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Adaptability Analysis of Water Pollution and Advanced Industrial Structure in Jiangsu Province, China

Qingling Peng, Yang Kong

Hohai University, China Three Gorges University

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Introduction

- **Frequent human activities are usually accompanied by the high intensity of water consumption and massive water pollutants discharge (FAO and UN-Water, 2021).**
- **It has significantly impacted the hydrological process (Rodell et al., 2018) and restricted the natural water system to effectively play the functions of water resources supply, water pollution containment, and water ecological service (Degefu et al., 2018; Mekonnen and Hoekstra, 2016).**
- **When human beings disturb the normal circulation process of water system, the water system responds spontaneously through flooding, drought, water environmental pollution and water ecological degradation (Hung et al., 2022; Sivapalan et al., 2014). Apparently, these adverse responses are extremely destructive once they occurring.**

Introduction

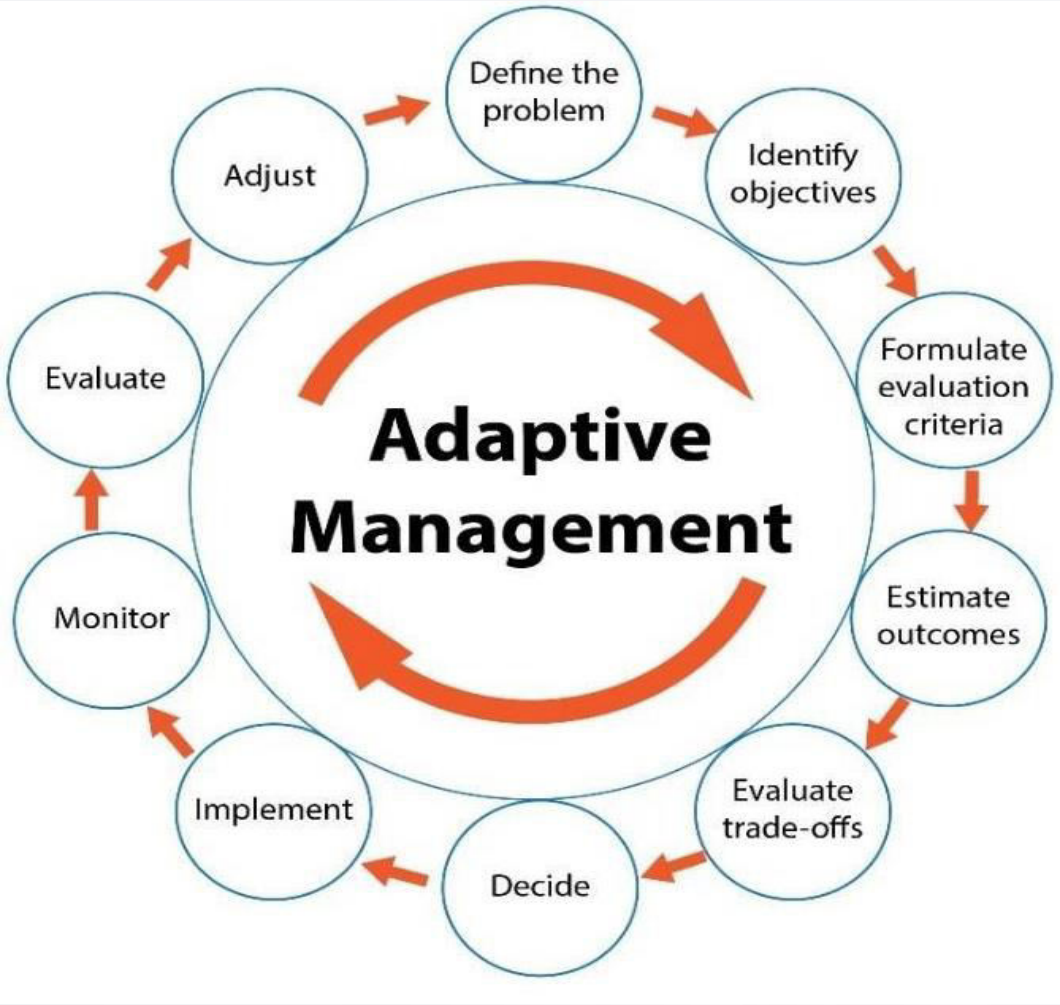
◆**The disharmonious relationship of human-water system** could profoundly affect the socio-economic activities and lives of human beings, restrict the natural water system from providing sustainable support for human development, and hinder the process of ecological civilization construction (Jiang et al., 2021; Luo and Zuo, 2019).

