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Spatial-temporal patterns and driving factors for industrial wastewater emission in China

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China's extraordinary economic growth, industrialization and urbanization coupled with inadequate investment in basic water supply and treatment infrastructures, have resulted in increasing industrial water pollution. However, due to imbalanced development, industrial wastewater emissions present significant regional disparity. Industrial wastewater management disparity requires more in-depth study on both spatial and temporal patterns across different regions for identification of appropriate and effective mitigation policies while considering practical and localized realities. This paper addresses this issue and contributes to new knowledge by analyzing the spatial-temporal characteristics and driving forces of industrial wastewater emission variations in China's 31 provinces during the years 1995–2010. Using the Logarithmic Mean Divisia Index (LMDI) method, the results show that economic factors are the main driving factors of industrial wastewater emission changes in all provinces during the study period. It is also found that technology improvement considerably offsets emission increases. Using these research findings, both general and specific measures for controlling industrial wastewater emissions are offered so that the overall industrial water efficiency can be improved, in China and potentially elsewhere.

1. Introduction

With globally increasing population, urbanization and industrialization, wastewater emissions have become a major environmental concern (Kundzewicz et al., 2008). These wastewater emissions contain high levels of heavy metals, organic compounds and pathogens (Shannon et al., 2008). The rapid urbanization in developing countries has further exacerbated negative health and environmental consequences (Wu et al., 2011).

As the largest developing country China faces serious water shortages and pollution issues (Geng et al., 2007). 45% of China's major rivers have become seriously polluted in the past couple decades, resulting in over half of China's 1.3 billion people consuming water contaminated with chemical and biological wastes such as petroleum, ammonia, nitrogen, volatile phenols, and mercury (Ministry of Environmental Protection, 2009). Nearly 700 million people continue to consume water containing excessive amounts of the e-coli bacterium. It is estimated that 180 million people drink water with a variety of organic pollutants (Feng et al., 2008).

Evidence has been found that increasing industrial wastewater emission is the main culprit of much of China's water pollution (Kendy et al., 2004). Total wastewater emission reached 58.9 billion tons in 2010, about 175% more than in 1990. Over 40% of this emission emanated from industrial sources (National Bureau of Statistics of China).

Fig. 1 depicts the detailed industrial wastewater emissions at provincial levels during 1995–2010. It is clear that the total amounts of industrial wastewater emissions in eastern regions (such as Jiangsu, Zhejiang, Shandong and Guangdong provinces) are much larger than those in western China (such as Tibet, Qinghai and Xinjiang). This regional disparity requires more detailed study and analysis, especially identifying the factors driving this industrial wastewater discharge.

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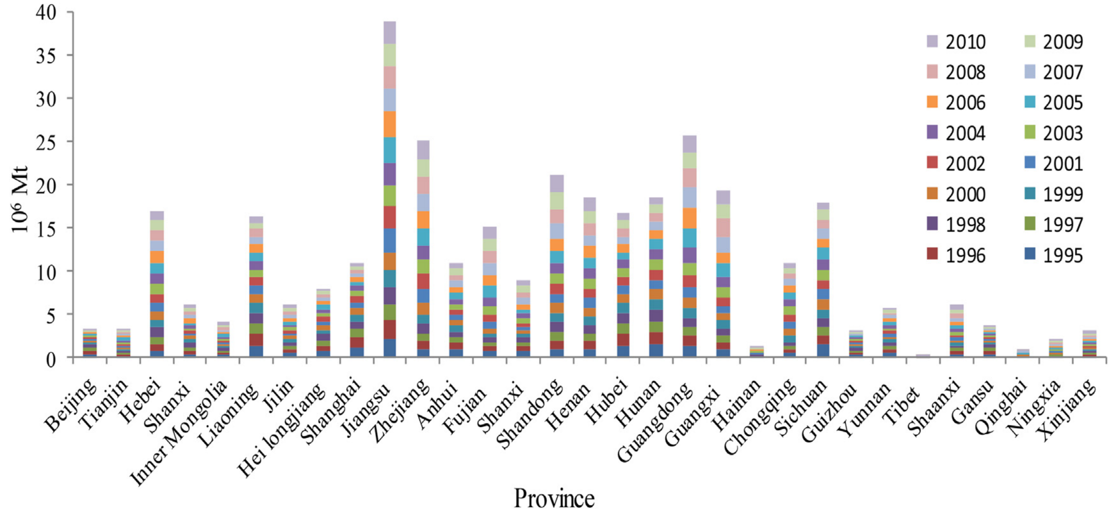

Fig. 1. Total amount of the industrial wastewater discharge at provincial level during 1995–2010 (MEP and NBSC, 1996–2011).

