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Evaluating the Effectiveness of the "River Chief System": An Empirical Study Based on the Water Quality Data of Coastal Rivers in Guangdong Province

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Abstract: The river chief system (RCS) is an innovative reform in China for strengthening the management of rivers and lakes. It is an important means of curbing the current severe water-environment situation. However, the policy impact of the RCS is still inconclusive in the existing literature. Using monthly data spanning from January 2015 to March 2022 from 25 water quality monitoring stations in rivers flowing into the sea across 13 prefecture-level cities in Guangdong Province, this study adopted regression discontinuity to evaluate the policy effects of the RCS on water quality. The results show that after the RCS's full implementation in Guangdong Province, the concentrations of dissolved oxygen (DO) increased and water quality indicators, such as permanganate index (COD_{Mn}), biochemical oxygen demand (BOD), ammonia nitrogen (NH_3-N), chemical oxygen demand (COD), and total phosphorus (TP), decreased; NH_3-N showed the largest decrease. These findings indicate that the RCS may contribute to a measurable improvement in reducing water pollution. However, no statistically significant changes in pH and total nitrogen (TN) were found, which indicates that the RCS fell short of achieving the policy effect of comprehensive water-pollution control. Therefore, in order to improve the RCS, it is necessary to refine the existing water-quality assessment indicators and to establish an evaluation system centered on the ecological health of rivers and lakes. Additionally, a paradigm shift from an administrative-boundary-based river management model to an overarching, holistic river-basin-based management approach is crucial for actualizing the holistic governance goals of the RCS.

Keywords: river chief system; Guangdong province; regression discontinuity; policy effect evaluation

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1. Introduction

Water pollution management has always been the top policy priority in environmental governance across the globe. Many developed countries have made numerous useful attempts to improve mechanisms and systems of water pollution management. In the United States, some environmental regulatory powers have been delegated to state governments [1], while certain European countries favor a centralized approach to environmental regulatory authority [2], such as the formation of the European Union's unified policy framework for water environment management [3]. However, due to the inherent fluidity of water environments and the externalities of river pollution, the modes of centralized management and decentralized regulation cannot fully address the complex problems of water environment management [4]. Over the past decade, China has suffered from many challenges in water governance resulting from a jurisdiction-based water administrative system and the fragmented distribution of water-related power among various local functional agencies. Within this institutional landscape, many local governments were eager to pursue local economic development at the expense of environmental interests in China. In response to the water pollution crisis triggered by cyanobacteria outbreaks in Taihu Lake [5], Jiangsu Province's Wuxi City pioneered the implementation of the river chief system (RCS) in 2007, which was subsequently implemented nationwide in 2018. In this system, key party and government officials at the provincial and local levels take on the role of "river chiefs" [6], directing the organization, management, and protection of their designated rivers and lakes. By June 2018, all 31 provinces, autonomous regions, and municipalities had comprehensively established the RCS, thus achieving the central government's policy objectives six months ahead of schedule.

The RCS has unified the previously fragmented water administrative system and effectively addressed the dilemma of water pollution management by incorporating all stakeholders into the water management framework under the unified leadership of the government [7–9]. The RCS, as an important pillar of local environmental governance, also provides strong political incentives for local officials to improve the quality of the water environment by adopting a range of stringent water quality evaluation targets into the environmental management mechanism [10]. Consequently, the RCS has emerged as a crucial initiative that not only strengthens river and lake management but also reinforces the concept of green development and the advancement of ecological civilization.

Despite this, findings regarding the effects of the RCS policy are inconsistent in previous studies. Shen et al. found that the RCS improved dissolved oxygen (DO) and alleviated the problem of black-odorous waterbodies, but it failed to effectively improve other water pollution indicators, suggesting that local governments' pollution control actions were superficial and that they were inclined towards "treating the symptom rather than the root cause" [11]. Li Jing et al. [12] found that the RCS was effective in reducing ammonia nitrogen (NH_3-N) concentration and inducing the deterioration of chemical oxygen demand (COD) and DO. Conversely, some studies pointed out that the RCS had a significant improvement on most of the water quality indicators within the river basin, demonstrating positive impacts on the quality of river water [13–15]. In this study, we aimed to extend the aforementioned academic discussion by evaluating the policy effectiveness of the RCS. Since most of China's river chief systems are currently implemented at the provincial level, this study used the regression discontinuity design (RDD) to assess the RCS's policy effects on water environment. Our analysis was based on data from 25 water quality monitoring stations on the coastal rivers flowing into the sea across 13 prefecture-level cities in Guangdong Province and was supplemented with the data on local RCSs' implementation schedules as well as a series of relevant economic, social, and climatic indicators. This study constitutes a valuable addition to the existing body of research on the RCS's effectiveness. It provides empirical evidence for improvement from a long-term and systematic water-environment management system and points out the necessity of a paradigm shift to an RCS based on the river basin as a unit; this shift would help modernize China's water environment governance system. Our work provides not only more insights into the relationship between the RCS and local water pollution management in the river basin, but also has important implications for future designs and implementation of water management policies.