◆To this end, the first document of the CPC （Communist Party of China） Central Committee officially proposed the principle of "upholding harmony between humans and water" in February 2011. **The concept of harmonious development between human and water was emphasized** in a number of government documents such as the **2020 National Conference on Water Conservancy Work.**

Introduction

- **Water pollution is closely related to industrial transition and industrial structure adjustment** (Hu and Cheng, 2013; Yuan et al., 2022a). Different industrial structure not only determines the regional displacement and discharge process, but also affects the water quality (Su et al., 2009).

- **The advanced development of industrial structure is a necessary guarantee of high-quality economic development and water sustainability** (Zhang et al., 2021). The level of advanced industrial structure can reflect the degree to which the industry develops towards the direction of service.



Introduction

- Although previous studies can provide some implications for exploring the adaptation between water pollution and advanced industrial structure, **there are still several research shortcomings we can't afford to ignore:**

① There is a lack of research on the adaptability between water pollution and advanced industrial structure;

② The measurement accuracy of water pollution needs to be improved because only physical water is considered while virtual water is ignored;

③ The measurement result of the advanced industrial structure is not accurate enough because it is quantified by the ratio of the added value of the tertiary industry to that of the secondary industry while ignoring the influence of the primary industry.

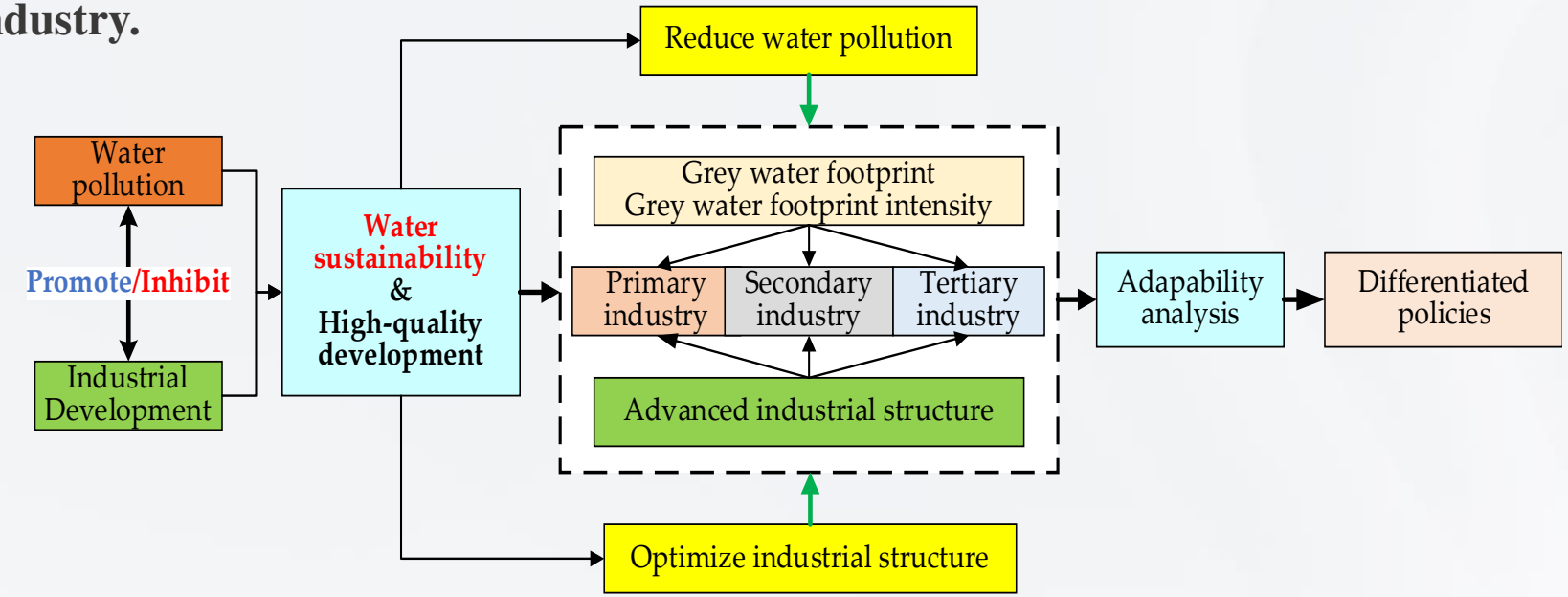


Figure 1. Research logical roadmap

Materials and Methods

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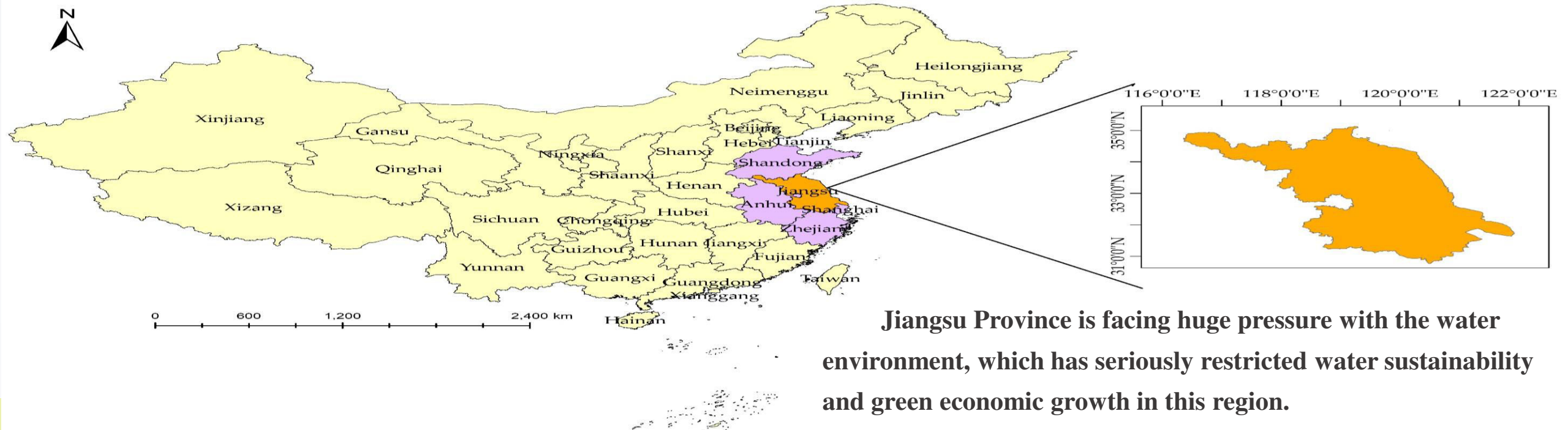
