Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 15	No. 2	pp. 497-502	2016

Original Research Paper

GIS-assisted Determination of the Environmental-Friendly Dredging Volume in a Reservoir Based on Risk Classification of Nutritive Salts

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 24-05-2015
Accepted: 21-06-2015

Key Words:
Sediment
Nutrients
Environmental-friendly dredging

ABSTRACT

In this study, the problems about dredging polluted sediments in a reservoir during the Environmental-friendly dredging engineering will be solved. To determine the dredging region, the spatial distribution characteristics of the sediments and main pollutants (nutrients) in the sediments were investigated, and the grading standards of nutrients were set up according to the adsorption-desorption method. The high risk regions of Total Nitrogen (TN) and Total Phosphorus (TP) were found out, and the environmental-friendly dredging volume was obtained by combining with security indices of environmental dredging engineering and spatial analysis method (i.e. GIS). From the study, the conclusions could be drawn as follows: (1) the average content of TN and TP in the surface sediments was 1414.8 mg/kg and 719.4 mg/kg, respectively; (2) the polluted areas, mainly were concentrated in estuaries and the upper-middle part of reservoir. The results of nutrient pollution grading showed that, 20.4% of the reservoir region was heavily polluted by TN and 66.3% by TP. Environmental-friendly dredging area accounted for about 68.4% of the reservoir; (3) the top of overlayer as dredging layer is average of 0.5 m; (4) the volume of environmental-friendly dredging is about 1.92×10^7 m^3. The study purpose is to provide theoretical and technical support for reservoir polluted sediments governance.

INTRODUCTION

Sediment is located at the bottom of the water, which is composed of clay, sand, nutrients and/or several mineral deposits, and is formed through certain physical, chemical and biological processes (Perkins & Underwood 2001). For now, the formation of sediment has been increasingly affected by human activities in recent years. The majority of hydrophobic organic compounds, metals and nutrients were carried into the water as particles, and then developed into contaminated sediment (Loska & Wiechula 2003). So the sediment has become the sink of all kinds of the pollutants in the water. Finally, pollutants are deposited into the sediment by various ways, such as water particle adsorption, complication, flocculation, sedimentation and so on. From another point of view, sediment can also seem to be an important source of "secondary pollution" in water (Kim et al. 2003). The pollutants adsorbed by sediment will return to the water by desorption, dissolved, biological decomposition and so on as environmental conditions changed, which produce a phenomenon called "secondary pollution", caused eutrophication of lakes and reservoir. In addition, the excessive deposition of sediment would greatly decrease the available capacity of lakes and reservoir, reduce the reservoir benefit and even affect the normal operation of the reservoir.

The goal of Environmental-friendly dredging is to decontaminate the polluted sediment, control internal pollution of sediment, and create conditions for the resumption of aquatic ecosystems, which could improve the water quality (Li et al. 2006, Pu et al. 2000, Mo et al. 2003). Before dredging, investigation and experiments should be undertaken. During this process, the distribution of major pollutants in sediments should be considered to make sure that the range of dredging is selected scientifically, as well as survival condition. If the range of dredging is determined, the dredging scheme could be made in a targeted manner. Within a reasonable range of dredging, we can, not only avoid the result that remove the polluted sediments incompletely, but also avoid ecosystem disruption and high cost caused by excessive dredging.

A typical reservoir in northeast China was selected in this study, in which dredging region was determined by site investigation, stationing monitoring, laboratory methods of chemical analysis and Geographic Information System (GIS) method. The purpose of this study is to provide theoretical and technical support for polluted sediments governance in the reservoir.

STUDY AREA AND RESEARCH CONTENTS

Characteristics of the study area: The reservoir is located in the southern of a city in northeast China, which belongs to the Songhua River (Fig. 1). The reservoir was constructed in July 1958, and completed in November 1962. The reservoir area is 85.2 km^2; the length of dam is 514 m and height is 182.75 m; the normal water level is 218.83 m; the storage capacity is 290 million m^3. The average disposable water of flood discharge is 67.72 million m^3 every year, and annual water supply is 88.8 million m^3. The reservoir primarily supplies water for the western part of the city, the capacity of daily water supply is 180,000 m^3 that is about a quarter of the urban daily water supply.

The river length above the reservoir is 90.2 km, the control drainage area is 1970 km^3, the basic width of the river is 10-20 m and the depth of the river is 3-5 m. The shape of the reservoir is slightly rectangular with an average width of 2.7 km. Mountains account for about two thirds in the basin, and the rest is river valley. During the early construction of the reservoir, the forest cover of the reservoir area reduced from 46% to 21%.

Sample collection and processing: In this study, we collected 22 samples at seven sections (Fig. 1). Sediment samples were collected using the bottom sampler (XDB0201), and sediment depth was estimated according to the mud volume and the location of the bottom sampler arrived. After packing seal, samples were taken back for the laboratory testing.