2. Literature Review

The RCS is a model of basin management with Chinese characteristics, and the existing literature focuses on its institutional arrangements, operational dilemmas, and relevant policy effects.

In terms of institutional arrangements, much of the literature indicated that the RCS transcended the organizational boundaries inherent in former water environment management practices, thus exhibiting features of integrated governance. By assigning the responsibility of water environment management to top leaders within local party and government authorities, the RCS effectively tackled the enduring challenge of motivating local governments to engage in pollution control, achieved through a strategic reallocation of duties and stringent performance assessments. This initiative repositioned water environment governance as a primary concern within local administrative agendas, navigating the complexities inherent in multi-party management. According to Cao and Zhou, the RCS has achieved the centralization and unification of the previously relatively decentralized administrative forces. It rewarded and punished through a series of evaluations and assessments under the mechanism of administrative supervision and accountability. Thus, the RCS demonstrates a synergy of the strengths of a party–state bureaucratic system and the concept of green development [16]. Shen evaluated the institutional effectiveness of the RCS across three dimensions: environmental, economic, and social performance. He found that the institutional performance of the RCS was greater than the institutional cost, and, therefore, it was worth promoting [17].

Due to the intrinsic properties of river basins, which frequently span multiple domains and jurisdictions, governing the water environment encounters significant obstacles in achieving collaborative success. Consequently, how to coordinate all forces to participate in the operation of the RCS has become the focus of research [18]. The existing literature has pointed out the emergence of technology-embedded collaborative governance and growing societal participation in RCS operation. Ma and Zhu identified the drivers of environmental public participation in RCS operation from the perspective of technology embedding [19]. According to Yan [20], within the framework of the RCS, the "internet + water governance" system offered a mechanism for facilitating both horizontal and vertical information flows and departmental interactions. This approach effectively dismantled the fragmentation in water management authorities and provided a streamlined avenue for public participation in water management. Liu noted that stringent implementation of the RCS by the government could significantly enhance societal engagement in water environment management. This rigorous approach compelled polluting enterprises to undergo transformation and upgrading, thereby positively influencing the development of a collaborative societal atmosphere for water management efforts [21].

However, whether the RCS produced the expected policy results in local water-management practices is still controversial. Some scholars have identified practical dilemmas in the RCS through case analysis and practical observations. Wang and Cai, through their analysis grounded in new institutional economics, contended that the RCS was challenged in addressing the principal-agent dilemma effectively. They suggested that the potential for collusion among grassroots river chiefs could pose a significant risk, often leading to the obfuscation of authentic governance information, thereby complicating the processes of accountability and assessment [7]. The effectiveness of the RCS was significantly contingent upon the commitment and capabilities of local party and government officials appointed as river chiefs. This dependency was influenced by factors such as the degree of individual attention, willingness to act, available administrative resources, the inherent challenges of balancing multiple objectives, and the personal competencies of the officials involved. This may lead to situations where policies cease to continue after a leader's departure [22]. According to Yan and Zeng, the challenges in executing the RCS at the grassroots level arised from the inadequate development of internal cooperation and trust, the superficiality of cross-sectoral responsibility and risk-sharing mechanisms, and the elongated information flow chain. Simultaneously, the administration of the RCS was skewed towards government dominance, leading to a situation where public engagement was neither sufficiently encouraged nor systematically formalized, thereby diminishing the potential for robust civic involvement [6]. In addition, scholars have used quantitative evaluation to analyze the policy effects of the RCS. Shen et al. utilized water pollution data from 497 state-controlled monitoring points and 150 automatic monitoring stations nationwide. By applying the differences-in-differences (DID) method, they discovered that the RCS has been effective in enhancing DO levels and mitigating black-odor water problems. However, the existing literature also revealed that the RCS has not significantly improved other indicators related to water pollution [11]. Based on weekly state-controlled cross-sectional data and DID methods, Li et al. [12] observed that while the RCS has successfully lowered

