Original Research Article

An HP filter-based study on water pollution in the Shandong section of the Yellow River Basin

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Abstract: This study analyzes economic and environmental pollution data from 2002 to 2022 in the Shandong section of the Yellow River Basin using the Hodrick-Prescott (HP) filter method. It decomposes regional GDP and chemical oxygen demand (COD) emissions into long-term trends and short-term fluctuations, aiming to explore the synergistic mechanism between economic development and water pollution control. The results show that Shandong's secondary industry has long dominated economic growth (peaking at 49.9% of GDP in 2006), but industrialization has exacerbated ecological pressure (Yellow River water accounts for 31.56% of the province's total supply). Through policy regulation (e. g., closure of high-pollution enterprises, wetland restoration), COD emissions decreased by 33.45% compared to 2015, although structural pollution remains. HP filtering reveals a three-phase pattern in the COD/GDP ratio: 2002–2010 (declining with volatility due to initial industrial adjustments and environmental policies), 2010–2015 (slower decline due to cross-provincial pollution and governance bottlenecks), and 2015–2022 (stabilization driven by intensified measures such as the "Water Ten Plan"). The study suggests promoting industrial upgrading (e. g., high-end manufacturing), establishing ecological compensation mechanisms (e. g., inter-provincial "gambling agreements"), and differentiated supervision (e. g., targeting high-risk areas like Dezhou) to achieve dynamic balance between environment and economy. This provides policy references for ecological protection and high-quality development in the Yellow River Basin.

Keywords: *Shandong section of the Yellow River Basin; Chemical oxygen demand (COD); Gross domestic product (GDP)*

1. Introduction

From 2000 to 2022, Shandong Province underwent rapid economic development and significant transformation in societal production and lifestyle. The secondary industry, led by manufacturing, has been the core driver of regional economic growth. According to the Shandong Statistical Yearbook, the secondary industry consistently accounted for over 30% of GDP, surpassing 40% between 2000 and 2013 and reaching a peak of 49.9% in 2006. Its contribution to economic growth exceeded 50% during 2000–2014 and remained stable at around 30% after 2015.

However, accelerated industrialization has severely disrupted the ecological system of the Yellow River Basin, leading to growing issues such as water pollution and ecological degradation. As a critical water source for Shandong Province, the Yellow River supplied 7.051 billion cubic meters of water in 2023, including 1.604 billion cubic meters of direct supply and 5.447 billion cubic meters of strategic transfers via inter-basin projects, accounting for 31.56% of the province's total water supply. This vital water system, flowing through nine prefecture-level cities and nourishing 25 counties, is essential for industrial, agricultural, and residential water needs. Thus, the ecological quality of the basin directly affects the province's economic and social development.

Exploring the relationship between economic development and pollution control in the basin is therefore crucial. Since 2000, Shandong has promoted rigid water resource management and pollution control through frameworks such as the Water Pollution Prevention and Control Ordinance. By 2022, wastewater discharge had dropped by 33.45% compared to 2015. Yet, structural pollution persists, and pollutants like COD remain tightly coupled with industrial distribution. It is necessary to further align environmental governance with the region's growth model.

This study employs HP filtering to decompose the trends and fluctuations of GDP and COD emissions from 2002 to 2022, aiming to reveal the multi-scale coordination mechanisms and policy responses. It also identifies the long-term impacts of industrial restructuring and technological innovation on environmental-economic systems, avoiding causality bias from traditional regression due to time series mixing. The study provides empirical support for coordinated ecological protection and high-quality development in the Yellow River Basin under the dual-carbon goal.

2. Literature review in recent years

with China's rapid economic development, water environmental issues have drawn increasing public attention. Scholars have deepened their research into the relationship between water pollution and economic development using multidimensional indicators.

The Environmental Kuznets Curve (EKC)[1] is widely used in this context[2]. Many studies, including those by Lu Ning et al., find a U-shaped relationship between COD or ammonia nitrogen emissions and per capita GDP[3]. However, the EKC's shape is influenced by both pollutant selection and econometric methods, with different pollutants displaying varied patterns, such as U-shaped, N-shaped, or inverted N-shaped curves[4].

As for methodologies, HP filtering is widely used to separate long-term trends and short-term cycles in economic indicators. The method, introduced by Hodrick and Prescott[5] and later improved by Ravn and Uhlig[7], is especially applicable to quarterly data. Domestic studies mostly apply HP filters to single economic variables, such as estimating potential growth rates[8], GDP output gaps in Shandong[9], or tax-GDP cointegration analysis[10]. However, its application to environmental-economic synchronization remains rare, particularly in complex inter-provincial systems like the Yellow River Basin.

3. Short-term fluctuation analysis of water pollution control and GDP in the Shandong section of the Yellow River

3.1. Data processing

To study the relationship between water pollution control and GDP fluctuation, we introduce COD as a key indicator. We collected annual GDP and COD data from cities in the Shandong section of the Yellow River from 2002 to 2022 and applied HP filtering for analysis.

