Research article

Customizing the coefficients of urban domestic pollutant discharge and their driving mechanisms: Evidence from the Taihu Basin, China

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ABSTRACT

Discharge of urban domestic pollution has risen sharply during China's extensive urbanization. Together with understanding the complexity of influencing factors underpinning this rise, it has become a pressing issue to estimate total discharge and illustrate its driving mechanism scientifically. This paper reports on the monitoring of discharge from 36 sampling sites in selected residential districts in the heavily polluted Taihu Basin, China. The data were used to estimate the total amount of discharge, to develop corresponding urban domestic pollutant discharge coefficients and to analyse associated spatial patterns. Data from a questionnaire survey of over 1000 households in downtown, suburb and market town areas were then used to apply an econometric model in order to distinguish driving mechanisms. The urban domestic pollutant discharge coefficients developed in this paper are generally smaller than those reported nationally for China, based on more generalised data, decaying from city centres to the urban periphery. This study quantifies the amount of discharge and also demonstrates that urban domestic pollutant discharge is driven by multiple factors. For example, urban domestic pollution discharge rates were positively correlated with income and female-dominated households also tend to discharge more wastewater. Other factors were found to have negative correlations, such as sewage treatment rates, awareness of environmental protection, age and degree of education. As well as providing new and refined data on urban pollution discharge characteristics, the research in this paper also demonstrates the utility of combining household questionnaire and sample monitoring data in order to yield greater insights into the causes of typical polluting behaviour in Chinese neighbourhoods.

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1. Introduction

Already the most populous country in the world, China has experienced extremely rapid urbanization since the late 1970s. The proportion of China's population classified as being urban grew from 17.9% in 1978 to 56.1% in 2015.[1] During this process, many aspects of the quality of human life have been dramatically improved. However it is true that many of the environmental problems that have haunted developed countries in different phases of their 100-year-long industrialization have also been occurring in China.[2] As a result, the conflict between the environment and development is becoming ever more prominent (Sun et al., 2013). The shortage of resources, a fragile ecological environment and insufficient environmental capacity are becoming critical problems hindering China's development (Sun et al., 2012). To make matters worse, the environments surrounding urban areas have already been seriously degraded (Liu et al., 2011). Under China's new urbanization strategies, the government attaches great importance to environmental protection and uses the environmental quality of urban areas as the most important indicator of regional sustainable development. However, despite continuous improvement, urban environmental problems still exist. Urban domestic water pollution is one such environmental problem. The total discharge of urban domestic pollution has risen sharply over recent years. Therefore, tackling urban domestic pollution has become a top priority to improve urban environmental quality. Important drivers of increasing pollution include the lack of sewage treatment facilities and the low efficiencies of existing facilities. Indeed, in some areas, these have become the most important

reasons why urban domestic pollution has shown such remarkable growth and explain why this source of pollution has gradually reached and exceeded industrial pollution to become the largest source of environmental pollution in China (Zhao et al., 2010). Calculating the rate of urban domestic pollutant discharge and distinguishing influence factors are prerequisites for reducing pollution (Sun et al., 2012). Due to the complexity and special nature of this form of pollution, a series of related studies for a particular area are required to generate a full picture of interconnections. Unfortunately, few such studies exist in the academic literature for highly polluted areas of China. The research presented in this paper addresses some of this gap. The empirical findings help to provide an important theoretical basis for the reduction and control of urban domestic pollution and help to shape future research efforts into this important problem.

At present, the discharge of domestic pollution from urban residents is mainly estimated using one of two approaches (Keyse et al., 2010). The first approach is the aggregate monitoring method, and the second approach is the pollution generation and emission coefficient method. The aggregate monitoring method has the benefit of producing actual discharge values for sources instantly, but it cannot easily take into account the discharge of all municipal points directly since it requires the input of considerable human and material resources (Wang, 2011). Therefore, the pollution generation and emission coefficient method was established by China's first general investigation on nationwide pollution sources in 2007. Considering geographical environmental factors, the urban economic level, climate characteristics, living habits and urban residential consumption levels, it developed a series of coefficients for different type of areas. A limitation of the method is that it ignored the differences in residential characteristics and the weakening function of the urban municipal sewage pipeline network (Zhang et al., 2013). In addition, emissions of urban domestic pollution are also affected by a variety of other factors, such as water consumption, sewage treatment and population characteristics (Fan and Liao, 2010; Zhao et al., 2015). Furthermore, exogenous forces, including the economic development level, urbanization rate and awareness of environmental protection, have also had an effect (Liu et al., 2011; Tsuzuki, 2009). Even sanitation, the water supply system, family size and structure, and living facilities may affect wastewater generation, including both the flow quantity and quality (Cao et al., 2009; Xu et al., 2010). The various factors are complex and interconnected, therefore scientific techniques are needed to make the driving mechanisms clear. Quantitative secondary data analyses, such as partial correlation, multiple linear regression and input-output (Yang and Wang, 2014; Wang, 2011), are widely applied to assess the influence of specific local factors and discharge rates. However, primary data, such as from questionnaires and interviews, are seldom used in such assessments due to their high costs. Most previous research has been limited to single-factor micro-scale analyses and has seldom involved measuring the discharge of key pollutants. Furthermore, researchers have still rarely touched upon the comprehensive driving mechanisms for the discharge of urban domestic pollution in the context of Chinese urban areas.

