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Structural Shift in Water Pollution Sources in China: A Provincial Comparative Study of Agricultural and Domestic Contributions

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Abstract. Industrialization has long been regarded as the dominant driver of water pollution in China. However, the 2024 national pollution-source statistical survey shows that the industrial share of total chemical oxygen demand (COD) and ammonia nitrogen (NH3-N) discharge has fallen to about 1%, leaving agricultural and domestic sources as the absolute majority. Using these data, this paper quantifies provincial variations in the contributions of COD, NH_3-N, TN, and TP from the agricultural and domestic sectors. In 2024, agricultural sources contributed 67.5% of national COD discharge, and domestic sources contributed 71.3% of NH3-N discharge. Between 2022 and 2024, domestic NH_3-N emissions surged by 43.8%, increasing their national share from 64.0% to 71.3%. Provinces reliant on agriculture (e.g., Hunan and Henan) exhibit elevated TN and TP loads, whereas highly urbanized provinces (e.g., Guangdong and Jiangsu) are dominated by domestic NH_3-N and COD. Key constraints include diffuse non-point pollution, lagging urban sewer infrastructure, and spatially mismatched governance investments. Targeted strategies—ranging from nutrient management to interregional ecological compensation—are proposed to optimize environmental fiscal allocations.

Keywords: Non-point Source Pollution, Domestic Wastewater, Source Apportionment, Provincial Heterogeneity, Ecological Compensation

1. Introduction

1.1. Research background

Water quality is a direct indicator of achievements in the construction of ecological civilization and a core indicator of regional sustainable development. For a long historical period, industrial wastewater was widely regarded as the primary source of surface-water pollution in China, and environmental governance focused heavily on end-of-pipe control of industrial point sources. Policies such as industrial discharge permits, total emissions control, and compliance requirements formed the backbone of past water pollution management. After more than two decades of intensive governance, industrial pollution has been significantly reduced. According to the 2024 national pollution source survey from the Ministry of Ecology and Environment, the contributions of

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industrial sources to COD and NH_3-N emissions were 1.1% and 0.9%, respectively, indicating that industrial pollution has been removed as a direct threat to water. This marked the completion of the industrial-centered pollution-control paradigm.

In contrast, agricultural and domestic sources have become the dominant contributors. In 2024, agricultural sources emitted 18.896 million tons of COD (67.5% of the national total), while domestic sources emitted 755,000 tons of NH_3-N (71.3% of the national total). Agricultural pollution mainly comes from livestock manure and fertilizer runoff, while domestic pollution grows with urban population concentration and the expansion of service industries. This structural shift means the core challenge of water-pollution control has moved from industrial to agricultural and urban sewer-system upgrades. Agricultural pollution is dispersed and random, making it difficult to collect through traditional facilities; domestic wastewater can be centrally treated, but its rapid increase demands higher treatment capacity. The two pollution sources differ fundamentally in mechanisms, spatial distribution, and governance pathways.

Against this background, clarifying the differences in contributions between agricultural and domestic sources across provinces and identifying hidden pollution drivers are crucial for reallocating environmental funds and designing region-specific policies. Such differentiation enables precise targeting of high-burden regions and reconciles pollution mitigation with food-security imperatives.

1.2. Literature review

Existing research has accumulated substantial findings on agricultural pollution mechanisms and domestic wastewater treatment. Prior studies identify fertilizer runoff and livestock waste as primary agricultural drivers of eutrophication and demonstrate that urbanization restructures nutrient fluxes by concentrating urban emissions while scaling up rural farming operations [1-3]. Decomposition analyses further confirm the divergent trajectories of industrial decline and domestic sewage growth across China [4]. Collectively, these advances inform the structural decomposition and multi-provincial comparative design adopted herein.

Existing research still has significant shortcomings in two areas. First, most studies focus on technologies for controlling industrial pollution or agricultural simulations within specific basins or provinces. Nationwide comparisons of agricultural and domestic source contributions are scarce, especially analyses that classify provinces by dominant pollution type and reveal spatial differentiation in emission structures. Second, few studies include the relationship between pollution loads and governance investment in a unified framework. Most stopped at describing pollution status or evaluating reduction technologies, without addressing whether governance resources are directed toward high-load regions—a key policy concern. Additionally, some studies relied on older census data that cannot reflect recent structural changes. This study bridges these gaps by leveraging the 2024 national pollution census to analyze emission structures and fiscal allocation patterns jointly.

