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Spatial and temporal relation rule acquisition of eutrophication in Da'ning River based on rough set theory

Hu Yong Yan[a], Xue Rui Zhang[a,1], Jian Hua Dong[a], Ming Sheng Shang[a,1], Kun Shan[a], Di Wu[a], Ye Yuan[a], Xu Wang[a,b], Hui Meng[a], Yu Huang[a], Guo Yin Wang[a,*,1]

[a] Big Data Mining and Applications Center, Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences, Chongqing 400714, China
[b] Chongqing Key Laboratory of Computational Intelligence, Chongqing University of Posts and Telecommunications, Chongqing 400065, China

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ABSTRACT

Since the mechanisms of eutrophication are complicated and many other factors affect these mechanisms, methods such as quantitative statistics and numerical simulation, have their limitations in analyzing the spatiotemporal relations of eutrophication. The rough set theory (RST) was used to describe the spatiotemporal relations of eutrophication in Da'ning River without any of other prior knowledge. Rules of relations in time and space affecting eutrophication in the Da'ning River backwater area were extracted by taking representation of relations in time and space among eutrophication at a long river section of Da'ning River backwater area, by taking nine sets of encrypted monitoring data in 2003 as example, and by making season, area and eutrophication level as the decision attributes, respectively, to represent specific features of the eutrophication phenomenon in the Da'ning River backwater area from the points of view of time, space, and level by analysis of spatiotemporal relationship rules. This study result shows that the temporal and spatial differences between eutrophication phenomena in the long river section of the Da'ning River backwater area are significant. Eutrophication for each section is less serious in autumn, more in spring and most in summer. Eutrophication degree gradually decreases from estuary to upstream, which is in conformity with reality. The RST of eutrophication in Da'ning River may inform environmental decision-makers and assist them in making more cost-effective decisions.

1. Introduction

Eutrophication can be identified as a natural process of enrichment of water with phosphorus and nitrogen that stimulates primary production, leading to enhanced algal growth and sometimes to phytoplankton blooms (Khan and Ansari, 2005). Water eutrophication is one of the most challenging environmental problems in the world. The increasing severity of water eutrophication has attracted more attention from both the governments and the public recently (Yang et al., 2008). Da'ning River, located on the north shore of the Yangtze River, is a typical first grade tributary flowing from the Three-Gorge Reservoir area. After impoundment of the Three-Gorge Reservoir, the changed hydrological conditions produced a large scale eutrophication in Da'ning River (Zheng et al., 2009). The mechanism of eutrophication in Da'ning River is mainly influenced by environmental, ecological factors, and trophic factors (Zhang et al., 2011).

1.1. Environmental factors

Environmental factors related to the physics and chemistry are essential factors for biological production in the water environment ranging from lakes to reservoirs. Water temperature, illumination, pH, dissolved oxygen, transparency, conductivity, organic matter, et al. are the most used environmental factors. (Kong and Gao, 2005). Water temperature and light radiation are the dominant environmental factors for eutrophication. When algae are in photosynthesis, the water temperature decides the reaction rate of intracellular enzymes, the light radiation provides energy for metabolism, and the interaction of both decides the biological productivity levels in lakes and reservoirs. The monitoring data of the Three-Gorges Reservoir area shows that, for most of the months, the temperature for Da'ning River stay in a temperature

* Corresponding author. Tel.: +86 023 6593 5694.
E-mail addresses: yanhuyong@cigit.ac.cn (H.Y. Yan), dongjianhua@cigit.ac.cn (J.H. Dong), shangmingsheng@cigit.ac.cn (M.S. Shang), shankun@cigit.ac.cn (K. Shan), wudi@cigit.ac.cn (D. Wu), yuanye@cigit.ac.cn (Y. Yuan), wangxu@cigit.ac.cn (X. Wang), menghui@cigit.ac.cn (H. Meng), huangyu@cigit.ac.cn (Y. Huang), wanggy@ieee.org (G.Y. Wang).
[1] These authors contributed equally to this work.

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range which is suitable for the growth of algae. Generally, lake water with weak alkalinity is suitable for the growth of algae, and after the survey of the Three-Gorges tributaries, it was found that most of the water is weakly alkaline, and the pH range is suitable for water bloom algae species is 8.0 to 9.0, which provides favorable conditions for the development of the algae in tributaries and the occurrence of eutrophication (Zheng et al., 2009). Dissolved oxygen is an indispensable environmental condition for algae growth and production of biodegradable organic matter. The results showed that the dissolved oxygen saturation in the Three-Gorges Reservoir is mainly affected by the dual influences of water temperature and phytoplankton (Zhang et al., 2010). The establishment of the Three-Gorges Reservoir changes seasonal storage process and makes the waters' limnology characteristics unique, so the transparency changes of Da'ning River have obvious seasonal characteristics. The other related research shows the transparency of Da'ning River is under the dual effects of algae biomass and suspended solids (Zheng et al., 2009).

