then precipitate as Fe(III) oxyhydroxides; whereas DOM has high selectivity and affinity for Fe(III), forming steady Fe–DOM complexes, so that DOM can control the solubility and stability of TDI (Nolting et al., 1998). The positive correlation between DOC and TDI was also documented in different works (Wang et al., 2012; Jiann et al., 2013). Furthermore, the species of TDI can be affected by DOM via control of the oxidation and reduction processes; the rate of Fe(II) oxidation may be accelerated by the presence of DOM such as humic acids (Pullin and Cabaniss, 2003). The process of oxidizing Fe(II) is capable of forming both complexed and colloidal iron. The current study provided a full

account of how DOC was observed to be positively correlated to complexed and colloidal iron; simultaneously, the dynamics of iron species suggested that the concentration of ionic iron decreased with the rise of DOC values, as well as the complexed and colloidal iron concentrations, after the extreme rainfall process. During the event, the riparian wetlands, which act as indispensable pools of DOM with abundant humic substances in MHR, could convey large quantities of humic substances into the river (Guo et al., 2010), which can accelerate the oxidizing process of ionic iron to form complexed and colloidal iron. Therefore, DOM played an important role in TDI transport and cycling in MHR during extreme rainfall events.

3.3. Potential effects of the impulse flux of TDI to the aquatic ecosystem

Iron has been reported to limit phytoplankton production in open ocean regions and coastal upwelling areas (Blain et al., 2007; Capone and Hutchins, 2013), moreover, organic complexed iron was reported to remain highly bioavailable and to be transported stably in rivers (Chen and Wang, 2008; Pan et al., 2011). Accordingly, TDI flux during the extreme rainfall event (1.2×10^5 tons), which was equal to the annual TDI flux level during 1990–2005 (1.54×10^5 tons, Kulakov et al., 2010) may greatly affect the primary production and relevant ecological processes. Increase of TDI flux was also observed in other studies on rainfall events (Abesser et al., 2006; Cánovas et al., 2008).

An impulse of TDI flux might affect the nutrient cycling in aquatic ecosystems greatly. The redox reaction between Fe(II) and Fe(III) is the principle process in iron cycling in aquatic environments that controls the cycling of other elements, especially nutrient elements, such as phosphorus. It is typical that the oxidization of ionic iron can generate colloidal iron with an average diameter ranging from 0.05 to 0.5 μm in fresh waters, and the iron colloids remain stable due to their small size and low rate of aggregation and sedimentation (Gunnars et al., 2002). As a result, the iron colloids may transport over a long distance to the estuary and coastal region accompanied by nutrients (Kaplan and Knox, 2004). In the current study, $\text{PO}_4^{3-}\text{-P}$ was observed to be positively correlated to TDI as well as colloidal iron in the event (Table 1). Thus, the impulse flux of TDI may potentially affect the water quality in the estuarine and coastal ecosystems. However, in consideration of the existing data, challenges still remain in identifying how exactly the impulse flux influences the related ecological processes in river, estuarine and coastal ecosystems. To explore its environmental impacts in the future, further research will be needed.

4. Conclusions

This study conducted in the midstream of the Heilongjiang River illustrates that extreme rainfall events are able to increase TDI flux to a great degree and alter the characteristics of its species. TDI concentrations averaged at 1.11 mg/L during the event, with an estimated flux of 1.2×10^5 tons in MHR. Most TDI existed in the form of LMWI; complexed iron was the major species, with the order complexed iron > colloidal iron > ionic iron; DOM had great importance in TDI transport and cycling in

Table 1 – Relationship between iron species and aquatic parameters in extreme rainfall event ($n = 35$).

	DOC	$\text{PO}_4^{3-}\text{-P}$	Mn
Ionic Fe	N.S.	N.S.	N.S.
Complexed Fe	0.735 ^a	N.S.	0.438 ^b
Colloidal Fe	0.474 ^b	0.425 ^b	N.S.
TDI	0.672 ^a	0.409 ^b	0.443 ^b

N.S.: no significant correlation.