1.3. Analytical framework

This study uses the 2024 national pollution source survey data from the Ministry of Ecology and Environment to develop an analytical framework comprising structural decomposition, provincial comparison, problem identification, and policy design. This sequential approach links macro-level emission trends to micro-level governance mismatches, enabling evidence-based fiscal optimization across provincial jurisdictions.

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2. Data sources and research methods

2.1. Data sources

The study primarily relies on the national pollution-source statistical results published in the Report on the State of the Ecology and Environment in China 2024. The survey follows the Emission Source Statistical Survey System, which categorizes industrial, agricultural, domestic, centralized treatment facilities, and mobile sources. Data collection operates at varying spatial resolutions: facility-level for industry, provincial aggregates for agriculture, and prefectural totals for domestic discharges.

The 2024 census spans 31 provincial jurisdictions and the Xinjiang Production and Construction Corps (XPCC), encompassing over 196,000 regulated facilities nationwide. The unified survey scope and large sample size ensure high authority and comparability of the data.

For pollutant indicators, COD and NH3-N are treated as core indicators of organic and nitrogen pollution in this study, supplemented with total nitrogen and total phosphorus as nutrient indicators to describe the risk of water eutrophication. To capture structural changes, 2022 data under the same statistical system are used for comparison. Provincial socio-economic indicators and urbanization rates are obtained from official national statistical releases to support the classification and interpretation of high-emission provinces.

2.2. Measurement framework

To quantify how much each pollution source contributes to a specific pollutant, the study defines a contribution index. Assume Eij represents the emission of the j-th pollutant from the i-th source, then the contribution Cij is calculated as:

$$C_{ij}=\frac{E_{ij}}{\sum_k E_{kj}}\times 100\% \quad (1)$$

In the formula, Cij is the contribution (%) of the j-th pollutant from the i-th source; Ekj is the emission (in 10,000 tons) of the j-th pollutant from the k-th source; the denominator is the sum of emissions of the specific pollutant.

To compare pollution load intensity across provinces, a composite water pollution load index is constructed. After standardizing the ranges of COD, total nitrogen, and total phosphorus, sum them weighted by their respective weights. The equation:

$$L_p=\sum_j w_j\cdot\frac{(X_{pj}-X_{j,min})}{(X_{j,max}-X_{j,min})} \quad (2)$$

In the formula, Lp represents the comprehensive water pollution load index of the p-th province; Xpj denotes the emission amount of the j-th pollutant in that province; Xj, max and Xj, min are the maximum and minimum values of this indicator among all provinces nationwide, respectively; wj is the weight of the j-th pollutant, determined based on its relative contribution to water eutrophication and organic pollution.

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3. Nation water-pollution emission structure analysis

3.1. National source apportionment

Total national COD and NH_3-N emissions in 2024 are summarized in Table 1. Figure 1 delineates the dominant roles of agricultural and domestic sources across both pollutants.

