Pol. J. Environ. Stud. Vol. 24, No. 3 (2015), 969-975
DOI: *10.15244/pjoes/37552*

Original Research

Composition and Distribution of Organic Carbon in River Sediments: a Case Study of Two Northern Chinese Rivers

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Received: 14 December 2014
Accepted: 28 January 2015

Abstract

In order to explore the composition characteristics and distribution pattern of organic carbon (OC) in river sediments, river sediments and riverbank soils were sampled from upstream to downstream of the Majia and Tuhai rivers in northern China, and then determined for heavy fraction organic carbon (HFOC) and light fraction organic carbon (LFOC). Results showed that the HFOC had a significant correlation with LFOC in Majia riverbank sediments or soils, indicating that HFOC and LFOC might have homology and that the Majia River is relatively stable. The distribution pattern of OC is changing irregularly along with rivers. Mean HFOCs in sediments were slightly higher than that in riverbank soils in both studied rivers. Contributions of some other sources of OC that accumulated in sediments might result in better capacity of sediments to OC than soils of riverbank. Our study demonstrated that sediments could accumulate HFOC and LFOC derived from many sources, and had a better capability for the storage of OC, irrespective of HFOC and LFOC.

Keywords: HFOC, LFOC, Majia River, river sediment, Tuhai River

Introduction

Many studies have suggested that organic carbon (OC) storage in soils could alleviate the greenhouse effect [1, 2], and the research of carbon sequestration has become the hot topic of global change ecology [3]. The carbon in global soils was 2500 Gt, which was 3.3 times the size of the atmospheric pool and 2-3 times the carbon in global vegetation [2], including about 1,550 Gt of soil organic carbon and 950 Gt of soil inorganic carbon [4, 5]. Storage of OC in soils of China was up to 1.5-3 times the amount of carbon stored in vegetation [6], and OC in river wetland should not be neglected in estimation of carbon storage considering that the wetland is an important carbon sink [7, 8].

The stability of different components in OC is not the same. Vegetation, microbes, and zoobenthos are the main ways for carbon to assimilate into soils [9-11]. In the processes of their decomposition, they are mainly decomposed into light fraction organic carbon (LFOC, specific gravity<1.7 g/cm^3) [12, 13], which is the active carbon pool and easy to be affected by environment and climate [14, 15]. Then, LFOC is decomposed into heavy fraction organic carbon (HFOC, specific gravity>1.7 g/cm^3) partially [16], which is relatively stable and complicated [17].

The studies of OC in rivers or terrestrial soils of China were mainly concentrated in southern China and most research did not distinguish between LFOC and HFOC [18-20]. Carbon sequestration of river sediments can be explored in depth by analyzing HFOC and LFOC as they are the stable and active components of OC [21]. Therefore, the study of HFOC and LFOC in river sediments in north-

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ern China is meaningful for understanding the capability of rivers for carbon storage.

In order to understand the composition characteristics and distribution pattern of organic carbon in river sediments. We sampled sediments and soils on the banks of the Majia and Tuhai rivers from upstream to downstream. This study tries to answer the following scientific questions:

1. Is the distribution of HFOC and LFOC in river sediments consistent?
2. Is the distribution pattern of organic carbon in river sediments influenced by soils of riverbank or other factors?

Materials and Methods

Study Area

The Tuhai and Majia rivers belong to the Haihe River Basin, which empties into the Bohai Gulf. They mainly flow through Shandong Province, China, which has a typical warm temperate monsoon climate. Annual average temperature is 11~14ºC. The mean annual frost-free period is 220 days, and increases from northeast to the southwest coast of Shandong Province progressively [22].

Field Sample Collection

Sixty samples were selected from the sediments and soils on the banks of the Tuhai River (36º07'26.3N, 115º28'35.0E-37º30'08.0N, 117º51'08.0E) and Majia River (36º18'42.8N, 115º33'41.1E-37º45'46.4N, 117º23'53.2E) in May 2014. Thirty samples were taken from each river, including 15 sediment samples and 15 soil samples. Nine, 3, and 3 of the 15 samples were obtained from upstream, midstream, and downstream in sediments or riverbank in each river, respectively. To study the small-scale distribution pattern of OC in continuous segments of both rivers' sediments, we sampled three groups in the upstream, each of which included three successive sampling points, and interblock space was 2 km, within every two sampling points of each group was 200 meters. Surface sediments (0-15 cm) and soils were sampled into sealed bags by sediment sampler. Two cutting rings of soil samples were gotten at each sampling point (one was used to measure the moisture content, the other used to measure organic carbon). Sampling distribution was shown in Fig. 1.