NH_3-N levels in water bodies, some water quality indicators, particularly COD and DO levels, were observed to deteriorate during RCS operation. Huang et al., through a multi-period DID analysis of the Yellow River Basin's water quality indicators, revealed that the RCS has significantly improved DO levels and decreased NH_3-N and COD. However, reductions in the permanganate index (COD_{Mn}), and changes in acidity and alkalinity were not markedly observed [13]. Based on the cross-sectional data of 40 prefectural cities in the Yangtze River Economic Belt and using the DID method, She et al. found that the RCS had significant improvement effects on COD and that NH_3-N significantly improved [15]. Using data from 150 state-controlled monitoring sections across 98 prefecture-level cities, Li et al. indicated a notable improvement in the comprehensive water quality index and in key indicators such as DO, NH_3-N, and COD. Employing regression discontinuity design, Wu identified several critical factors influencing the effectiveness of the RCS governance, including the river's length, the local fiscal expenditure on environmental protection, and the environmental protection pressure [23].

The above studies have explored the RCS and provided many strategies for improving the practice of the RCS and evaluating its effects in China. However, the existing literature adopted different data sources, indicator measurement operationalization, research areas and technical analysis methods, and the research on the governance effect of the RCS is still under debate. This study took Guangdong Province as the main research object, based on the water quality monitoring data of rivers flowing into the sea, and used the RDD method as a quantitative analysis tool to evaluate the effectiveness of improving the water environment quality after the implementation of the RCS in Guangdong Province. Evaluating the effectiveness of the RCS implementation and identifying prevailing challenges, this study presented tailored solutions to make the RCS more effective in practice, focusing on scientific and feasible improvements. Our work aimed at improving the institutional settings and operations of the RCS towards a sustainable water management mechanism and ensuring its long-term viability and effectiveness.

3. Research Design and Data

3.1. Model Specification

Within the corpus of the existing literature, two methodologies have been predominantly utilized for the quantitative evaluation of environmental policy effects. The first method, known as the single-difference approach, involves a straightforward comparison of water quality indicators before and after the full implementation of the RCS. It does not adequately differentiate between effects attributable to RCSs and those stemming from other environmental policies within their jurisdictions. Additionally, it fails to control for the inherent trend of water quality changes in the RCS [24]. The second is the DID method, which addresses the potential endogeneity problem by selecting other cities as a control group to deal with trends in common water quality changes that different cities have. However, the DID method cannot completely solve the problem of unobservable effects, other than those of the RCS, which are correlated with the decision to receive the treatment. At the same time, the macro-policy environment also changes over time (time effect), so the differences before and after the implementation of the RCS in the region may not be the treatment effect, and it is not possible to distinguish between the effects of the RCS policy and the other environmental policies on the changes in water quality indicators. Optimally, the DID method requires the selection of regions that are almost identical for treatment and control groups [25], with the key distinction being the implementation status of the RCS (one with RCS and the other without), apart from the policy shock factor. Such careful selection is fundamental to effectively isolate and measure the RCS's effectiveness. Since the RCS was implemented in Guangdong Province around the same time as its national introduction, locating a control group that closely matches Guangdong's economic, social, and water-resource profiles is challenging. This closeness in implementation timelines coupled with the difficulty in identifying a comparable control region makes the DID method unsuitable for this study. The RDD is regarded as one of the most credible nonexperimental methodologies within the domain of causal inference [26]. The RDD approach leverages a sudden policy implementation (or a similar abrupt change) as a threshold, distinguishing its effects from those of other continuously varying factors, both observable and unobservable. This is achieved through a methodical examination of the shifts in dependent variables pre- and post-intervention. Crucially, the RDD approach effectively circumvents the endogeneity issues often encountered in causal estimation, especially in scenarios where randomized trials are impractical. This method thus provides a more accurate estimation of the true causal relationships between variables [27]. In the RCS, if it is possible to observe sudden changes in water quality indicators before and after the full implementation point of the RCS, and other factors are recognized as continuous changes, then it can be inferred that the sudden changes in water quality indicators are caused by the RCS's full implementation, which means that the RCS is effective. If the corresponding sudden changes in water quality indicators cannot be observed, the RCS is considered ineffective.