Sample testing: After nature drying, the sediment samples were ground through 0.15 mm sieve, and TN and TP were tested by the adsorption-desorption method which come from "Methods for Agricultural Chemical Analysis of Soils" (Lu 2000).

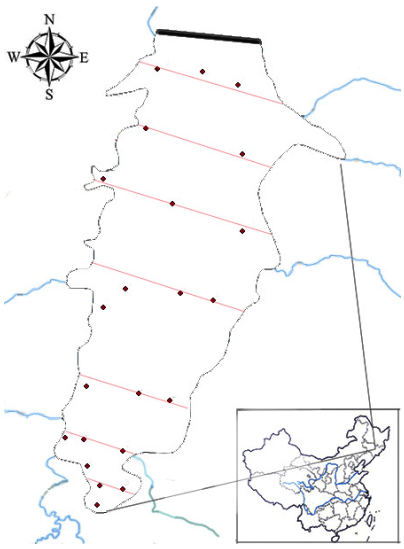

Fig. 1: Schematic diagram of sampling points for sediments in the reservoir.

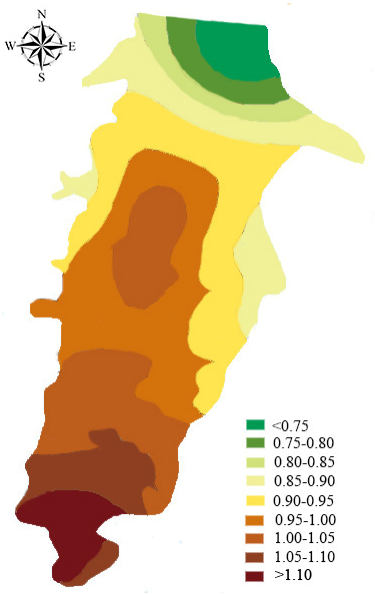

Fig. 2: The sediment thickness profiles in the reservoir.

METHODS AND DISCUSSION

The Spatial Distribution Characteristics of the Sediment

***The distribution of sediment thickness in the reservoir*:** Before Environmental-friendly dredging, sediment exploration must be carried out to learn the distribution and accumulation of sediment in dredging area. Studies have shown that as an information database of the reservoir environment, sedimentary section can reflect the degree of pollution and evolution of a reservoir (Shen 2009). Therefore, the study of sediment distribution and accumulation has great significance for researching endogenous pollution, developing environmental dredging projects and controlling water pollution effectively.

The distribution of sediment is mainly affected by the location of river channels, water currents, river sediment input and so on. According to the distribution data on sediment thickness from each measuring point, the spatial analyst module of GIS is used to carry out the spatial analysis on the reservoir sediment thickness, and draw the reservoir sediment thickness distribution, as shown in Fig. 2.

As can be seen from Fig. 2, the distribution of reservoir sediment is uneven. Sediments mainly concentrated in the middle of the reservoir and southern estuarine areas, which gradually decreased from south to north. The thickness of

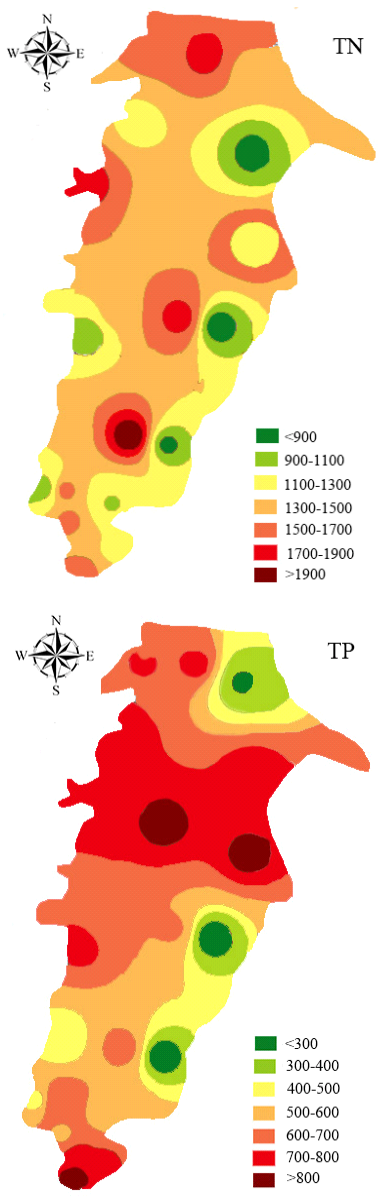

Fig. 3: The spatial distribution of TN and TP.

sediment is more than one meter in 20% of the areas.