Statistical Analysis

All data were analyzed using SPSS (version 21.0). One-Way ANOVA was used to determine the significant differences in both rivers from upstream to downstream, and bivariate correlations were analyzed in the relationship of HFOC and LFOC, sediments and soils on banks, certain functional constants, and OC. An outlier from soils on upstream Majia banks was rejected in the process of statistical analysis by SPSS. OriginPro (version 8.0) and Adobe illustrator (version 16.0.0) were used to draw the figures.

Laboratory Analysis

The modified gravity method was used to separate HFOC and LFOC [16]. The drying method was used to measure moisture content and bulk density [23]. HFOC, LFOC, and total nitrogen were determined by elemental analyzer (Vario EL III, Elementar Analysensysteme, Germany). The pH of soil and sediment samples was measured with a 1:2.5 soil-water ratio by pH meter.

Results

The Composition and Distribution Characteristics of Organic Carbon in Sediments

HFOC had a significant correlation with LFOC in Majia sediments (r=0.650, p<0.05), as did that in Majia shore soil (r=0.787, p<0.01; Table 3). However, the same correlation in Tuhai sediments or riverbank soils was not significant (Table 2). Distribution patterns of HFOC and LFOC in upstream continuous segments of the two rivers were changed irregularly (Figs. 2 and 4).

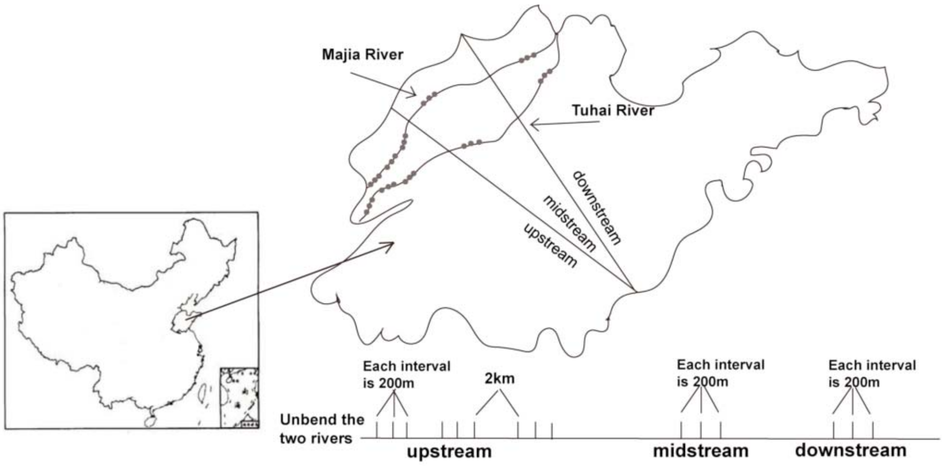

Fig. 1. The sampling points in the sediment of Majia and Tuhai River.

Table 1. Mean contents of HFOC and LFOC, and mean C/N values in sediment and riverbank soil of the Tuhai and Majia (means± standard deviation; one extremum in the Majia was rejected by SPSS).

Sample sites	n	LFOC (%)	HFOC (%)	C/N
Tuhai sediment	15	0.064±0.081	1.568±0.480	27.169±10.216
Tuhai shore soil	15	0.065±0.060	1.412±0.281	18.787±5.131
Majia sediment	14	0.045±0.054	1.619±0.470	25.125±7.285
Majia shore soil	14	0.033±0.032	1.332±0.419	13.207±4.048

By comparing the river sediments and soils on banks, we could see that the correlation of LFOC in the Tuhai was significant ($r=0.723$, $p<0.01$; Fig. 2) and mean LFOC in sediments and soils of riverbank was almost equal. However, the correlation of HFOC in the Tuhai was not significant ($r=0.345$, $p<0.05$; Table 2), especially in midstream. HFOC and LFOC all had significant correlation between sediments and soils of the Majia shore (Table 3 and Fig. 4).