^a Correlation is significant at the 0.01 level (2-tailed).

^b Correlation is significant at the 0.05 level (2-tailed).

the period of the extreme rainfall event. The sources of TDI impulse flux owe to the hydrological connection to riparian wetlands and terrestrial runoff. The consequent results, such as the changes in transport and cycling of nutrients as well as related ecological processes, need to be further identified in the future.

Acknowledgments

The authors wish to express particular gratitude to Prof Zongming Wang in the Northeast Institute of Geography and Agroecology for remote sensing analysis. This work was supported by the National Nature Science Foundation of China (No. 41271499) and the Major Science and Technology Program for Water Pollution Control and Treatment (No. 2012ZX07201004).

REFERENCES

- Abesser, C., Robinson, R., Soulsby, C., 2006. Iron and manganese cycling in the storm runoff of a Scottish upland catchment. *J. Hydrol.* 326 (1–4), 59–78.
- Berman-Frank, I., Lundgren, P., Chen, Y.B., Küpper, H., Kolber, Z., Bergman, B., et al., 2001. Segregation of nitrogen fixation and oxygenic photosynthesis in the marine cyanobacterium *Trichodesmium*. *Science* 294 (5546), 1534–1537.
- Blain, S., Quéguiner, B., Armand, L., Belviso, S., Bombled, B., Bopp, L., et al., 2007. Effect of natural iron fertilization on carbon sequestration in the Southern Ocean. *Nature* 446 (7139), 1070–1074.
- Brand, L.E., 1991. Minimum iron requirements of marine phytoplankton and the implications for the biogeochemical control of new production. *Limnol. Oceanogr.* 36 (8), 1756–1771.
- Cánovas, C.R., Hubbard, C.G., Olías, M., Nieto, J.M., Black, S., Coleman, M.L., 2008. Hydrochemical variations and contaminant load in the Río Tinto (Spain) during flood events. *J. Hydrol.* 350 (1), 25–40.
- Capone, D.G., Hutchins, D.A., 2013. Microbial biogeochemistry of coastal upwelling regimes in a changing ocean. *Nat. Geosci.* 6 (9), 711–717.
- Chen, M., Wang, W.X., 2008. Accelerated uptake by phytoplankton of iron bound to humic acids. *Aquat. Biol.* 3 (2), 155–166.
- Chen, J.B., Busigny, V., Gaillardet, J., Louvat, P., Wang, Y.N., 2014. Iron isotopes in the Seine River (France): natural versus anthropogenic sources. *Geochim. Cosmochim. Acta* 128, 128–143.
- Chi, G.Y., Chen, X., Shi, Y., Zheng, T.H., 2010. Forms and profile distribution of soil Fe in the Sanjiang Plain of Northeast China as affected by land uses. *J. Soils Sediments* 10 (4), 787–795.