Studies on wastewater problems have traditionally been conducted from hydrological (Duarte et al., 2002), chemical (Mendas et al., 2008) and physical perspectives (Jia et al., 2012), mainly focusing on the supply side of water resources and water quality (Cochran and Logue, 2011). However, few studies have sought to identify the antecedent factors of industrial wastewater discharge, especially in developing countries. Studies on antecedent factors can help decision-makers develop more effective policies for controlling industrial wastewater emissions, especially in situations where regional disparities exist. These disparities point to challenges that may be unique to different regions. Hence, this study contributes to this body of knowledge by identifying antecedent factors contributing to China's wastewater emissions and their regional variations and disparities.

To meet the objectives of this study we first present our methodology, including research method, data sources and treatment details. We then present our research outcomes and provide an in-depth analysis on four specific regions. Finally, we clarify policy implications so as to provide appropriate mitigation policies that can be prepared by considering the regional (spatial) disparities.

2. Research method

2.1. Decomposition analysis

Decomposition analysis is a useful method for identifying key sustainable development driving factors (Ang, 1994; Shao et al., 2014). This methodology has been widely employed within China, for example to identify key factors for regional sustainable development (Geng et al., 2011). Decomposition analysis has also been successfully applied to identifying key driving forces on energy-related greenhouse gas (GHG) emissions in Chinese mega cities (Liu et al., 2012a), and uncovering China's GHG emissions from regional and sectoral perspectives (Liu et al., 2012b).

There are two typical decomposition analysis methods, namely, the index decomposition analysis (IDA) method and the structural decomposition analysis (SDA) method. IDA method uses index number concept in decomposition analysis and has advantages in temporal analysis due to its adaptability and simplicity (Liu et al., 2012a), while SDA method has its advantages in analyzing detailed industrial sectoral emissions but requires the complete input–output table (Diakoulaki et al., 2006). Due to a lack of a complete input–output table, IDA was selected for this study. Among various IDA approaches, the logarithmic mean divisa index (LMDI) approach has become the most popular one due to its path independency, consistency in aggregation and easily interpreted results (Ang, 1994). Another advantage of this approach is that it can absolutely eliminate residuals and tackle the zero value issue that conventional IDA methods are facing (Ang, 2004). It cannot only undertake multiplicative decomposition and chain development index analysis which cannot be achieved by Laspeyres index decomposition method, but also conduct continuous-time link relative analysis which cannot be achieved by structural decomposition analysis due to the limitation of the input–output table (Ang, 2004). For instance, a practical LMDI application was conducted for investigating Canada's industrial energy consumption and CO_2 emissions (Ang, 2005). Consequently, given these advantages, the LMDI approach was selected in this study in order to identify the antecedent factors influencing China's industrial wastewater emissions.

In order to observe spatial patterns of industrial wastewater emissions, a GIS (Geographical Information System)-based database was established. GIS is especially adept at forming a spatial database for regional industrial wastewater discharge, identifying the current distribution, the amounts, densities, and historical (temporal) changes of industrial wastewater discharge, serving as a powerful decision and policy tool to effectively manage industrial wastewater. In order to observe temporal patterns of industrial wastewater discharge, time series decomposition analysis was conducted. The original application of time series decomposition analysis can be traced to the early 1990s (Ang and Lee, 1994), in which decomposition analysis was completed between year t and $t+1$ (here t varies from the first year to the last year of the study period). Most previous studies undertook their temporal analysis by using a period-wise approach and comparing indices between the first and the last year of a given period. However, results of a period-wise decomposition analysis are sensitive to the choices of the baseline year and the final year. This approach is often unable to uncover detailed evolutionary effects of the decomposed factors over the whole study period (Liu et al., 2012a). The LMDI approach can be applied in both a period-wise and a time series manner. Therefore, LMDI's flexibility makes it suitable to conduct a comprehensive time series analysis and can provide a holistic picture of China's industrial wastewater emissions.

Referring the previous LMDI approach (Ang, 2005), total industrial wastewater discharge can be expressed by the following Equation (1):