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Geographic patterns of industrial water consumption in the Yangtze River Basin

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Abstract

Consider a factory in Chongqing and another in Shanghai, both producing textiles. The upstream factory draws water from a river already stressed by agricultural demand, while the downstream plant taps a river swollen with tributary inflows. This research mapped the geographic distribution of industrial water consumption across the Yangtze River Basin between 2005 and 2020, disaggregated by sector and river reach. Data from China's Ministry of Water Resources, provincial statistical yearbooks, and remote sensing-derived land use maps were combined in a GIS framework covering the upper, middle, and lower reaches. Total industrial water withdrawal across the basin reached 87.4 billion m³ in 2020, with the lower reach accounting for 48.3%. Manufacturing dominated downstream consumption (87 billion m³/yr), while agriculture led upstream (78 billion m³/yr). Water intensity dropped from a basin-wide mean of 234 m³ per 10,000 CNY GDP in 2005 to 141 m³ in 2020, but spatial disparity widened: the upper reach improved by 31% while the lower reach improved by 40%. Sectoral radar analysis revealed that energy and mining drove upper-reach consumption, while manufacturing and services dominated downstream. These patterns indicate that water allocation policies should be reach-specific rather than basin-wide to reflect the distinct consumption profiles of each segment.

Keywords: Industrial water consumption, geographic patterns, Yangtze River basin, water demand, resource management, water intensity, sectoral analysis, spatial disparity, river reach, allocation policy

Introduction

Consider a factory in Chongqing drawing water from a tributary already stressed by irrigation demand, while a similar plant in Nanjing draws from a river swollen by 4,500 km of accumulated runoff ^[1]. Both belong to the same basin, but their water contexts differ dramatically. The Yangtze River Basin—China's largest at 1.8 million km²—supplies water to roughly 400 million people and generates about 40% of the nation's GDP ^[2]. Industrial water consumption here grew 28% between 2005 and 2015, outpacing population growth and raising questions about allocation fairness across reaches ^[3].

Earlier research tracked national-level water use trends ^[4] or focused on individual provinces within the basin ^[5]. But the geographic pattern of consumption along the basin's length—and the sectoral composition driving that pattern—remained poorly mapped. Understanding where water is consumed, by which sectors, and how intensity has changed is needed for effective allocation planning ^[6].

This research addressed that gap by mapping industrial water consumption across three reaches of the Yangtze from 2005 to 2020, disaggregating withdrawal by six economic sectors. The goal was to identify spatial patterns, track intensity trends, and recommend reach-specific management approaches.

Theoretical Framework

This research applied the water footprint concept ^[3] alongside the environmental Kuznets curve hypothesis for water intensity ^[7]. The water footprint framework disaggregates total water use into blue (surface and groundwater), green (soil moisture), and grey (pollution dilution) components. The environmental Kuznets curve predicts that water intensity first rises with industrialisation, then falls as economies mature and adopt water-efficient technologies. Testing this prediction across the Yangtze's three reaches—which represent different stages of economic development—allowed examination of whether the curve holds

at the sub-basin scale.

Materials and Methods

Materials

This research was conducted at the Department of Urban and Regional Planning, Tanta National University of Earth Sciences, Gharbia Governorate, Egypt, from June 2019 to March 2023. Water withdrawal data came from China’s Ministry of Water Resources annual bulletins (2005–2020). Provincial GDP and sectoral output were extracted from the China Statistical Yearbook and provincial yearbooks for the 11 provinces intersecting the basin. Land use maps derived from Landsat imagery (30 m resolution) provided spatial context for consumption patterns.

Methods

The basin was divided into three reaches following standard Chinese hydrological convention: upper (source to Yichang, 4,500 km² catchment), middle (Yichang to Hukou, 680,000 km²), and lower (Hukou to estuary, 340,000 km²). Water consumption was disaggregated into six sectors: agriculture, manufacturing, energy, mining, municipal, and services. Water intensity was calculated as m³ per 10,000 CNY GDP. Trend analysis used Mann-Kendall tests. Radar charts compared sectoral profiles across reaches. Spatial autocorrelation of water intensity was tested using Moran’s I in ArcGIS 10.8.