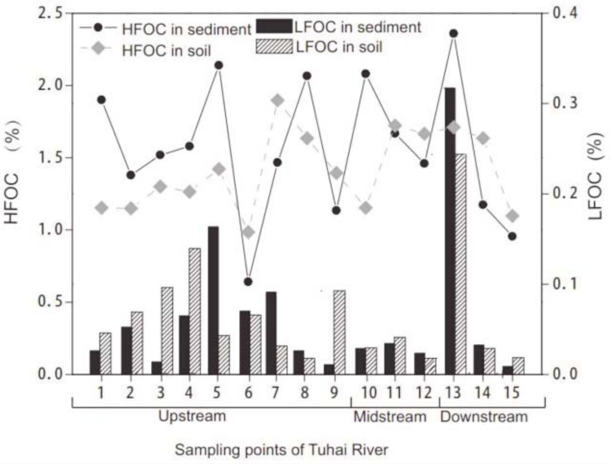

Fig. 2. The distribution of OC in the sediment and soil of Tuhai River shore.

Comparison and Distribution Pattern of Organic Carbon in These Two Rivers

LFOC was far less than that of HFOC at each sampling point of these two rivers (Table 1). And from the view of mean HFOC, Majia sediments>Tuhai sediments>soils of Tuhai shore>soils of Majia shore. As for LFOC: Tuhai sediments≈soils of Tuhai shore>Majia sediments>soils of Majia shore. Mean HFOC in sediments was slightly higher than that in soils of riverbank, while the distribution of LFOC was not the same in these two rivers.

HFOC and LFOC in sediments were evenly distributed from upstream to downstream in the Tuhai, thus HFOC and LFOC were much higher in downstream Majia than that in upstream and midstream (Fig. 3).

Effects of Environmental Factors on the Composition and Distribution of Organic Carbon

Our study showed that OC was significantly correlated with total nitrogen (TN) in Majia sediments, particularly HFOC ($r=0.958$, $p<0.01$), as was that in Majia shore soils (Figs. 5 and 6). HFOC was also significantly correlated

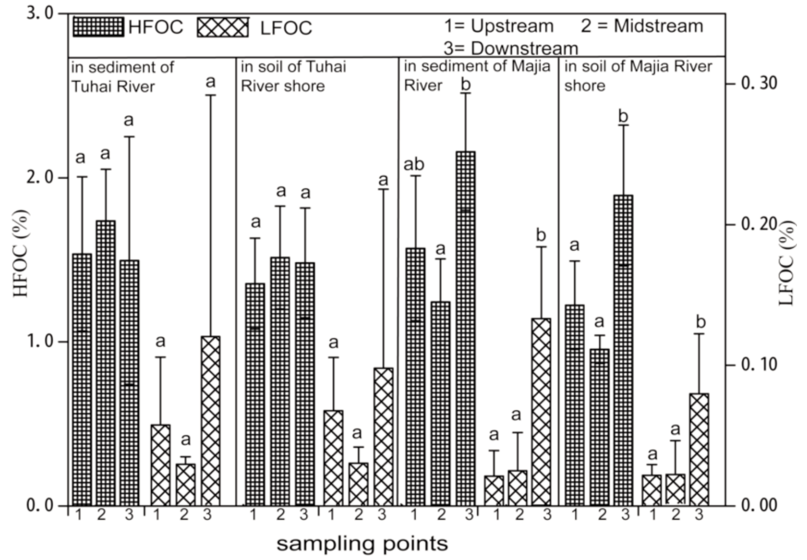

Fig. 3. The mean organic carbon in sediments and soils of the Tuhai and Majia River (Duncan test). The bars sharing the same letter have no difference at $p<0.05$.

Table 2. Pearson correlation analysis of HFOC and LFOC in sediment and soil on the banks of the Tuhai.

r	HFOC in Tuhai sediment	LFOC in Tuhai sediment	HFOC in Tuhai shore soil
LFOC in Tuhai sediment	0.507		
HFOC in Tuhai shore soil	0.345	0.309	
LFOC in Tuhai shore soil	0.285	0.723*	0.048

n=15, *p<0.01

with TN in Tuhai sediments (r=0.675, p<0.05), while LFOC was not (Fig. 6). Mean carbon nitrogen ratio (C/N) of most sampling points in sediments of these two rivers was higher than that in riverbank soils (Table 1).