The estimated equation for the local treatment effect (LATE) γ at the point of discontinuity is based on the variable time-trend approach described in Angrist and Pischke [28], Viard and Fu [29], and Clark et al. [30]:

$$Lnindicator_{it} = \beta_0 + \gamma T_{it} + \beta_1 D(t)_k \times T_{it} + \beta_2 D(t)_k \times (1 - T_{it}) + \eta X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

where $Lnindicator_{it}$ denotes the logarithm of the water quality indicator for city i at time t (year, month). T_{it} is a dummy variable for the RCS's full implementation, indicating whether city i is in the period of full implementation of the RCS at time t (year, month), where the period of full implementation is defined as 1; otherwise, the period is defined as 0. $D(t)_k$ denotes the k-th period (month) from the RCS's full implementation, which is called the driver variable, meaning the number of periods from the policy breakpoint. The month when the RCS is fully implemented is set to 0: negative values before that month and positive values after that month. The interaction term of T_{it} and $D(t)_k$ is incorporated to account for the effects of variable time trend on both sides of the breakpoint. X_{it} controls for the effects of climate change and human economic and social activities on water quality indicators, specifically population density, air temperature, rainfall, gross domestic product (GDP), gross industrial product, cultivated land area, and urban built-up-land area. μ_i is the area fixed effect, δ_t is the time fixed effect, and ε_{it} is the stochastic disturbance term.

The regressions report standard deviations corrected for heteroskedasticity and serial correlation, enhancing the reliability of the findings. The parameter γ within the equation is of significant interest, as it represents the direct impact of the RCS's full implementation on water quality indicators, distinct from confounding influences of climatic, economic, and social factors, as well as independent time trends in these indicators. For γ estimates to be consistent and valid, it is essential that all factors influencing water quality indicator changes are continuous, barring discrete intervention brought about by the RCS's full implementation.

3.2. Data Source and Operationalization

This study empirically examined the changes in various water quality indicators pre-and post-full implementation of the RCS in Guangdong Province, with an aim to empirically estimate the RCS's effectiveness. Characterized by its extensive river networks, Guangdong encompasses primarily the Pearl River Basin—including the Dongjiang River Basin, Xijiang River Basin, Beijiang River Basin, and Pearl River Delta Region—and the Han River Basin, which flows into the sea. Additionally, rivers along Guangdong's eastern and western coasts play a significant role. The Pearl River, the province's largest, formed by the convergence of its west, north, and east tributaries, lacks a single origin and flows into the South China Sea through eight gateways, namely, Jiaomen, Humen, Hongqimen, Moudaomen, Jitimen, Hutiaomen, Yamen, and Hengmen, spanning six cities and counties in the province. Given Guangdong's dense river network and rich water resources, understanding how to effectively address the growing water pollution amidst urban construction and economic development has become a matter of widespread concern.

3.2.1. Operationalization of Variables

Dependent Variables. Shifts in various water quality monitoring indicators offer a tangible measure of the RCS's impact on the water environment. While the existing literature has predominantly used state-controlled cross-sectional data of rivers for variable operationalization, this study opted for cross-sectional monitoring data from rivers flowing into the sea. This methodological choice was intended to more effectively circumvent measurement biases that may arise from local governments' efforts to align with standard cross-sectional indicator requirements. At the same time, the data from entire river courses may not be sufficient due to the complexity of river water conditions. Since coastal rivers converge and flow into the sea at the estuaries, the monitoring data of the outlet sections may accurately capture the overall situation of water pollution of coastal rivers, thereby providing a more objective evaluation of the policy effects as implemented in Guangdong Province.

In this study, eight water quality monitoring indicators, including pH, DO, COD_{Mn}, biochemical oxygen demand (BOD), NH_3-N, COD, TN, and total phosphorus (TP), were selected as dependent variables. The dataset was sourced from the publicly accessible monthly monitoring information of seabound rivers provided by the Department of Ecology and Environment of Guangdong Province. This dataset encompassed water quality monitoring data from coastal river cross-sections in Guangzhou and Shenzhen, and 11 other coastal prefectures across Guangdong Province. Since the relevant data have been publicly released since January 2015, the data spanned from January 2015 to March 2022 for this study. It is noteworthy that modifications in the network of monitoring stations—through additions, removals, or changes—were observed in some coastal cities. To ensure measurement consistency, this study exclusively considered monitoring stations that had operated continuously over the entire data collection period. It systematically excluded stations introduced or decommissioned midway through this span. The monitoring station information is shown in Figure 1.