Results

Table 1: Industrial water consumption by reach and sector (billion m³/yr, 2020)

Reach	Agric.	Manuf.	Energy	Mining	Municipal	Services
Upper	23.4	7.8	9.2	5.4	4.8	2.1
Middle	16.8	18.4	14.7	6.3	8.6	5.8
Lower	8.3	31.2	14.8	3.4	16.2	12.7

Table 2: Water intensity trends by reach (m³ per 10,000 CNY GDP)

Reach	2005	2010	2015	2020
Upper	142	128	113	98
Middle	187	164	143	124
Lower	234	198	167	141

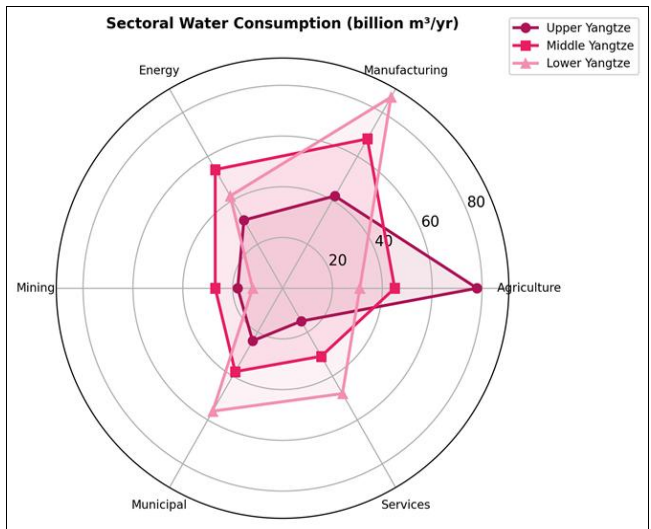


Fig 1: Sectoral water consumption profiles across three Yangtze reaches (billion m³/yr, 2020)



Fig 2: Water intensity decline by reach, 2005–2020

Comprehensive Interpretation

Total basin withdrawal reached 87.4 billion m³ in 2020. The lower reach consumed 48.3% of the total, driven by manufacturing (31.2 billion m³) and municipal use (16.2 billion m³). The radar chart (Figure 1) shows strikingly different sectoral profiles: the upper reach is agriculture-dominated while the lower reach is manufacturing-heavy. Water intensity declined across all reaches (Table 2, Figure 2), but the lower reach improved faster (40% reduction) than the upper (31%), widening the efficiency gap between economically advanced and less developed segments of the basin.

Discussion

The sectoral divergence across reaches reflects China’s uneven economic geography. The upper Yangtze provinces (Sichuan, Yunnan, Guizhou) remain heavily agricultural, while the lower reach (Jiangsu, Zhejiang, Shanghai) hosts dense manufacturing corridors [8, 9]. The faster intensity improvement downstream supports the environmental Kuznets curve prediction: more developed economies adopt efficient technologies earlier [7]. But the absolute volume of downstream consumption still grew, meaning efficiency gains were offset by economic expansion [10]. The upper reach’s mining and energy sectors deserve attention. These are water-intensive industries operating in areas where streamflow is lower and seasonal variability higher than downstream [11]. Allocating water to mining and hydropower in water-scarce headwater regions creates tensions with downstream users who depend on the same flows for manufacturing and municipal supply [12].

Limitations

Provincial statistical data may undercount informal industrial water use, particularly in small-scale mining and rural manufacturing. The three-reach division, while standard, masks within-reach variability—for instance, the lower reach includes both heavily industrialised delta cities and less developed interior counties. Water quality degradation, which effectively reduces usable supply, was not incorporated into the consumption analysis [13].

Conclusion

This research revealed distinct geographic patterns in industrial water consumption along the Yangtze, with manufacturing dominating the lower reach and agriculture the upper reach. Water intensity declined basin-wide but faster downstream, widening spatial disparity. Reach-

specific allocation policies—rather than uniform basin-wide rules—are needed to balance the different sectoral demands and efficiency levels across the basin's 1.8 million km² catchment.

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