Jiangsu Province is located in latitude 30°45'~35°08' N and longitude 116°21'~121°56' E, geographically spanning the north and south of China. **It borders Zhejiang, Anhui and Shandong Provinces and Shanghai Municipality,** with a total land area of 107,200 square kilometers.

The local water resources in Jiangsu Province are insufficient. Its average per capita water resources was only 539.7 m3 from 2011 to 2019. Rapid economic development and urbanization have led to problems such as over-utilization of water resources and deterioration of water quality. **Furthermore, the ecological environment water use in Jiangsu Province was overstretched,** its proportion in the region has decreased 4.51% from 2010 to 2018 and accounts for only 0.8 percent in 2019, **well below the national level of 4.1% during the same year.**



Jiangsu Province is facing huge pressure with the water environment, which has seriously restricted water sustainability and green economic growth in this region.

Materials and Methods

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Grey water footprint method:

Based on the *Water Footprint Evaluation Manual* **(Hoekstra et al., 2011)** and **Han et al. (2016)**, the regional grey water footprint (GWF_{total}) is obtained from agricultural grey water footprint (GWF_{agr}), industrial grey water footprint (GWF_{ind}) and domestic grey water footprint (GWF_{dom}). Due to the variety and concentration difference of water pollutants, only the major pollutants are considered in the calculation of grey water footprint, and the specific formula is as follows:

$$GWF_{total} = GWF_{agr} + GWF_{ind} + GWF_{dom} \quad (1)$$

Tapio decoupling adaptation model:

As shown in Formula (19) **(Tapio, 2005)**, the Tapio decoupling elasticity coefficient can be used to reflect the asynchronous change relationship between water pollution (WP) and advanced industrial structure (W).

$$e = \frac{WP\%}{W\%} = \frac{\frac{WP_{t_1} - WP_{t_0}}{WP_{t_0}}}{\frac{W_{t_1} - W_{t_0}}{W_{t_0}}} \quad (1)$$

Where, e refers to the elasticity coefficient, WP indicates the GWFt and the GWFI, and W represents the advanced degree of industrial structure (W).