- Clark, J.M., Lane, S.N., Chapman, P.J., Adamson, J.K., 2007. Export of dissolved organic carbon from an upland peatland during storm events: implications for flux estimates. *J. Hydrol.* 347 (3–4), 438–447.
- Gaiero, D.M., Probst, J.L., Depetris, P.J., Bidart, S.M., Leleyter, L., 2003. Iron and other transition metals in Patagonian riverborne and windborne materials: geochemical control and transport to the southern South Atlantic Ocean. *Geochim. Cosmochim. Acta* 67 (19), 3603–3623.
- Gunnars, A., Blomqvist, S., Johansson, P., Andersson, C., 2002. Formation of Fe(III) oxyhydroxide colloids in freshwater and brackish seawater, with incorporation of phosphate and calcium. *Geochim. Cosmochim. Acta* 66 (5), 745–758.
- Guo, Y.D., Wan, Z.M., Liu, D.Y., 2010. Dynamics of dissolved organic carbon in the mires in the Sanjiang Plain, Northeast China. *J. Environ. Sci. (China)* 22 (1), 84–90.
- IPCC, 2012. Summary for policy makers. In: Field, C.B., Barros, V., Stocker, T.F., et al. (Eds.), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, pp. 1–19.
- Jiann, K.T., Santschi, P.H., Presley, B.J., 2013. Relationships between geochemical parameters (pH, DOC, SPM, EDTA Concentrations) and trace metal (Cd, Co, Cu, Fe, Mn, Ni, Pb, Zn) Concentrations in river waters of Texas (USA). *Aquat. Geochem.* 19 (2), 173–193.
- Kaplan, D.I., Knox, A.S., 2004. Enhanced contaminant desorption induced by phosphate mineral additions to sediment. *Environ. Sci. Technol.* 38 (11), 3153–3160.
- Knapp, A.K., Beier, C., Briske, D.D., Classen, A.T., Luo, Y., Reichstein, M., et al., 2008. Consequences of more extreme precipitation regimes for terrestrial ecosystems. *Bioscience* 58 (9), 811–821.
- Kulakov, V.V., Kondratyeva, L.M., Golubeva, Y.M., 2010. Geological and biogeochemical prerequisites for high Fe and Mn contents in the Amur River water. *Russ. J. Pac. Geol.* 4 (6), 510–519.
- Levshina, S.I., 2012. Iron distribution in surface waters in the middle and lower Amur basin. *Water Resour.* 39 (4), 375–383.
- Heilongjiang Bureau of Statistics and National Bureau of Statistics Survey Office in Heilongjiang (Ed.), 2013. *Heilongjiang Statistical Year Book 2013*. China Statistic Press, Beijing.
- Lorieri, D., Elsenbeer, H., 1997. Aluminium, iron and manganese in near-surface waters of a tropical rainforest ecosystem. *Sci. Total Environ.* 205 (1), 13–23.
- Meunier, L., Laubscher, H., Hug, S.J., Sulzberger, B., 2005. Effects of size and origin of natural dissolved organic matter compounds on the redox cycling of iron in sunlit surface waters. *Aquat. Sci.* 67 (3), 292–307.
- Mishra, S.K., Singh, V.P., 2003. *Soil Conservation Service Curve Number (SCS-CN) Methodology*. Springer Press, Netherlands, pp. 84–146.
- Nolting, R.F., Gerringa, L.J.A., Swagerman, M.J.W., Timmermans, K.R., De Baar, H.J.W., 1998. Fe (III) speciation in the high nutrient, low chlorophyll Pacific region of the Southern Ocean. *Mar. Chem.* 62 (3–4), 335–352.
- Pan, X.F., Yan, B.X., Yoh, M., Wang, L.X., Liu, X.Q., 2010. Temporal variability of iron concentrations and fractions in wetland waters in Sanjiang Plain, Northeast China. *J. Environ. Sci. (China)* 22 (7), 968–974.
- Pan, X.F., Yan, B.X., Yoh, M., 2011. Effects of land use and changes in cover on the transformation and transportation of iron: a case study of the Sanjiang Plain, Northeast China. *Sci. China Earth Sci.* 54 (5), 686–693.
- Perdue, E.M., Beck, K.C., Reuter, J.H., 1976. Organic complexes of iron and aluminium in natural waters. *Nature* 260 (5550), 418–420.
- Pullin, M.J., Cabaniss, S.E., 2003. The effects of pH, ionic strength, and iron-fulvic acid interactions on the kinetics of non-photochemical iron transformations. I. Iron(II) oxidation and iron(III) colloid formation. *Geochim. Cosmochim. Acta* 67 (21), 4067–4077.
- Siemann, E., Rogers, W.E., Grace, J.B., 2007. Effects of nutrient loading and extreme rainfall events on coastal tallgrass prairies: invasion intensity, vegetation responses, and carbon and nitrogen distribution. *Glob. Change Biol.* 13 (10), 2184–2192.
- Stumm, W., Sulzberger, B., 1992. The cycling of iron in natural environments: considerations based on laboratory studies of heterogeneous redox processes. *Geochim. Cosmochim. Acta* 56 (8), 3233–3257.
- Vuori, K.M., 1995. Direct and indirect effects of iron on river ecosystems. *Ann. Zool. Fenn.* 32 (3), 317–329.
- Wang, L.X., Yan, B.X., Pan, X.F., Zhu, H., 2012. The spatial variation and factors controlling the concentration of total dissolved iron in rivers, Sanjiang Plain. *Clean: Soil, Air, Water* 40 (7), 712–717.
- Yan, B., Xia, Z.Q., Zhou, Y.X., Wang, J.C., Chen, Q.C., 2013. Variation of runoff at Khabarovsk Station on Heilongjiang River. *Water Resour. Prot.* 29 (3), 29–33.
- Yang, S.Y., Sun, F.H., Ma, J.Z., 2008. Evolvement of precipitation extremes in northeast China on the background of climate warming. *Sci. Geogr. Sin.* 28 (2), 224–228.
- Yang, Y.H., Yan, B.X., Shen, W.B., 2010. Assessment of point and nonpoint sources pollution in Songhua River Basin, Northeast China by using revised water quality model. *Chin. Geogr. Sci.* 20 (1), 30–36.
- Yoshimura, T., Nishioka, J., Nakatsuka, T., 2010. Iron nutritional status of the phytoplankton assemblage in the Okhotsk Sea during summer. *Deep-Sea Res.* 57 (11), 1454–1464.
- Zou, Y.C., Jiang, M., Yu, X.F., Lu, X.G., David, J.L., Wu, H.T., 2011. Distribution and biological cycle of iron in freshwater peatlands of Sanjiang Plain, Northeast China. *Geoderma* 164 (3–4), 238–248.