3.2. HP Filter technique

The GDP and COD series contain both trend and cyclical components. Direct analysis of short-term fluctuations would be influenced by long-term trends. HP filtering addresses this issue by decomposing the time series $\{Y_t\}$ into trend $\{Y^c{}_t\}$ and cyclical $\{Y^T{}_t\}$ components[11]:

$$\{Y_t\}=\{Y^c{}_t\}+\{Y^T{}_t\}$$

HP filtering minimizes the variance of $\{Y_t\}$ under second-order difference smoothing of $\{Y^T{}_t\}$. The smoothing parameter λ is generally set to 1600 for quarterly data.

Using this method, we extracted the cyclical components of GDP and COD for 2002–2022. The analysis results are shown in **Figure 1**.

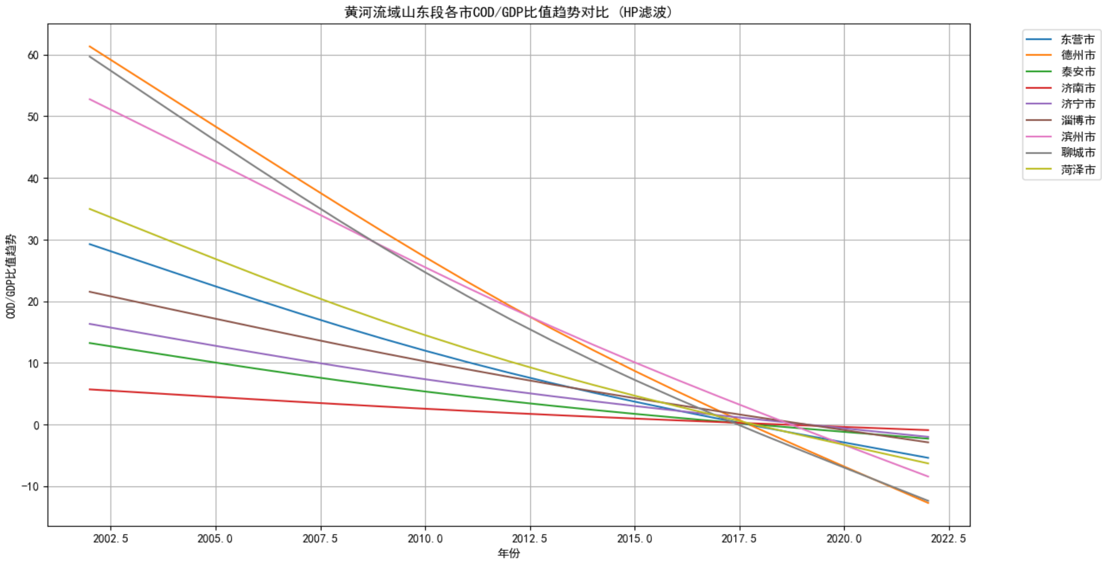

Figure 1. Fluctuations in COD/GDP ratio for cities in the Shandong section of the Yellow River.

The overall trend is downward. The figure is divided into three stages for analysis:

Early Fluctuation Stage (2002–2010): The COD/GDP ratio declined with volatility, suggesting unstable relationships between GDP and COD emissions. This may be attributed to industrial restructuring and early environmental policies, such as the closure of over 1,000 high-pollution enterprises (e. g., in Zibo and Binzhou) between 2006 and 2015, and the implementation of pollutant control standards for COD and ammonia nitrogen.

Mid Fluctuation Stage (2010–2015): The ratio declined at a slower rate. New wastewater treatment methods were implemented (e. g., constructed wetlands in Dongying from 2012), and over 100,000 mu of wetlands were restored by 2015. However, non-point agricultural pollution and cross-provincial pollution (e. g., at the Henan-Shandong border) remained challenges.

Recent Fluctuation Stage (2015–2022): Fluctuations stabilized across cities, reflecting the impact of the “13th Five-Year Plan” and intensified environmental regulations (e. g., “Water Ten Plan”). Although the COVID-19 pandemic slowed GDP growth, the overall COD/GDP ratio remained stable or declined.

4. Policy recommendations

(1)Promote high-end manufacturing and IT industries in economically advanced cities like Jinan and Dongying to reduce COD intensity per GDP. Restrict new high-pollution projects in cities with high COD/GDP ratios (e. g., Dezhou, Liaocheng, Binzhou), and support technological upgrades in existing enterprises.

(2)Impose ecological compensation fees on upstream polluting cities (e. g., Liaocheng, Dezhou) to fund downstream restoration efforts (e. g., Dongying, Binzhou). Establish inter-provincial water quality assessment mechanisms (e. g., Shandong and Henan signed “gambling agreements” in 2021 and 2024).

(3)A systematic strategy combining industrial restructuring, strict supervision, and ecological compensation can shift the Shandong section of the Yellow River Basin from end-of-pipe treatment to source prevention. Focus should be placed on historically high-pollution areas while avoiding one-size-fits-all policies to balance environment and economic development.

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