Table 1. The classification criteria of the Tapio decoupling adaptation **(Kong et al., 2021)**

ΔWP	ΔW	e	Decoupling states	Decoupling adaptation states
>0	>0	(0,0.8]	Weak decoupling	Relatively ideal
>0	>0	(0.8,1.2]	Expansive coupling	Uncertain
>0	>0	(1.2, +∞)	Expansive negative decoupling	Non-ideal
>0	<0	(-∞,0]	Strong weak decoupling	Least ideal
<0	>0	(-∞,0]	Strong decoupling	Ideal
<0	<0	(1.2, +∞)	Recessive decoupling	Non-ideal
<0	<0	(0.8,1.2]	Recessive coupling	
<0	<0	(0,0.8]	Weak negative decoupling	

Advanced industrial structure model:

The advanced industrial structure refers to the development of the industry towards the direction of service with the continuous economic growth (Fu, 2010; Liu and Ling, 2020).

The larger the value, the higher is advanced level of the industrial structure . The specific calculation steps of the degree of advanced industrial structure (W) are as follows:

Firstly, GDP is divided into three parts according to the three industries. The proportion of the added value of the three industries in GDP is taken as one component o the spatial vector to form a group of 3 -dimensional vectors $X_0 = (x_{1,0}, x_{2,0}, x_{3,0})$. Secondly, the angles θ_1, θ_2, θ_3 between X_0 and vectors $X_1 = (1,0,0)$, $X_2 = (0,1,0)$, $X_3 = (0,0,1)$ are calculated respectively.

$$\theta_j = \arccos\left(\frac{\sum_{i=1}^{3}\left(x_{i,j} \cdot x_{i,0}\right)}{\left(\sum_{i=1}^{3} x_{i,j}^2\right)^{1/2} \cdot \left(\sum_{i=1}^{3} x_{i,0}^2\right)^{1/2}} \right) \quad (j = 1,2,3) \quad (1)$$

3.1 Analysis of water pollution assessment

- The GWF of Jiangsu Province showed an overall trend of "rising first and then declining with fluctuations" during 2003-2019.
- It can be found that agriculture was the largest source of water pollution in Jiangsu Province from 2003 to 2016. During this period, both agricultural GWF and industrial GWF showed a slight downward trend, while the proportion of domestic GWF increased significantly from 32.5% in 2003 to 43.06% in 2016. Since 2017, domesticity has replaced agriculture as the biggest source of water pollution.
- The GWFI in Jiangsu Province showed a strict decreasing trend. Since the GWFI is obtained by the ratio of GWF to regional GDP, it represents the water pollution generated by unit GDP output.