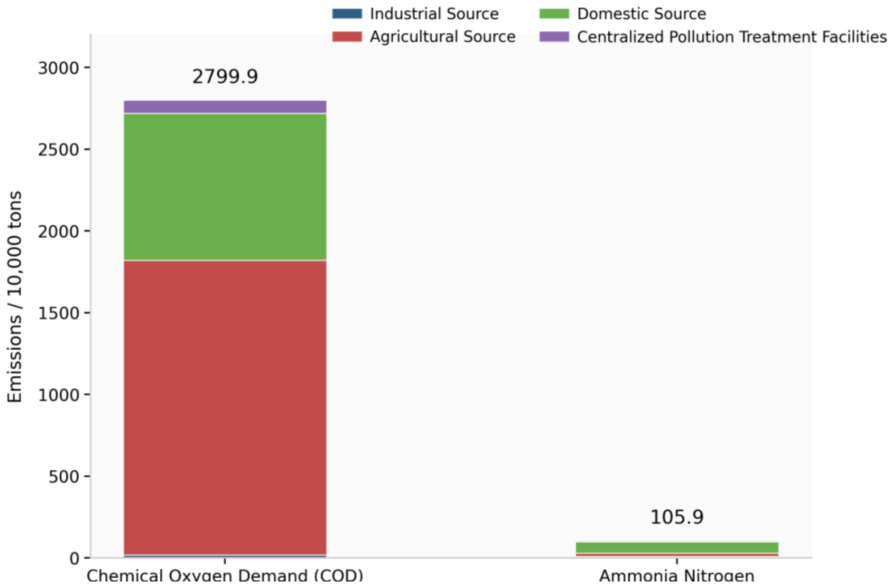

Figure 1. 2024 national COD and NH3-N source-specific emissions (photo credit: origin)

Table 1. 2024 emissions and contributions of major water pollutants from sources nationwide

Sources	COD/ 10,000 tons	Contribution/ %	NH_3-N/ 10,000 tons	Rate of Contribution/%
Industrial	30.8	1.1	1.0	0.9
Agricultural	1889.6	67.5	29.3	27.7
domestic	879.0	31.4	75.5	71.3
Centralized treatment facilities	0.5	0.02	0.1	0.09
Total	2799.9	100.0	105.9	100.0

Agricultural and domestic discharges collectively constitute the vast majority of national pollution loads, contributing 67.5% of COD and 71.3% of NH_3-N, while industrial sources account for less than 1.1% (Table 1).

COD is dominated absolutely by agricultural sources, showing that COD is primarily driven by organic loads from livestock manure and farmland runoff, whereas ammonia nitrogen is absolutely dominated by domestic sources, indicating that the nitrogen load from domestic sewage generated by urban population concentration has surpassed that from agriculture and industry, becoming the core contributor to nitrogen pollution in water bodies. The dual-subject pattern, with agriculture dominating organic pollution and domestic sources dominating nitrogen pollution, constitutes the basic structural feature of current water pollution management.

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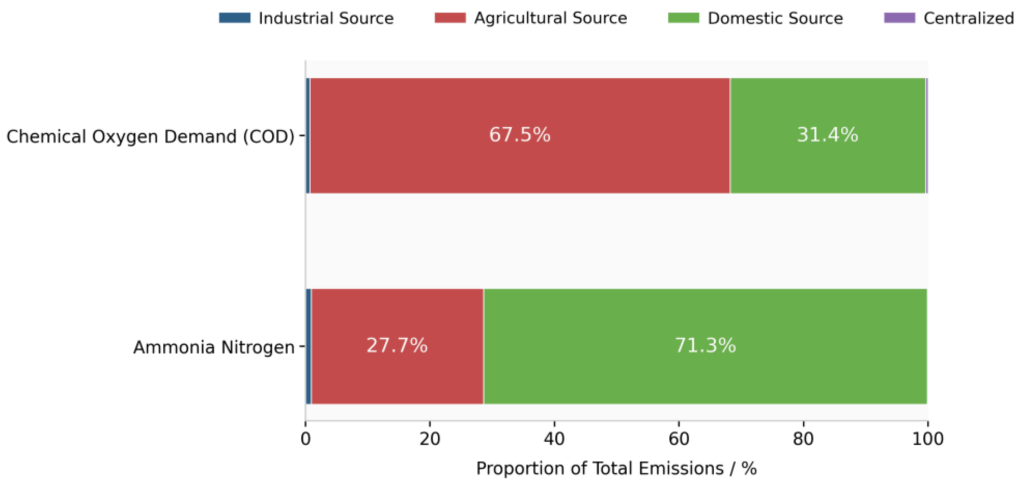

Figure 2. 2024 contribution of major water pollutants by source (photo credit: origin)

Notably, COD and NH_3-N exhibit non-overlapping source apportionment (Figure 2). The generation of COD is directly related to the discharge of organic matter, with agricultural sources having an absolute advantage in this indicator due to livestock and poultry waste and the loss of soil organic matter from farmland. The generation of ammonia nitrogen, on the other hand, is closely related to the discharge of nitrogen-containing substances, with nitrogen components in domestic sewage from densely populated areas constituting the main source of ammonia nitrogen. This misalignment of sources across indicators suggests that experience controlling a single pollutant cannot be directly transferred, and that water pollution prevention must adopt differentiated reduction strategies based on the pollutant generation mechanisms of different contaminants. The contribution of centralized pollution control facilities to both pollutants is negligible, indicating that secondary emissions during their operation have been effectively controlled and they do not constitute a major pollution source.