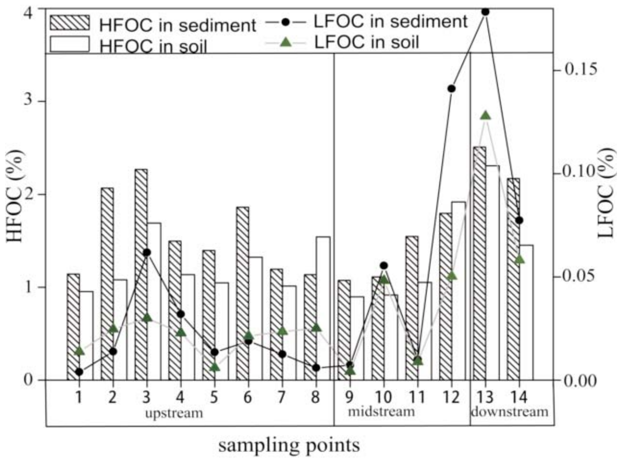

Fig. 4. The distribution of organic carbon in sediments and riverbank soils of Majia River.

Discussion

Our study found that distribution patterns of OC were different between rivers. Previous studies showed that complicated surroundings [24] and human interference [25, 26] could influence the distribution of OC in soils. The two studied rivers have different surroundings and part of the Tuhai was recently dredged, while the Majia was relatively stable as suggested by strong resonance of HFOC and LFOC in sediments and riverbank soils. The correlations analysis (Tables 2 and 3) also suggested that the Tuhai suffered more influence by humans and surroundings than the Majia. HFOC and LFOC in Tuhai sediments and soils were evenly distributed, while they were not in the Majia (Fig. 3). Besides, the distribution pattern of HFOC and LFOC in upstream continuous segments of the two rivers had no unified trend. The distribution trend of OC from upstream to downstream of rivers might be changing irregularly, though they are all plain rivers.

The significant correlation and the almost equal content of LFOC between Tuhai shore soils and sediments indicated that LFOC in sediments and soils might have homology. HFOC was more influenced than LFOC in the Tuhai,