1.2. Ecological factors

Water ecological factors refer to the ecological conditions of the water itself and aquatic ecosystem structure, which is the inner condition and factor of eutrophication occurrence (Kong and Gao, 2005). Xing, Li and others (Zhong et al., 2004; Li et al., 2005) think that total nitrogen and total phosphorus is the potential cause of eutrophication in the mainstreams and their tributaries for the reservoir, but flow condition changes caused by the water holdup in the reservoir and tributaries is the greatest potential factors. Before the formation of the reservoir, the river water flow rate in the natural river course is faster. At the same time, the depth of water is deeper, and the light energy loss is bigger, which are not suitable for growth of the algae. Both the mainstream and tributaries did not display eutrophication phenomena. After the formation of the reservoir, the water flow condition of tributaries changed greatly, the flow velocity slowed rapidly, resulting in a large amount of sediment deposition. The water transparency increased and the light transmittance was raised, which promoted the photosynthesis of planktonic algae, leading to the growth of algae, and thus providing an environment more conducive to the occurrence of eutrophication. This is the most direct inducing factor of eutrophication (Zeng et al., 2006). At present, many scholars affirm the water flow rate for the tributaries of the Three-Gorges Reservoir is the major cause of eutrophication. They further pointed out that the reservoirs reserve water, and the water velocity of tributaries is slowed down which is convenient for water bloom occurrence (Li et al., 2007); On the other hand, the water in the mainstream and tributaries connecting to reservoir have different chemical and physical properties. The manipulation of reservoir water level creates a frequent communication condition for the reservoir mainstream and its tributaries, and this exchange will, in turn, further change the water physical and chemical properties in the bay, which affects the blooms that occur continuously (Yang et al., 2010). Therefore, studying the relationship between velocity and algae growth is the theoretical foundation to solve the water eutrophication issue. Huang et al., based on field monitoring results, through curve estimation to build a flow velocity and algae growth relationship model, pointed out that the backwater zone velocity and algae growth of Da'ning River have a significant negative correlation relationship, and velocity is the main limiting factor of algae growth (Huang et al., 2006). Long et al. built a two-dimensional unsteady algae growth dynamics model, and pointed out that in the Chongqing section of Jialing River, the left and right side flow velocity was mostly conducive to the growth of algae (Long et al., 2010). In addition to the eutrophication being closely related to the velocity of the reservoir area, volume, water depth, shoreline coefficient, incoming runoff recharge coefficient, water change cycle, the outbound flow, and the velocity variation range of water level are also closely associated with eutrophication (Wagner and Zalewski, 2000).

1.3. Trophic factors

The present survey results of the Three-Gorges mainstream and its tributaries show that the nutrient salt content of the reservoir water has a long history which is close to or more than the nutrient salt level status required for eutrophication to happen and develop (Zhang et al., 2010). In lakes and reservoirs, chlorophyll-a concentration and part of the nutrient salts are significantly positive related to each other. In the Three-Gorges Reservoir, since each tributary is a very complicated water environmental ecology system, though the backwater area of a tributary has various degrees of decline other than the state of the natural river flow velocity, there is exchange between water in the mainstream and tributaries, which is not totally the same situation compared with hydrologic reservoirs and lakes. Therefore, phytoplankton biomass and nutrient content in the Three-Gorges Reservoir have no obvious correlation between each other. Zheng et al., taking the sensitive data of Da'ning River in the bloom period as an example, believe that during the bloom period, the total phosphorus has some relationship with algae growth, while nitrogen pollution mainly comes from external pollution, which has no big relation to algae agglomeration (Zheng et al., 2009). Although the current study results show that the nutrient salt and phytoplankton have no obvious correlation, the nutrient salt is an important material base for phytoplankton to perform photosynthesis, so a sufficient nutrient salt is still a sufficient condition for bloom outbreaks.

Multidisciplinary researchers have performed many studies on different aspects of water eutrophication, such as the Carlson trophic state index (Carlson, 1977), modified Carlson's trophic state index (TSIM) (Aizaki, 1981), trophic state (TRIX) (Vollenweider et al., 1998) eutrophication index (Fertig et al., 2014), and comprehensive nutrition state index (Xu et al., 2012) in the environmental field; neural network (Jiang et al., 2006; Kuo et al., 2007; Melesse et al., 2008), genetic algorithm (Song et al., 2012), and support vector machine (Huo et al., 2014) in the field of informatics, and species diversity index (Spatharis and Tsirtsis, 2013) in the field of ecology. Although many studies are available for water eutrophication analysis, all of these studies have their own limitations. For example, all of these studies need prior knowledge for analysis and demand the dataset to be processed to be confirmed and accurate but in most cases the raw dataset is always filled with noise and not confirmed. It's difficult for these traditional studies to extract useful knowledge from large amounts of raw data which are filled with a lot of noise.

Rough set (RS) theory is a flexible and powerful mathematical tool for uncertainty, vagueness, and imprecision, first proposed by Pawlak (1982). This algorithm extracts predictive and useful knowledge in the form of rules from imprecise data (Wang et al., 2014). RS theory has also been successfully employed in vague and uncertain information problems in many fields and has provided many exciting results, such as financing risk credit evaluation (Lin et al., 2008), analysis of customer complaints (Yang et al., 2007), network security (Wang et al., 2005), location services (Sikder and Gangopadhyay, 2007), learning models for low-level medical data (Brtka et al., 2008), and image segmentation (Fu et al., 2012).

However, until now, the RS theory approach has not been widely applied in water eutrophication, and only a few documents have recorded some preliminary studies on RS applications in water resources and hydrology (Pai and Lee, 2010; Liu et al., 2013; An et al., 2014; Karami et al., 2014; Pai et al., 2014).