Editorial Board of Journal of Environmental Sciences

Editor-in-Chief

X. Chris Le University of Alberta, Canada

Associate Editors-in-Chief

Jiuhui Qu Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Shu Tao Peking University, China
Nigel Bell Imperial College London, UK
Po-Keung Wong The Chinese University of Hong Kong, Hong Kong, China

Editorial Board

Aquatic environment

Baoyu Gao Shandong University, China
Maohong Fan University of Wyoming, USA
Chihpin Huang National Chiao Tung University, Taiwan, China
Ng Wun Jern Nanyang Environment & Water Research Institute, Singapore
Clark C. K. Liu University of Hawaii at Manoa, USA
Hokyong Shon University of Technology, Sydney, Australia
Zijian Wang Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Zhiwu Wang The Ohio State University, USA
Yuxiang Wang Queen's University, Canada
Min Yang Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Zhifeng Yang Beijing Normal University, China
Han-Qing Yu University of Science & Technology of China, China

Terrestrial environment

Christopher Anderson Massey University, New Zealand
Zucong Cai Nanjing Normal University, China
Xinbin Feng Institute of Geochemistry, Chinese Academy of Sciences, China
Hongqing Hu Huazhong Agricultural University, China
Kin-Che Lam The Chinese University of Hong Kong, Hong Kong, China
Erwin Klumpp Research Centre Juelich, Agrosphere Institute, Germany

Peijun Li

Institute of Applied Ecology, Chinese Academy of Sciences, China
Michael Schlöter German Research Center for Environmental Health, Germany
Xuejun Wang Peking University, China
Lizhong Zhu Zhejiang University, China

Atmospheric environment

Jianmin Chen Fudan University, China
Abdelwahid Mellouki Centre National de la Recherche Scientifique, France
Yujing Mu Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Min Shao Peking University, China
James Jay Schauer University of Wisconsin-Madison, USA
Yuesi Wang Institute of Atmospheric Physics, Chinese Academy of Sciences, China
Xin Yang University of Cambridge, UK