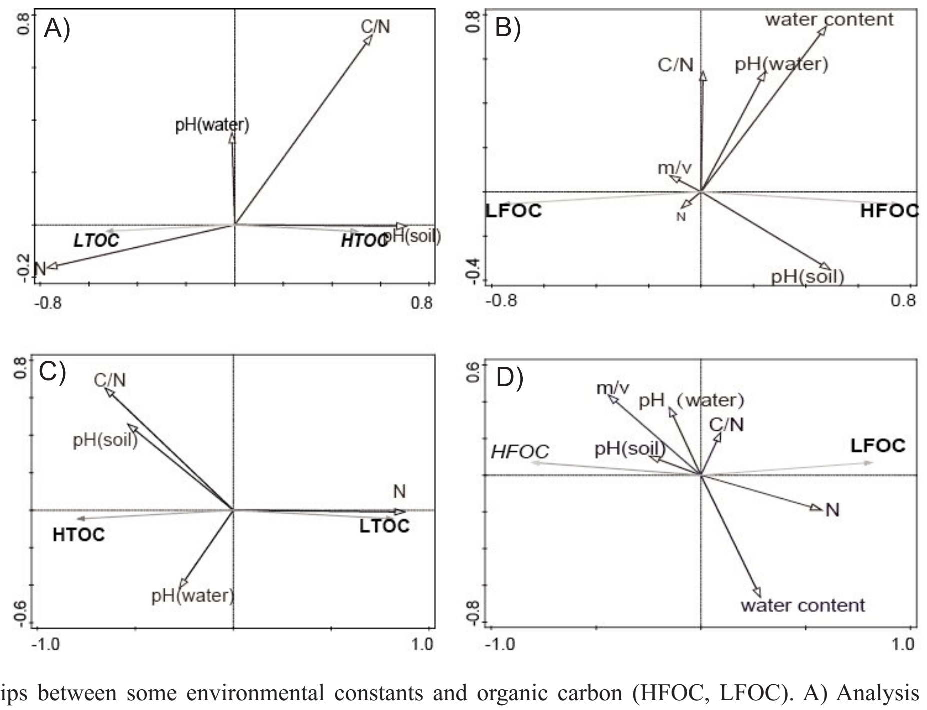

Fig. 5. Relationships between some environmental constants and organic carbon (HFOC, LFOC). A) Analysis of the relationship among the factors and organic carbon in Tuhai River Sediment; B) Analysis of the relationship among the factors and organic carbon in the soil on banks of Tuhai River; C) Analysis of the relationship among the factors and organic carbon in Majia River Sediment; D) Analysis of the relationship among the factors and organic carbon in the soil on banks of Majia River.

Table 3. Pearson correlation analysis of HFOC and LFOC in Majia sediment and soil.

r	HFOC in Majia sediment	LFOC in Majia sediment	HFOC in Majia shore soil
LFOC in Majia sediment	0.650*		
HFOC in Majia shore soil	0.719**	0.854**	
LFOC in Majia shore soil	0.631*	0.898**	0.787**

n=14, *p<0.05, **p<0.01

which might reveal that the interference in this river was mostly from human activity such as dredging of the midstream, tillage of the upstream, etc. The significant correlation of OC (HFOC and LFOC) in Majia sediments and soils further proved that OC between sediments and soils had homology, and the contribution of soils to sediments of HFOC and LFOC was very large, which might be related to the formation of surface sediments [27]. There were other parts of OC coming from the deposition of fine sediments [28, 29] and bacteria groups [30, 31] in river waters, microbial fixed effects in sediments to organic matter [32], and residues of zooplankton [33], etc.

Total nitrogen (TN) was one of the important indicators of nutrition levels and microbial abundance, which had much to do with TOC in sediments and soils [34]. The significant correlation of LFOC and TN in the Majia might be largely connected with primary producers and microbes (Fig. 5) [35]. The more significant correlation of HFOC with TN than LFOC in these two rivers might be that HFOC and TN were proportional to each other in many components of sediments and soils (Fig. 5) [34]. Carbon nitrogen ratio (C/N) might be an indicator of main origins and sources of OC [25]. Mean C/N values in most Majia sampling points were less than that in the Tuhai overall, indicating that the sources of the Tuhai were relatively complicated. Besides, mean C/N values in riverbank soils were slightly lower than that in the sediments of both rivers (Table 1), which proved that OC in sediments of both rivers had multiple sources.