***Estimation of sediment volume in the reservoir*:** The sediment volume can be estimated based on Triangulated Irregular Network (TIN) module of GIS. Wet weight, dry weight and thickness of sediment are shown in Table 1.

The Spatial Distribution and Assessment of Nutrient Pollution

***The spatial distribution of nutrients TN and TP*:** Reservoir sediment is an important warehouse of nutrients. A large number of survey data showed that when the injection nutrients reduce, the nutrients in the sediment will be released gradually. In other words, eutrophication can still occur due to the sediment nutrients load, after controlling the external pollution sources, even appears "bloom" (Jin 1992). Therefore, understanding the partial distribution characteristics of sediment nutrients can provide a scientific basis for the environmental dredging project of removing nutrient from polluted sediment, and it is significant for reservoir water environmental governance. The spatial distribution of TN and TP is shown in Fig. 3.

Analysis showed that the TN content of the sediment is 616.7-2010.3 mg/kg, and the average value is 1414.8 mg/kg; TP is 378.2~860.3.44 mg/kg, with an average of 719.4 mg/kg. As can be seen from Fig. 3, the distribution rule of TN and TP in reservoir sediment is similar, and high value area is mainly concentrated in the upper-middle part of the reservoir and estuaries.

***Pollution degree of TN and TP*:** The balance point regression equations of TN and TP were set up by the adsorption-desorption method. The equations are shown as below:

$$\text{TN: } y_1 = 499.65x + 627.6 \quad ...(1)$$

$$\text{TP: } y_2 = 1271.83x + 370.1 \quad ...(2)$$

y_1/y_2: concentration of TN/TP, mg/kg;

x: equilibrium concentration of adsorption-desorption.

Combining the balance point regression equations and the quality standard of surface water, the grading standards of nutrient pollution in the sediment were set up (Table 2).

The Spatial Distribution of the Environmental-Friendly Dredging Range

***Main principle and methods*:** The main purpose of sediment pollution, environmental-friendly dredging project is to decontaminate the contaminated sediment, control endogenous pollution and improve quality of the water environment. Determination of the reservoir dredging range is based on the survey results of sediment. The classification criteria of nutrient pollution are used to conduct a comprehensive assessment of the sediment pollution situation. Finally, environmental dredging range should be determined in the perspective of economic feasibility and engineering safety.

***Determination of indexes and control values*:** According to the survey results of the sediment, the amount of TN and TP are in majority among the reservoir sediments. So the potential ecological risk of TN and TP is to be control indicator of sediment pollution. Meanwhile, sediment thickness is selected to be the basic physical parameter that reflects the sediment accumulation and construction accuracy. The dredging area control values of polluted sediments are given in Table 3.

Fig. 4: Environmental-friendlydredging area.

***Determination of the Environmental-friendly dredging range*:** The sediment dredging areas are determined by controlling indicators of the reservoir sediment dredging. Analyse the amount of TN and TP in reservoir sediment, and then determine the nutrients heavily polluted area where the controlling indicator of TN and TP is exceeding 1627 mg/kg and 625 mg/kg, respectively. The sediment thickness of this area is more than 10 cm; the areas seriously polluted by TN and TP are superimposed by intersect module in GIS; the environmental-friendly dredging area are determined finally, as shown in Fig. 4.

Estimation of the Environmental-Friendly Dredging Depth

After determining the range of the dredging, we determine the depth of dredging as follows:

First, the content of TN and TP in the sediment of each sediment layer was determined to make the depth content characteristics of the nutrients in the sediment (Fig. 5).

Then, adsorption-desorption test of N and P (ENC0 and EPC0) is conducted to understand risks from the release of N and P in sediment of each layer, and find out the sediment layer which has the equilibrium concentration higher than the concentrations in the overlying water (Fig. 6).

Finally, determine the sediment layer which has a high content of N and P and high risk of releasing N and P as dredging layer, the corresponding sediment thickness as dredging depth. Therefore, from the perspective of environmental dredging effects and engineering economic, determine the top of overlayer as dredging layer, and average of 0.5m.

Calculation of the Environmental-Friendly Dredging Volume of Sediments

Table 1: Estimation of sediment thickness, volume and wet/dry weight.

Area /$10^5 m^2$	Thickness /cm	Volume /$10^5 m^3$	Wet weight /$10^5 t$	Dry weight /$10^5 t$
560	95	525	612	200

Table 2: Grade division standards of nutrients in sediment.

	I	II	III	IV	V
TN (mg/kg)	<703	878	1128	1377	>1627
TP (mg/kg)	<383	402	434	497	>625

Table 3: Indexes and control values to identify the environmental dredging area of reservoir sediments.