3.2. Temporal structural changes

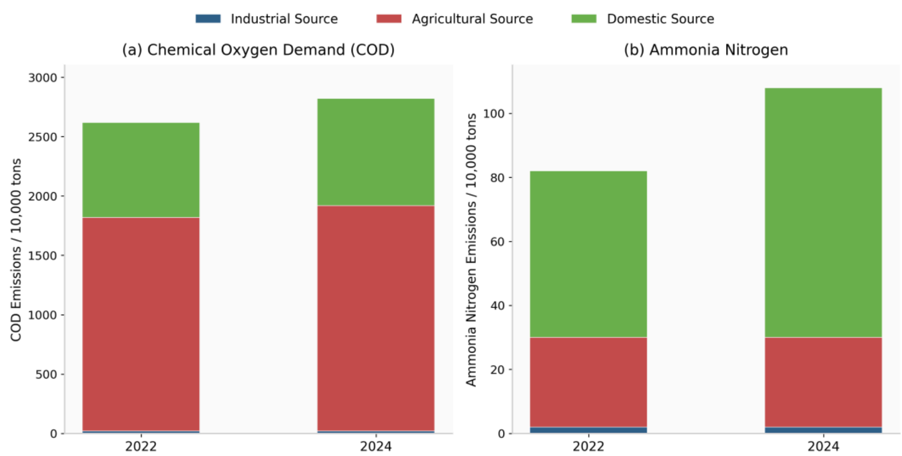

Figure 3. Comparison of COD and NH_3-N emission structures between 2022 and 2024 (photo credit: origin)

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Intertemporal comparison with 2022 data reveals pronounced structural shifts in national emission profiles. Industrial COD emissions fell from 0.369 to 0.308 million tons (a 16.5% decrease), while domestic COD increased by 13.8% and agricultural COD by 5.8% [5]. Domestic NH_3-N exhibited the most salient increase, surging 43.8% to claim a 71.3% national share (Figure 3). Industrial NH_3-N decreased from 0.014 to 0.01 million tons.

These trends highlight two parallel dynamics: industrial pollution continues to decline due to stable end-of-pipe control, while domestic nitrogen pollution grows rapidly with urbanization. The sharp rise in domestic NH_3-N reflects insufficient expansion of sewer networks and nitrogen-removal capacity relative to population growth. This provides quantitative evidence for the structural challenges discussed later.

4. Provincial comparison of pollution-source contributions

4.1. Typology of provinces

Provincial pollution loads exhibit marked spatial heterogeneity, necessitating a typological classification. High-emission provinces cluster geographically, with southern and central regions dominating national COD, NH_3-N, TN, and TP inventories. Table 2 synthesizes the socio-economic and emission profiles of four representative cases spanning this spectrum.

Based on socio-economic characteristics, high-emission provinces can be grouped into two categories: Agriculture-dominated provinces such as Hunan and Henan, where crop production and livestock farming form the economic foundation. Urbanization-dominated provinces (e.g., Guangdong and Jiangsu), exhibiting high population density and service-sector reliance (Table 2). This dichotomy underpins the divergent apportionment of pollution sources across provinces.