The Taihu Lake Basin is the most developed area in China. Recently, the area has been at the forefront of China's urbanization process (Su et al., 2010), while at the same time, it is also one of the areas suffering the heaviest water pollution. River inflows are the main source of pollutants to the lake watershed, connecting China's third largest freshwater lake to the rapidly developing urban areas surrounding it (Zhao et al., 2012). The government has constantly improved the treatment of urban domestic sewage and strengthened the urban sewage treatment system. Nevertheless, sewage collection rates and treatment levels are both still relatively low. As

a result, water quality in this area is poor and this is having a detrimental effect on lacustrine and riverine ecosystems (Stone, 2011). Since 2007, around half of all urban domestic pollution discharge has been found to comprise of Chemical Oxygen Demand (COD), ammonia nitrogen (NH_4-N), total phosphorus (TP) and total nitrogen (TN) (Zhao et al., 2012). There is evidence that urban domestic pollution has become one of the main reasons for the heavy pollution of rivers, lakes and reservoirs in the basin at present (Cui et al., 2010). However, there has been little systematic research on rates of pollutant discharge in the area and this inhibits effective environmental management. In this paper, we provide a contribution to this missing knowledge by analysing contributing factors developed from an analysis of sample monitoring and a residential questionnaire survey.

2. Materials and methods

2.1. Study area

The study area is located in the western Taihu Lake Basin, China. It is recognised as being a heavily polluted area because pollutant discharges from the increasingly urban areas in the basin flow into local rivers which in turn flow into Taihu Lake (Zhao et al., 2013a,b). The study area covers parts of two prefecture-level cities, Changzhou and Wuxi. Changzhou includes 5 districts, Xinbei, Zhonglou, Tianning, Qishuyan and Wujin, and Wuxi covers 6 districts and one county-level city, namely, Huishan, Beitang, Chong'an, Nanchang, New District, Binhu and Yixing, respectively (Fig. 1). The total area is approximately 5271.6 km^2, accounting for 14.3% of the whole Taihu Lake Basin (36895 km^2). In recent years, but especially after 2000, the heavily polluted area began a rapid development phase with an annual GDP increase of 20.0%; that is, its gross domestic product (GDP) grew from an equivalent of 1.63×10^{10} in 2000 to $ 88.4 \times 10^{10}$ in 2013. Moreover, in 2013, there were 6.76×10^6 inhabitants and the population density was 1283 persons/km^2, approximately 9 times the Chinese average (143 persons/km^2). The wastewater discharge per square kilometre was 15.1×10^4 t, 20.7 times than that of China's average rate of 0.73×10^4 t. The study area is covered by a dense water network. Pollution from 14 major rivers enters the lake and accounts for more than 80% of the pollution load of Taihu Lake (Zhao et al., 2013a,b). The watershed of these major rivers in the Taihu Lake Basin is taken as being typically representative of other areas affected by water pollution in the region.

2.2. Methods

Considering the large study area and differences in social and economic characteristics within it, the study area was divided into three zones, namely, downtown areas, suburbs and market towns. Furthermore, residential districts were selected according to differences in factors which include location, construction date and sewage treatment facilities. On this basis, the research developed a set of discharge coefficients for urban residents' domestic pollution discharge. These data were subsequently analysed to determine the driving mechanism for differences through the use of sample monitoring, a questionnaire survey and an econometric model.

2.2.1. Discharge coefficient investigation and monitoring

2.2.1.1. Sample selection.
In this study, urban domestic pollution is taken to include sewage pollution and other pollutants directly resulting from urban residents' daily lives. It excludes pollution generated from the hotel and restaurants, hospitals, residents' services and other service industries. Therefore, residential districts are the main cause of pollution discharge and are also the main