Environmental biology

Yong Cai Florida International University, USA
Henner Hollert RWTH Aachen University, Germany
Jae-Seong Lee Sungkyunkwan University, South Korea
Christopher Rensing University of Copenhagen, Denmark
Bojan Sedmak National Institute of Biology, Slovenia
Lirong Song Institute of Hydrobiology, Chinese Academy of Sciences, China
Chunxia Wang National Natural Science Foundation of China
Gehong Wei Northwest A & F University, China

Daqiang Yin

Tongji University, China
Zhongtang Yu The Ohio State University, USA

Environmental toxicology and health

Jingwen Chen Dalian University of Technology, China
Jianying Hu Peking University, China
Guibin Jiang Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Sijin Liu Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Tsuyoshi Nakanishi Gifu Pharmaceutical University, Japan

Willie Peijnenburg University of Leiden, The Netherlands
Bingsheng Zhou Institute of Hydrobiology, Chinese Academy of Sciences, China

Environmental catalysis and materials

Hong He Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Junhua Li Tsinghua University, China
Wenfeng Shangguan Shanghai Jiao Tong University, China
Ralph T. Yang University of Michigan, USA

Environmental analysis and method

Zongwei Cai Hong Kong Baptist University, Hong Kong, China
Jiping Chen Dalian Institute of Chemical Physics, Chinese Academy of Sciences, China
Minghui Zheng Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Municipal solid waste and green chemistry
Pinjing He Tongji University, China

Editorial office staff

Managing editor Qingcai Feng
Editors Zixuan Wang Suqin Liu Kuo Liu Zhengang Mao
English editor Catherine Rice (USA)

JOURNAL OF ENVIRONMENTAL SCIENCES

环境科学学报(英文版)

www.jesc.ac.cn

Aims and scope

Journal of Environmental Sciences is an international academic journal supervised by Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. The journal publishes original, peer-reviewed innovative research and valuable findings in environmental sciences. The types of articles published are research article, critical review, rapid communications, and special issues.

The scope of the journal embraces the treatment processes for natural groundwater, municipal, agricultural and industrial water and wastewaters; physical and chemical methods for limitation of pollutants emission into the atmospheric environment; chemical and biological and phytoremediation of contaminated soil; fate and transport of pollutants in environments; toxicological effects of terrorist chemical release on the natural environment and human health; development of environmental catalysts and materials.

For subscription to electronic edition

Elsevier is responsible for subscription of the journal. Please subscribe to the journal via <http://www.elsevier.com/locate/jes>.

For subscription to print edition

China: Please contact the customer service, Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China. Tel: +86-10-64017032; E-mail: journal@mail.sciencep.com, or the local post office throughout China (domestic postcode: 2-580).

Outside China: Please order the journal from the Elsevier Customer Service Department at the Regional Sales Office nearest you.

Submission declaration

Submission of the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The publication should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

Editorial

Authors should submit manuscript online at <http://www.jesc.ac.cn>. In case of queries, please contact editorial office, Tel: +86-10-62920553, E-mail: jesc@rcees.ac.cn. Instruction to authors is available at <http://www.jesc.ac.cn>.

Journal of Environmental Sciences (Established in 1989) Volume 30 2015

Supervised by	Chinese Academy of Sciences	Published by	Science Press, Beijing, China
Sponsored by	Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences		Elsevier Limited, The Netherlands
Edited by	Editorial Office of Journal of Environmental Sciences P. O. Box 2871, Beijing 100085, China Tel: 86-10-62920553; http://www.jesc.ac.cn E-mail: jesc@rcees.ac.cn	Distributed by	
		Domestic	Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China Local Post Offices through China
		Foreign	Elsevier Limited http://www.elsevier.com/locate/jes
Editor-in-chief	X. Chris Le	Printed by	Beijing Beilin Printing House, 100083, China

CN 11-2629/X Domestic postcode: 2-580

Domestic price per issue RMB ¥ 110.00

ISSN 1001-0742