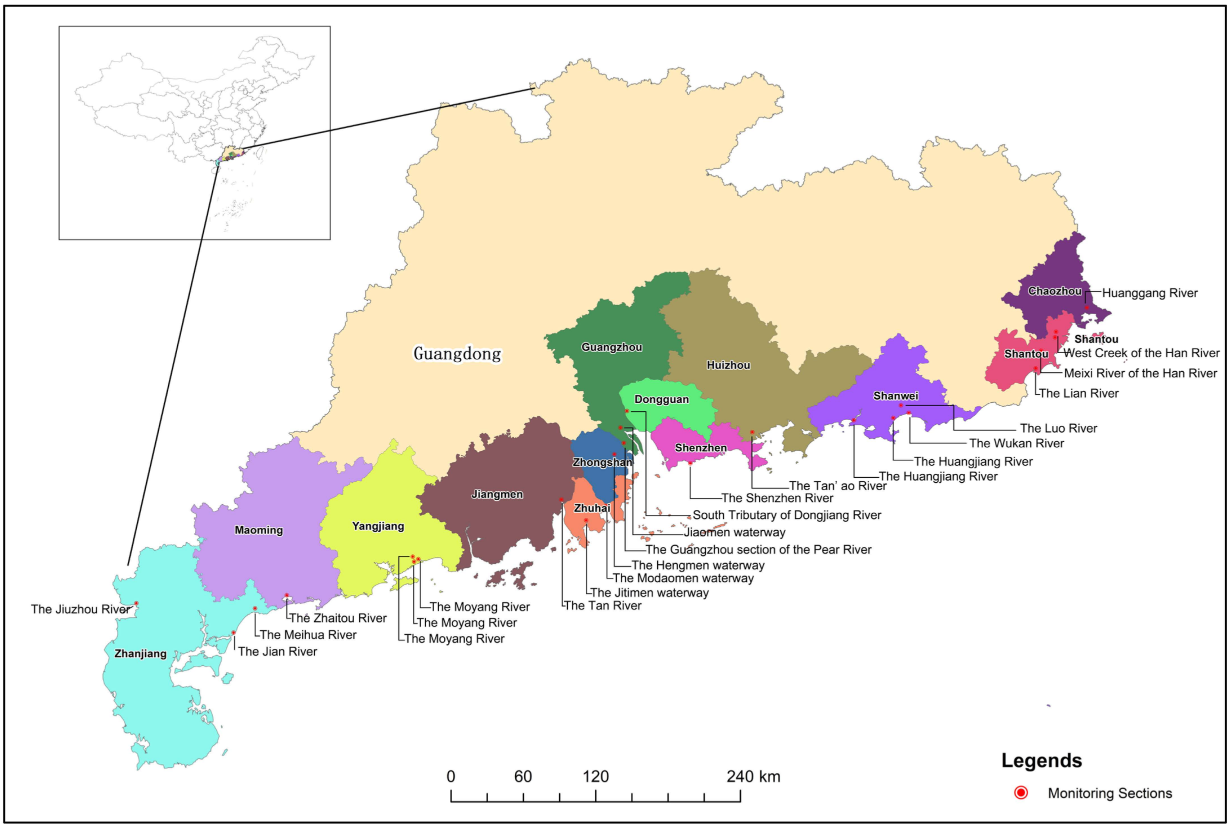

Figure 1. Monitoring Sections of rivers flowing into the sea in 13 coastal cities of Guangdong Province. Source of Information: Guangdong Provincial Department of Ecological Environment, information disclosure on monitoring of rivers entering the sea in Guangdong Province.

Independent Variable. The dummy variable for the RCS's full implementation is the independent variable for our interest. In 2017, Guangdong Province proactively released the Working Program for the Comprehensive Implementation of the RCS. This program, elaborating on the national directive, advocated for a five-level RCS structure (provincial, city-level, county/district-level, township-level, and village-level units). Due to the variation in timelines among the cities of Guangdong Province for achieving full implementation of the RCS and establishing its organizational framework, the dummy variable for the RCS's full implementation is measured with the information on the exact months of the RCS's full implementation in each city retrieved from the cities' RCS work programs, supplemented by press releases and communications from city river-chief offices. Guangzhou and Shenzhen, with prior exploration experience, achieved full implementation of the RCS in July 2017, while the time point for the full implementation of the RCS in the other 11 prefectural-level cities, including Maoming, Jiangmen, Huizhou, Dongguan, Chaozhou, Zhuhai, Zhanjiang, Yangjiang, Shanwei, Shantou, and Zhongshan, was January 2018.

Control Variables. Data on control variables such as population, GDP, arable land area, urban-construction land area, and secondary industry outputs were obtained from the statistical bureaus of each city and the China City Statistical Yearbook. Monthly temperature and rainfall figures for the cities were calculated using historical data from China Weather, Weather Underground, and the Environmental Cloud big data service platform. The descriptive statistics of the main variables are shown in Table 1.