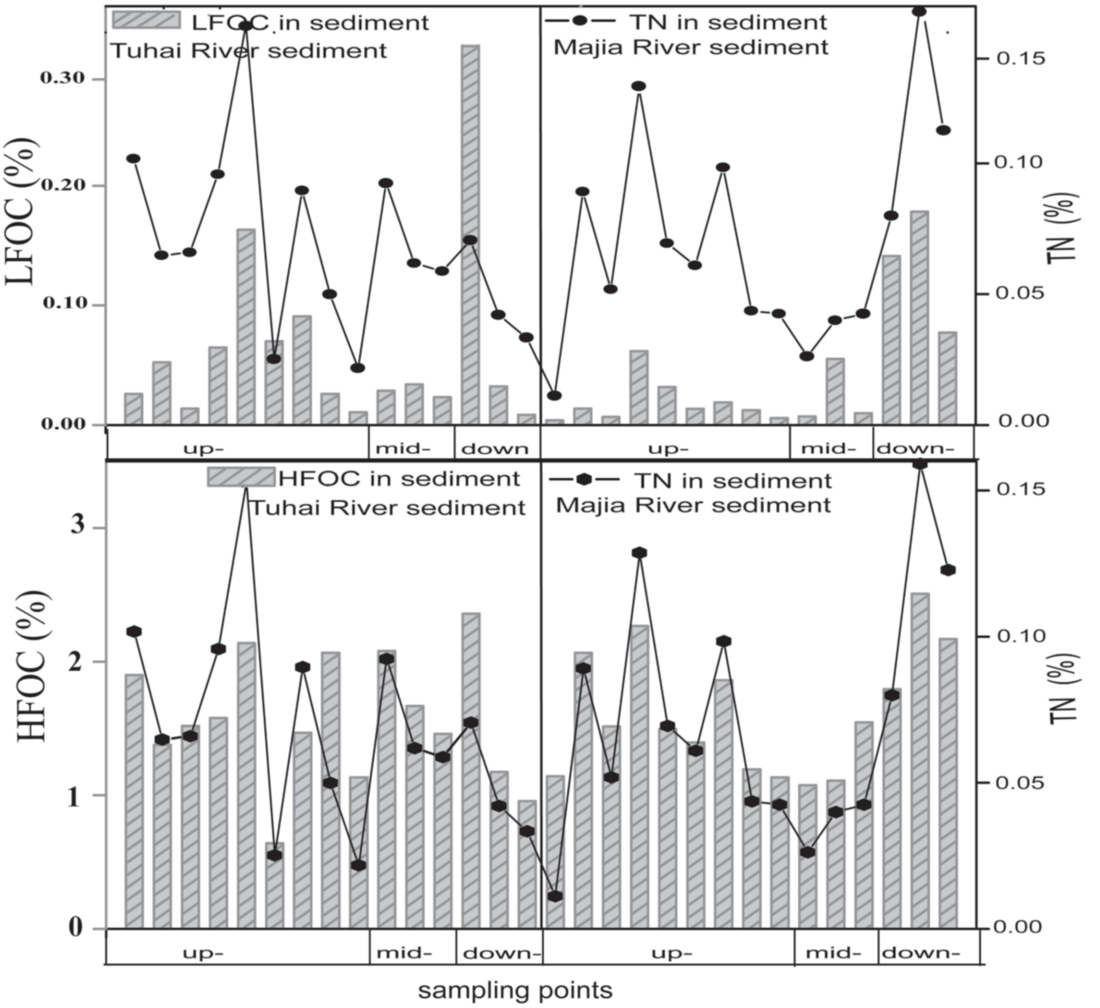

Fig. 6. The relationship between HFOC and TN, the relationship between LFOC and TN.

Soil bulk density, moisture content and other physical constants were also indirectly associated with OC, whether through microbial activities or growth degree of primary productivity [30, 36]. A previous study suggested that OC increased with moisture content and decreased with bulk density in soils [37]. However, it was not significant in our study as many other factors, including human interference, might influence river sediments.

With the perennial impact of rain on soils and the flow of river waters, OC in soils of riverbank and upstream gradually deposit in surface sediments, leading to the loss of a part of OC in riverbank soils [38]. Therefore, the mean HFOC in sediments was slightly higher than that in soils of riverbank and the high HFOC of river sediments indicated that sediments might have more capability to store HFOC than soils on corresponding banks. High LFOC upstream of the Tuhai might be caused by the residues of crops [39], which also might be proved by C/N values and TN [40]. There were many microbes and plant residues accumulated in surface sediments, and organic components with high molecular weight derived from river waters gathered into sediments, causing the LFOC in Majia sediments to rise, though a very small fraction of carbon would decompose and be released into the atmosphere [41]. Results in our study suggest that sediments of natural rivers might have better capacity to store HFOC and LFOC than riverbank soils. By comparing the HFOC and LFOC between sediments and soils, and analyzing the results overall, we could find that the distribution trend of Majia HFOC and LFOC were in line with the normal characteristics of natural rivers, and the analysis above suggested that sediments could accumulate HFOC and LFOC that derived from many sources, and had better capability for OC storage.

Conclusions

Our results suggest that the Majia was relatively stable while the Tuhai was complicated and influenced by artificial factors. HFOC and LFOC in river sediments had multiple sources and they had homology in Majia sediments but not in the Tuhai. The distribution patterns of OC change irregularly along with rivers. All results demonstrated that river sediments have a better capability for storing OC, irrespective of HFOC and LFOC.

Acknowledgements

We would like to thank Qin Xu for her help with fieldwork, and Xinjuan Cui, Xiaocui Chen, and Xiuli Ge for the their help in laboratory determination. This study was financially supported by the National Water Special Project (No. 2012ZX07203-004) and the National Natural Science Foundation of China (No. 31200426).

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