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Establishing reference nutrient conditions using improved statistical methods in a river network with typical monsoon climatic pattern

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ABSTRACT

Establishing reference conditions for water quality variables is a critical step towards developing pollutant reduction goals for river pollution control. The term reference condition is used to describe the naturalness condition of the water quality, and helps us identify the best water quality that can be obtainable if human impacts are absolutely controlled. The percentile of reference streams approach (PRSA) and the percentile of general streams approach (PGSA) are two methods recommended by the U.S. Environmental Protection Agency (U.S. EPA) for developing nutrient reference conditions. The PGSA is a surrogate for the PRSA to establish nutrient conditions when reference data are unavailable. Many studies had examined the matching relationship between the PRSA and the PGSA for developing nutrient reference conditions. However, there is little information on whether there were differences on the matching relationships between the PRSA and the PGSA for different nutrients. In addition, it is unknown whether very high seasonal variations in precipitation and river runoff in monsoon climatic region could affect the well-known PRSA-PGSA relationship. In this study, we determined the total nitrogen (TN) and total phosphorus (TP) reference conditions in the dry and rainy seasons using the PRSA, the PGSA and regression approach based on hydro-chemical data in the Luan River with typical monsoon climatic pattern during 2006–2013. The results showed that the matching relationships between the PRSA and the PGSA were different for TN and TP, and were consistent in dry and rainy seasons. The regression approach results verified the different matching relationships. The reference nutrient concentrations established by the three methods all had seasonal variations. The recommended reference concentrations of the Luan River for TN were 1.642 mg/L and 1.297 mg/L respectively in dry and rainy season, while the reference concentrations for TP were 0.041 mg/L and 0.049 mg/L, respectively. These results imply that a few reference sites should be located to develop the reference-to-general river sites relationship for different nutrient species, and the seasonal variation of the reference nutrient concentrations should be considered for better water quality management.

1. Introduction

Eutrophication caused by nutrients remains the greatest stressor affecting water ecosystems worldwide (Baulch, 2013). The loading of nutrients into the world's water bodies is strongly affected by human activities, such as land use, the population densities of human and livestock (Smith et al., 1999; Woodward et al., 2012). The term reference condition is used to describe the naturalness condition of the water quality, and help us identify the best water quality that can be obtainable if human impacts are absolutely controlled (Cunha et al., 2011). Therefore, establishing reference conditions is one of the key issues of pollution control (Dodds and Oakes, 2004; Herlihy and Sifneos, 2008; McDowell et al., 2013).

Several approaches have been suggested to estimate the reference conditions of streams including: (1) the percentile of reference streams approach (PRSA) (USEPA, 2000b); (2) the percentile of general streams approach (PGSA) (USEPA, 2000b); (3) multiple linear regression approach (MLRA) (Dodds and Oakes, 2004); (4) watershed modelling approach (Makarewicz et al., 2015). The MLRA incorporates the effect of human activities in measured local nutrient concentrations, and therefore the reasonable historical nutrient concentrations could be obtained (Dodds and Oakes, 2004). This method would be most useful where there are few to no minimally human-affected sites, such as urban or heavy agricultural areas. Another advantage of the method is

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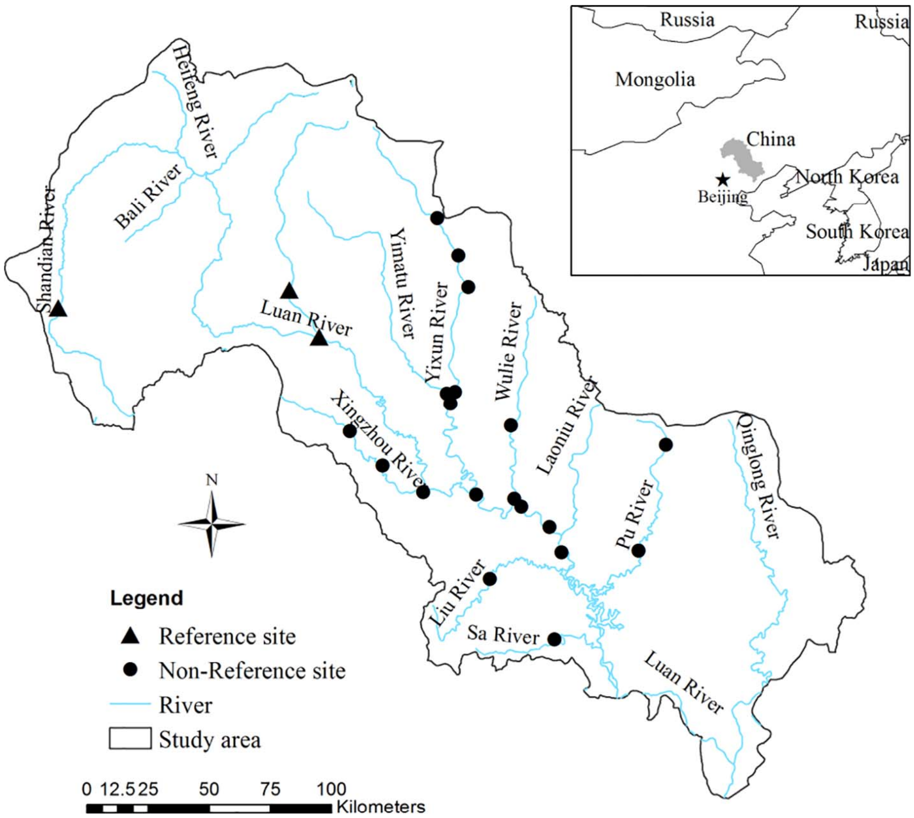