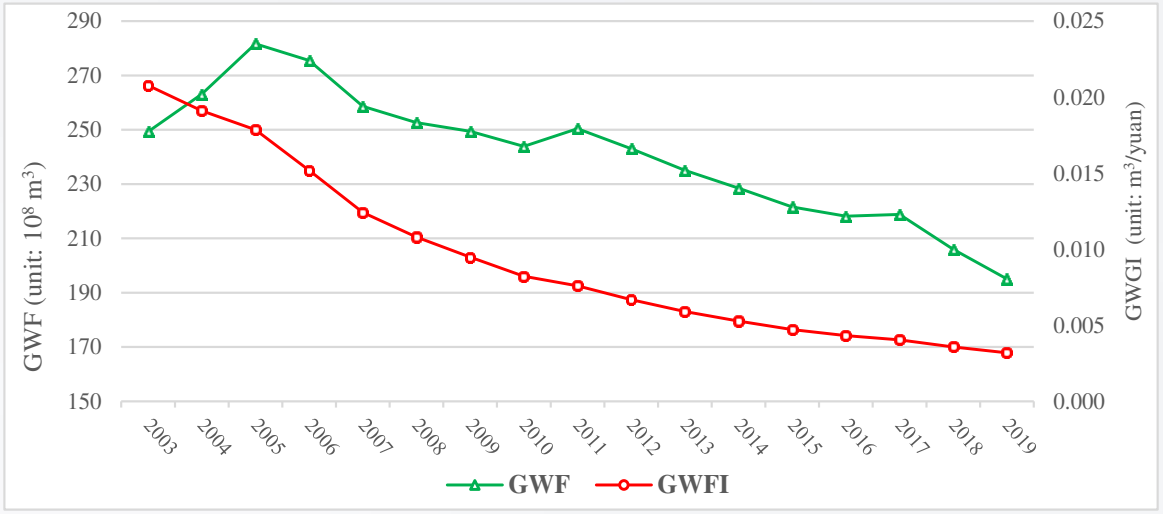

Figure 2. The variation trend of GWF and GWFI in Jiangsu Province from 2003 to 2019

Table 1. Grey water footprint and its components in Jiangsu Province during 2013-2019

Year	Agricultural GWF (proportion)	Industrial GWF (proportion)	Domestic GWF (proportion)	GWF	GWFI
2003	121.39 (48.70%)	46.86 (18.80%)	81.02 (32.50%)	249.27	0.0208
2007	110.07 (42.56%)	46.38 (17.93%)	102.17 (39.51%)	258.62	0.0124
2011	110.12 (43.98%)	39.89 (15.93%)	100.38 (40.09%)	250.39	0.0076
2015	104.77 (47.28%)	33.55 (15.14%)	83.27 (37.58%)	221.59	0.0047
2019	85.82 (43.99%)	14.63 (7.50%)	94.63 (48.51%)	195.09	0.0032

Note that: the units of GWF and GWFI are 10^8 m^3 and m^3/yuan respectively.

3.2 Analysis of advanced industrial structure

- **In terms of the proportion of the three industries, the industrial development of Jiangsu Province showed a positive trend as a whole. That is, the proportion of the primary and secondary industries decreased, while that of the tertiary industry increased.**
- **The secondary industry was still in the leading position. Accordingly, the development of the advanced industrial structure in Jiangsu Province still needs to be accelerated.**
- **The value of advanced industrial structure (W) in Jiangsu Province increased from the minimum value of 6.49 in 2003 to the maximum value of 6.77 in 2019, with an overall growth rate of only 4.31% (Table 3).**
- **The added value of the three industries in Jiangsu Province presented a steady growth trend during this period.**

Table 1. Development of three industries in Jiangsu Province from 2013 to 2019

Year	Added value of the primary industry (Proportion)	Added value of the secondary industry (Proportion)	Value-added of tertiary industry (Proportion)	GDP	Advanced industrial structure
2003	1090.22 (9.08%)	6556.15 (54.63%)	4355.54 (36.29%)	12001.91	6.49
2007	1287.31 (6.18%)	11931.73 (57.27%)	7616.63 (36.56%)	20835.68	6.59
2011	1526.31 (4.63%)	19145.46 (58.11%)	12274.65 37.26%)	32946.42	6.66
2015	1750.63 (3.73%)	27406.61 (58.37%)	17795.79 (37.90%)	46953.03	6.70
2019	1824.90 (2.99%)	34856.08 (57.07%)	24391.79 (39.94%)	61072.77	6.77

Note: the units of the added value of three industries and GDP are 10^8 yuan.

3.3 Adaptability analysis of water pollution and advanced industrial structure

- In general, the Tapio elastic coefficient of GWF and advanced industrial structure in Jiangsu Province was minus 5.09 during the whole study period, indicating that strong decoupling adaptation (ideal adaptation) has been achieved.
- Considering the continuous growth of advanced industrial structure, we could figure out that the GWF in this region has achieved water pollution reduction in general, but the reduction effect was not stable in a certain period.
- By contrast, the GWFI and advanced industrial structure in Jiangsu Province always showed SDA, which was the ideal adaptation state. This showed that the intensity of water pollution in Jiangsu Province continued to decrease with the development of advanced industrial structure.