Table 2. Comparison of socio-economic and emission characteristics between two representative types of provinces

Province	Type	Urbanization rate (%)	Dominant pollution source	Primary pollutants
Hunan	Agriculture-dominated	62.0	Agricultural sources	Total nitrogen, total phosphorus
Henan	Agriculture-dominated	58.1	Agricultural sources	Total nitrogen, total phosphorus
Guangdong	Urbanization-dominated	75.4	Domestic sources	Ammonia nitrogen, chemical oxygen demand (COD)
Jiangsu	Urbanization-dominated	75.0	Domestic sources	Ammonia nitrogen, chemical oxygen demand (COD)

4.2. COD source structure

Figure 4 illustrates stark contrasts in COD source structures between these provincial archetypes. In agriculture-dominated provinces such as Hunan and Henan, agricultural sources account for 68.5% and 71.2% of COD emissions, respectively—significantly higher than the national average [6]. Livestock manure and farmland runoff are the primary drivers. In contrast, in

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urbanization-dominated provinces such as Guangdong and Jiangsu, domestic sources account for 43.9% and 46.4% of COD emissions, respectively.

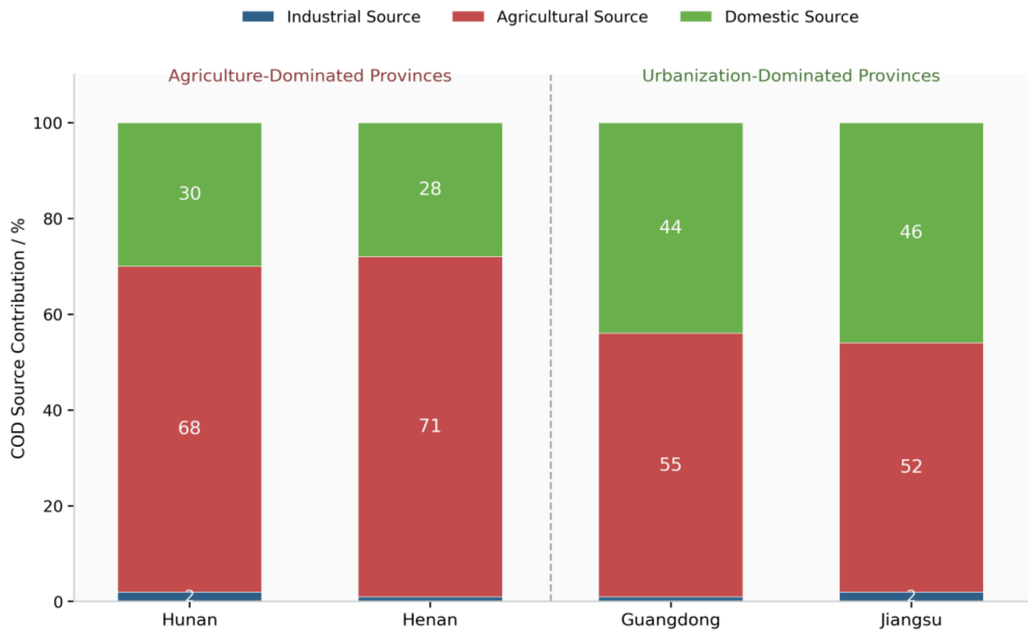

Figure 4. Share of COD emissions from different sources in representative provinces (photo credit: origin)

Although both types of provinces rank high in total COD emissions, their internal source structures differ sharply. This means identical total emissions may mask very different pollution origins and governance needs: Agricultural provinces require strategies targeting dispersed livestock operations and farmland runoff. Urbanized provinces need to expand wastewater-treatment capacity and improve collection systems. A uniform governance model cannot accommodate this spatial heterogeneity; policies must align with local pollution structures.

4.3. Nutrient loading patterns

Nutrient loading patterns reinforce this provincial dichotomy (Figure 5). A scatter plot analysis of the proportion of agricultural sources in total nitrogen and total phosphorus emissions in eight high-emission provinces (Figure 5) shows that agriculture-dominated provinces generally fall in the upper right of the plot—Hunan and Henan have approximately 64% and 66% of total nitrogen from agricultural sources, and about 70% and 71% of total phosphorus, respectively; whereas urbanization-dominated provinces such as Guangdong and Jiangsu fall in the lower left, with relatively lower proportions of total nitrogen and total phosphorus from agricultural sources. This indicates that in agriculture-dominated provinces, nitrogen and phosphorus pollution mainly originates from diffuse agricultural sources, making prevention and control more difficult.