Fig. 1. Location of the study area and water quality monitoring sites.

that it can help us identify the main anthropogenic factors impacting nutrient concentrations (Chen and Lu, 2014). The drawback of the method is that the accuracy of the regression approach is low in regions where there is an absence of a strong anthropogenic nutrient gradient (Herlihy et al., 2013). The watershed model approach can predict the reference conditions by removing the anthropogenic impacted land use (Makarewicz et al., 2015). The watershed models are an effective tool in determining reference conditions for both small streams and large rivers. However, using watershed models such as the soil and water assessment tool (SWAT) in many regions has many limitations because of data shortage problems, and the reliability is probably low (Ongley et al., 2010).

The PRSA and the PGSA are two methods recommended by the U.S. Environmental Protection Agency (U.S. EPA) to States and Tribes for developing nutrient reference conditions. The percentile used in the PRSA is the 75th, and the percentile used in the PGSA ranges from the 5th to the 25th percentile, but the 25th is typically selected. The U.S. EPA suggested that the results from the two percentile approaches were similar (USEPA, 2000b). Among these two percentile approaches, the PRSA is preferred, but reference sites are rare in most agricultural regions (Smith et al., 2003). The PGSA, which always select the 25th percentile, is a surrogate for the PRSA to establish nutrient conditions when reference data are unavailable (Suplee et al., 2007). However, some studies indicated the differences of reference values were evident obtained from the 75th PRSA and the 25th PGSA (Evanswhite et al., 2013). The reliability of the 25th PGSA mainly relies upon the degree of eutrophication (Dodds and Oakes, 2004; Smith et al., 2003). In regions that are highly eutrophied, using the 25th percentile can establish artificially large values for nutrient criteria and cannot protect water quality. If the eutrophication in regions has not reach a substantial degree, the results established by the 25th PGSA would yield overly rigorous criteria (Suplee et al., 2007). In previous studies, the same 25th percentile of the general river sites was always used for TN and TP. However, degrees of disturbance caused by anthropogenic activities for TN and TP may be different in the same area, because there are many differences in sources and delivery mechanisms between TN and TP (Alexander et al., 2007). For example, Smith et al. (2003) found that the current TN and TP concentrations of streams and rivers in USA exceed natural background conditions by factors of 6.4 and 2.0, respectively. However, there is little information on whether there were differences on the matching relationships between the PRSA and the PGSA for different nutrient species, such as TN and TP.

It has been widely accepted that reference nutrient conditions would have differences in different regions, due to many natural factors, such as geology, climate, soils and watershed area, have effects on nutrient concentrations (Sanchez-Montoya et al., 2012; Suplee et al., 2007). The monsoon climate regions present a marked seasonal pattern in precipitation, and more than 60% of annual precipitation occurs during the rainy season (from June to September) (Du et al., 2014b). Due to the seasonality of precipitation, the hydrological and geochemical processes of monsoon rivers usually show distinct differences (Liu and Xia, 2004), which could affect reference nutrient conditions. However, there are few studies on the effect of monsoon climate on reference nutrient conditions and the matching relationships between the two percentile approaches.

In this study, the PRSA, the PGSA and the MLRA were applied to establish reference nutrient conditions for the Luan River, which is a typical monsoon climate river in northern China (Hao et al., 2016). The MLRA not only can verify the results from the two percentile approaches, but also can identify the most important anthropogenic activities influencing the water quality in the Luan River. The main research questions addressed in this study include: (1) Is there a difference in the PRSA and the PGSA matching relationship between TN and TP to establish reference conditions? (2) How does the monsoon climate influence the matching relationship between the PRSA and the PGSA? (3) Is there a seasonal variation in the reference conditions of TN and TP in the monsoon rivers?