The types of indexes	Control value
TN (mg/kg)	>1627
TP (mg/kg)	>625
Thickness (cm)	>90

Through the above research, we determine the range and the depth of the environmental-friendly dredging. The volume of environmental-friendly dredging can be derived by the following equation:

$$V = TA \times A \times H = 1.92 \times 10^7 \ m^3 \quad ...(3)$$

V: The volume of Environmental-friendly dredging (m^3);

TA: Total reservoir area (m^2)

A: Rate of dredging area (%)

H: The depth of the dredging (m)

CONCLUSION

The volume of environmental-friendly dredging was determined as follows: (1) the spatial distribution characteristics of sediment and nutrient was investigated in the study area; (2) grade division standards of nutrients was established, referred to the adsorption-desorption method; (3) the high-risk areas of TN and TP in sediment based on the grade division standard was divided; (4) after considering the safety indicators of environmental dredging, the sediment thickness distribution and nutrient distribution were superimposed by using GIS to determine the environmental-friendly dredging area polluted by sediment in the study area; (5) determine the dredging layer; (6) derived the volume of environmental-friendly dredging.

From the study, the conclusions could be obtained as following: (1) the average content of TN and TP in the surface sediments was 1414.8 mg/kg and 719.4 mg/kg, respectively; (2) the distribution rule TN and TP was similar; (3) high value areas mainly concentrated in estuaries and the

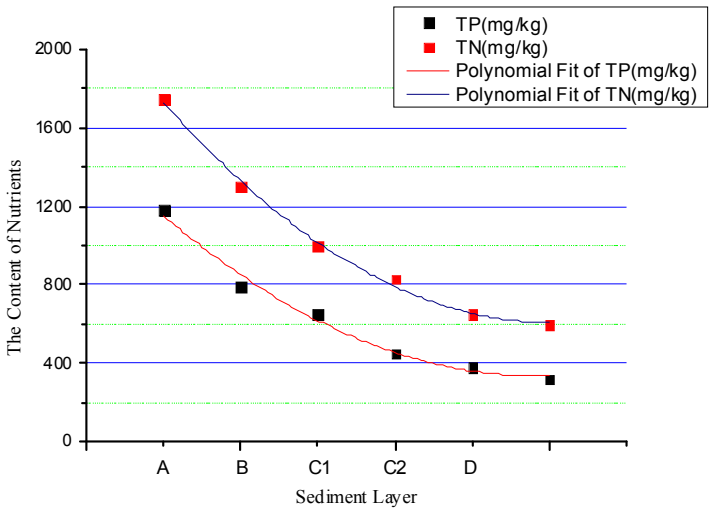

Fig. 5: Vertical distributions ofTN and TP in the sediments (A: suspension layer; B: pollution layer; C1: top of over layer; C2: bottom of over layer; D: normal sediment).

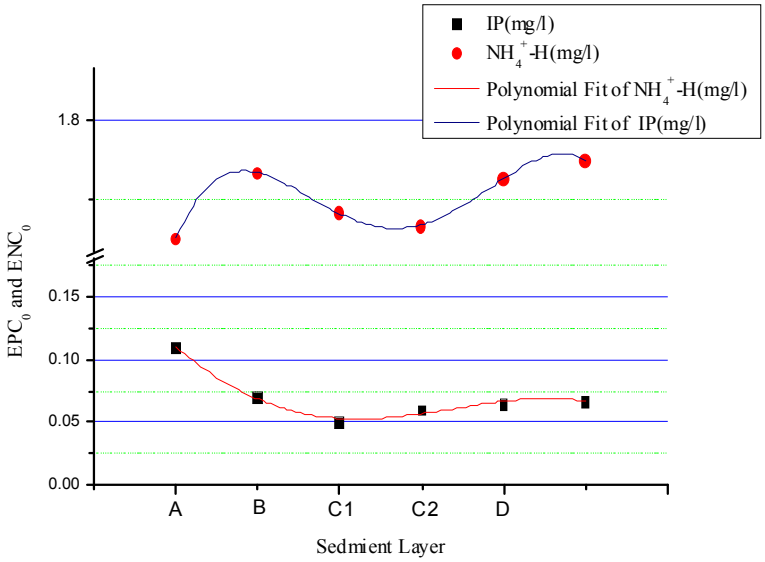

Fig. 6: ENC0 and EPC0 changes in sediments (A: suspension layer; B: pollution layer; C1: top of over layer; C2: bottom of over layer; D: normal sediment).

upper-middle part of reservoir. The results of nutrient pollution grading showed that, 20.4% of the reservoir region was heavily polluted by N and 66.3% by P. Environmental-friendly dredging area accounted for about 68.4% of the total area; (4) determine the top of over layer as dredging layer, and average of 0.5 m; (5) the volume of environmental-friendly dredging is 1.92×10^7 m^3.

ACKNOWLEDGEMENT

This study was sponsored by the Ministry of Water Resources of China; financial support was supplied by a special fund from the Finance Department of Jilin Province (2013-931).

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