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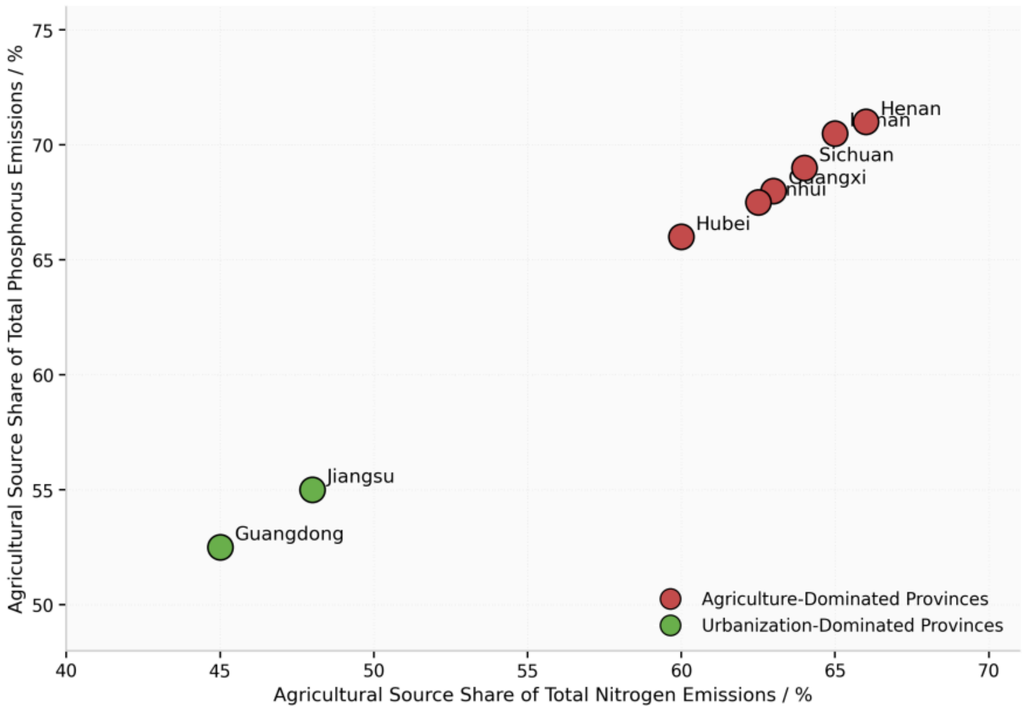

Figure 5. Contribution shares of nitrogen and phosphorus emissions from agricultural sources in representative provinces (photo credit: origin)

Intensive crop-livestock systems in these regions sustain national food security but concurrently generate substantial nutrient surpluses. Excess nutrients mobilize via rainfall-driven runoff and leaching into adjacent water bodies [7, 8]. This kind of pollution is widespread across large watersheds and is difficult to collect and treat at centralized sewage treatment plants, directly increasing the risk of eutrophication in water sources and posing a major threat to regional water ecological safety. In contrast, in provinces dominated by urbanization, household sources account for a larger share of nitrogen and phosphorus emissions, which can be treated more effectively through centralized urban sewage treatment systems [9]. This difference further confirms the divide in pollution control challenges between the two types of provinces: agriculture-dominated provinces face diffuse non-point source pollution that's hard to monitor and collect, making its management rely more on long-term investments in source control and ecological restoration.

5. Challenges and policy implications

5.1. Institutional achievements

5.1.1. Industrial point-source mitigation

Industrial sources now contribute only about 1% of national COD and NH_3-N emissions, and both indicators have continued to decline compared with 2022. This demonstrates that China's industrial wastewater-control system—centered on discharge permits, end-of-pipe treatment, and compliance enforcement—has achieved decisive success. Most industrial facilities now operate treatment systems reliably and discharge within standards, effectively removing industrial point sources as major threats to water bodies.

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This success not only improves water quality in industrial regions but also creates conditions to shift governance resources toward agricultural and domestic uses. The institutional experience gained from industrial control also provides useful references for managing non-point pollution.