Table 1. Adaptation of GWF/GWFI and AIS in Jiangsu Province during 2003-2019

Period	W%	GWF%	*e* (GWF)	Adaptation state	GWFI%	*e* (GWFI)	Adaptation state
2003-2004	0.24%	5.54%	23.28	ENDA	-8.02%	-33.68	SDA
2004-2005	0.48%	7.06%	14.76	ENDA	-6.50%	-13.60	SDA
2005-2006	0.39%	-2.18%	-5.64	SDA	-14.93%	-38.67	SDA
2006-2007	0.48%	-6.14%	-12.69	SDA	-18.31%	-37.85	SDA
2007-2008	0.27%	-2.32%	-8.44	SDA	-13.00%	-47.31	SDA
2008-2009	0.32%	-1.27%	-4.01	SDA	-12.19%	-38.56	SDA
2009-2010	0.24%	-2.22%	-9.14	SDA	-13.27%	-54.58	SDA
2010-2011	0.16%	2.67%	16.40	ENDA	-7.58%	-46.59	SDA
2011-2012	0.07%	-2.94%	-42.03	SDA	-11.97%	-171.34	SDA
2012-2013	0.15%	-3.28%	-21.72	SDA	-11.77%	-77.89	SDA
2013-2014	0.24%	-2.81%	-11.65	SDA	-10.55%	-43.78	SDA
2014-2015	0.18%	-3.01%	-16.28	SDA	-10.62%	-57.49	SDA
2015-2016	0.34%	-1.54%	-4.49	SDA	-8.49%	-24.68	SDA
2016-2017	0.26%	0.29%	1.12	ENDA	-6.32%	-24.08	SDA
2017-2018	0.22%	-5.87%	-26.44	SDA	-11.61%	-52.30	SDA
2018-2019	0.13%	-5.28%	-40.20	SDA	-10.67%	-81.23	SDA
2003-2019	4.27%	-21.73%	-5.09	SDA	-84.62%	-19.81	SDA

Note: Strong decoupling adaptation (SDA) is the most ideal state, while expansive negative decoupling adaptation (ENDA) is a nonideal state.

Conclusions

The main conclusions are as follows:

- **The largest source of GWF in Jiangsu Province from 2003 to 2016 was agriculture and that eventually changed into domesticity since 2017.** Combined with the total amount and intensity, the water pollution in Jiangsu Province showed a downward trend.
- **The industrial structure of Jiangsu Province has achieved a certain degree of advanced development during, but the effect is not significant.** The industry remains dominant in the region.
- **On the whole, water pollution and industrial structure were well adapted in Jiangsu Province.** Specifically, the GWF and advanced industrial structure achieved the ideal adaptation in the majority of years, while the GWFI and the advanced industrial structure always remained the ideal.

This study provides a new analytical framework for the adaptability of water pollution and advanced industrial structure. The findings of adaptation analysis could be used as a basis for regional zoning, which is conducive to the formulation of regional differentiation policy.

Ecological Modelling 481 (2023) 110365

Contents lists available at ScienceDirect

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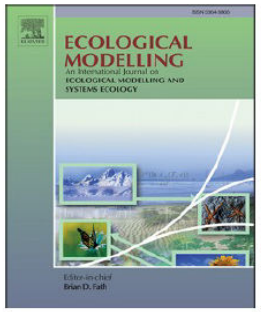

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Adaptability analysis of water pollution and advanced industrial structure in Jiangsu Province, China

Yang Kong [a,b], Weijun He [b], Juqin Shen [c,*], Liang Yuan [b], Xin Gao [d], Thomas Stephen Ramsey [b], Qingling Peng [a], Dagmawi Mulugeta Degefu [e], Fuhua Sun [c,*]

[a] Business School, Hohai University, Nanjing, 211100, China
[b] College of Economics and Management, China Three Gorges University, Yichang, 443002, China
[c] College of Agricultural Science and Engineering, Hohai University, Nanjing, 211100, China
[d] Antai College of Economics and Management, Shanghai Jiao Tong University, Shanghai, 200030, China
[e] Department of Architecture Science, Toronto Metropolitan University (Formerly Ryerson University), Toronto, ON, M5B 2K3, Canada

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Qingling Peng, Yang Kong

Hohai University, China Three Gorges University

Email: qinglingpeng@hhu.edu.cn

yangkong@hhu.edu.cn

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