5.1.2. Food-environment nexus

Although agricultural provinces bear heavy non-point pollution loads, their intensive crop production and large-scale livestock farming are essential for the national food and protein supply. Provinces such as Hunan and Henan are major producers of grain, pork, and poultry, playing strategic roles in ensuring food security.

Therefore, pollution control in these provinces cannot rely on reducing agricultural output. This necessitates reconciling agricultural productivity with aquatic ecosystem integrity through integrated source-management approaches.

5.2. Persistent governance constraints

5.2.1. Diffuse agricultural non-point sources

Agricultural TN and TP pollution does not originate from single discharge outlets but is widely distributed across landscapes. Its occurrence is influenced by rainfall, terrain, and land-use patterns, making it highly dispersed, concealed, and temporally delayed. Traditional wastewater-treatment plants cannot collect such pollution.

Large amounts of nitrogen and phosphorus enter water bodies through surface runoff and leaching, increasing the risk of eutrophication. Studies in the South-to-North Water Diversion source area show that livestock manure generates substantial COD, TN, and TP loads, with TP being the most critical pollutant—highlighting the severity of non-point pollution [10].

5.2.2. Urban infrastructure deficits

Rapid urbanization drives population concentration in coastal and provincial capital cities. Domestic wastewater generation—especially nitrogen-rich wastewater—has grown faster than sewer-network expansion and wastewater-treatment capacity.

The 43.8% surge in domestic NH_3-N emissions from 2022 to 2024 directly reflects this imbalance. Problems such as combined sewer systems, pipe leakage, and insufficient nitrogen-removal processes in treatment plants limit reductions in domestic nitrogen pollution [11, 12]. As a result, urbanized provinces face increasing water-environment pressure.

5.2.3. Fiscal allocation bias

Environmental expenditures exhibit a pronounced spatial bias relative to pollution burdens (Figure 6). Comparing pollution-load indices with investment indices shows that wealthy provinces such as Guangdong and Jiangsu invest far more than their pollution loads would require. Meanwhile, agricultural provinces such as Hunan, Henan, and Anhui—bearing heavy non-point pollution—receive relatively insufficient funding.

Environmental investment tends to concentrate in economically developed urban areas, while high-load agricultural regions lack adequate resources for ecological restoration. This creates a structural contradiction: high pollution load but low investment.

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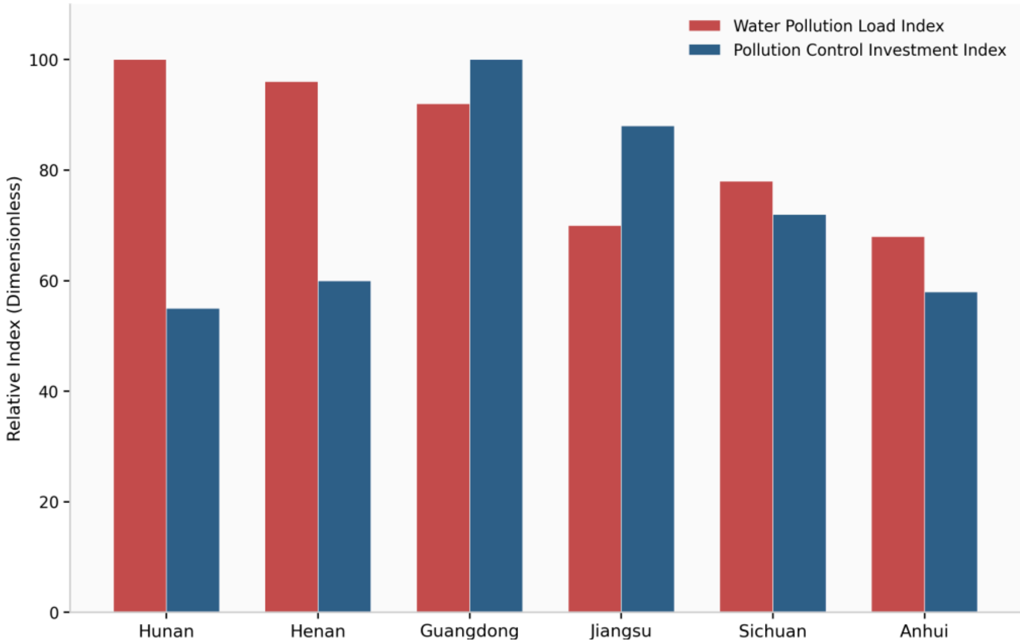

Figure 6. Comparison of water pollution load and pollution control investment in representative provinces (photo credit: origin)

5.3. Integrated governance strategies

5.3.1. Promote scientific fertilization and source reduction

Mitigating agricultural non-point pollution requires scaling soil-test-based fertilization and substituting synthetic fertilizers with recycled livestock manure. These source-reduction measures simultaneously curb nutrient runoff and enhance soil carbon sequestration.

5.3.2. Upgrade urban nitrogen and phosphorus removal processes

Urbanized provinces should accelerate rain–sewage separation, improve sewer-network coverage, and reduce overflow pollution. Wastewater-treatment plants must enhance nitrogen-removal and phosphorus-removal processes to ensure effluent consistently meets or exceeds Class-A discharge standards. Strengthening NH_3-N removal is especially critical to match the rapid growth of domestic wastewater.

5.3.3. Establish horizontal ecological compensation mechanisms

To correct spatial mismatches in investment, downstream beneficiary regions and major consumer provinces should compensate upstream agricultural provinces for pollution-control efforts [13, 14]. Scientifically designed compensation standards and dynamic incentive mechanisms can encourage upstream regions to strengthen non-point pollution control and rebalance regional responsibilities and benefits [15].

5.3.4. Optimize environmental investment transfers

At the national level, environmental-investment structures should be adjusted to increase fiscal transfers to central and western agricultural provinces. Funding should be directed toward regions

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with high pollution loads and strong restoration needs. Digital monitoring and pollution-load accounting can help precisely match funding to pollution contributions, preventing resource misallocation and improving overall environmental effectiveness. Together, these four strategies integrate technical measures (source reduction and treatment upgrades) with institutional reforms (compensation and fiscal transfers), forming a comprehensive response to China's shifting water-pollution structure.

6. Conclusion

This study elucidates a structural transformation in China's water pollution profile, delineating the divergent contributions of agricultural and domestic sources at national and provincial scales. The main conclusions are as follows. (1) Dual-dominant pattern of agricultural organic pollution and domestic nitrogen pollution. Agricultural sources account for 67.5% of national COD emissions, while domestic sources account for 71.3% of ammonia-nitrogen emissions. Industrial contributions are below 1.2%, indicating that the core challenge of water-pollution control has shifted from industrial point sources to agricultural non-point sources and urban sewer-system upgrades. (2) Dynamic Evolution of Emission Structure. Compared with 2022, domestic ammonia-nitrogen emissions increased by 43.8%, while their share rose from 64.0% to 71.3%. Industrial COD emissions decreased by 16.5%. The rapid growth of domestic nitrogen load is the most prominent structural change, reflecting insufficient expansion of sewer networks and nitrogen-removal capacity relative to population growth. (3) Agricultural VS Urbanized Provinces Exhibit Distinct Pollution Structures. Dispersed TN and TP loads from farming and livestock dominate agricultural provinces such as Hunan and Henan. Urbanized provinces such as Guangdong and Jiangsu are dominated by domestic NH_3-N and COD loads. Governance strategies must therefore be tailored to local pollution structures, rather than applying uniform national measures. (4) Persistent governance constraints—including diffuse agricultural pollution, urban infrastructure gaps, and fiscal allocation biases—require integrated solutions. Synergizing source-directed technological upgrades with institutional reforms, such as ecological compensation and fiscal transfers, is imperative to realign environmental investments with actual pollution burdens.

This study primarily relies on macro-statistical data for cross-sectional analysis and lacks empirical data to support the migration process of non-point source pollution. In the future, combining watershed-scale water quality monitoring with remote sensing inversion could further characterize the spatiotemporal mechanisms of the evolution of agricultural and domestic source pollution, thereby enhancing the precision of governance strategies.

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