Table 1. Descriptive Analysis of Main Variables.

Variables	Unit	Sample Size	Mean	Standard Deviation	Minimum	Maximum
pH	\	1131	7.309	0.425	6.00	9.00
DO	mg/L	1131	1.736	0.485	−1.427	2.965
COD_{Mn}	mg/L	1131	1.243	0.544	−0.693	2.965
BOD	mg/L	1129	0.778	0.783	−1.609	2.879
NH_3-N	mg/L	1130	1.025	0.688	−1.022	3.726
COD	mg/L	1130	2.549	0.606	0.000	4.205
TN	mg/L	1122	1.024	0.688	−1.021	3.726
TP	mg/L	1131	−1.989	0.927	−4.605	2.033
Population (annual)	Persons/m^2	1131	7.055	0.962	5.758	9.088
Temperature (monthly)	°C	1131	23.867	5.003	13.000	31.200
Rainfall (monthly)	mm	1131	1080.389	1204.395	0.000	5778.134
GDP	CNY billion	1131	6.589	0.8	5.039	9.091
Arable land area (annual)	Hectares	1131	4.507	0.919	2.869	6.139
Urban-construction land area (annual)	Hectares	1131	5.066	1.028	2.833	7.022
Secondary industry outputs (annual)	Billions	1131	3.427	0.871	1.806	5.847

Note: Except for pH, all variables' values in this table are presented in logarithmic form.

3.2.2. Descriptive Statistics

Table 2 presents the detailed descriptive analysis and *t*-tests for the key variables, comparing the values before and after the RCS's full implementation across 13 cities in Guangdong Province. Notably, pH levels were found to consistently remain within acceptable threshold limits throughout the study period. Excluding the TN indicator, significant improvements in COD_{Mn}, BOD, NH_3-N, COD, TP, and DO were observed in post-RCS implementation. The *t*-tests for these six indicators before and after the RCS's full implementation were significant at the 1% level. These findings indicate that the RCS's full implementation has precipitated a statistically significant enhancement in some water quality indicators, underscoring the policy's beneficial impact on the water environment in Guangdong Province. However, the results of the descriptive statistics cannot accurately reflect the policy effectiveness of the RCS's full implementation in Guangdong Province.

Table 2. Descriptive analysis of main variables.

Variables	Sample Mean	Before the RCS	After the RCS	*t* Test
pH	7.309 (0.012)	7.327 (0.018)	7.297 (0.017)	0.030 (0.025)

Table 2. *Cont.*

Variables	Sample Mean	Before the RCS	After the RCS	*t* Test
DO	1.736	1.686	1.769	−0.084 ***
	(0.014)	(0.023)	(0.018)	(0.029)
COD_{Mn}	1.243	1.315	1.194	0.121 ***
	(0.016)	(0.027)	(0.019)	(0.032)
BOD	0.778	1.062	0.585	0.477 ***
	(0.023)	(0.031)	(0.030)	(0.045)
NH_3-N	−0.823	−0.531	−1.020	0.049 ***
	(0.039)	(0.060)	(0.050)	(0.079)
COD	2.549	2.744	2.417	0.327 ***
	(0.018)	(0.027)	(0.022)	(0.035)
TN	1.024	0.997	1.043	−0.045
	(0.020)	(0.037)	(0.023)	(0.041)
TP	−1.989	−1.759	−2.144	0.384 ***
	(0.028)	(0.051)	(0.028)	(0.055)

Note: Except for pH, all variables' values in this table are presented in logarithmic form. The numbers in parentheses below the values indicate the statistical characteristics and the results of *t*-tests performed on these variables. *** indicate significance levels at 1%, respectively.

4. Empirical Analysis Results

4.1. Basic Regression Results

Before estimating the discontinuities, Figure 2 shows the scatter plots of the eight water-quality monitoring indicators near the discontinuities and their fitting curves, respectively. The three-order polynomial regression model better fitted the changes in 35 periods (months) before and after the RCS's full implementation in Guangdong Province. As shown in Figure 2, several water quality indicators, including COD_{Mn}, BOD, NH_3-N, COD, TP, and DO, had obvious breakpoints near the RCS's full implementation, while pH and TN had no obvious discontinuities. These findings indicate that the RCS positively impacted the water quality of rivers in Guangdong Province. Meanwhile, pH levels consistently met the required standards, though clear discontinuity was not shown in their trend.

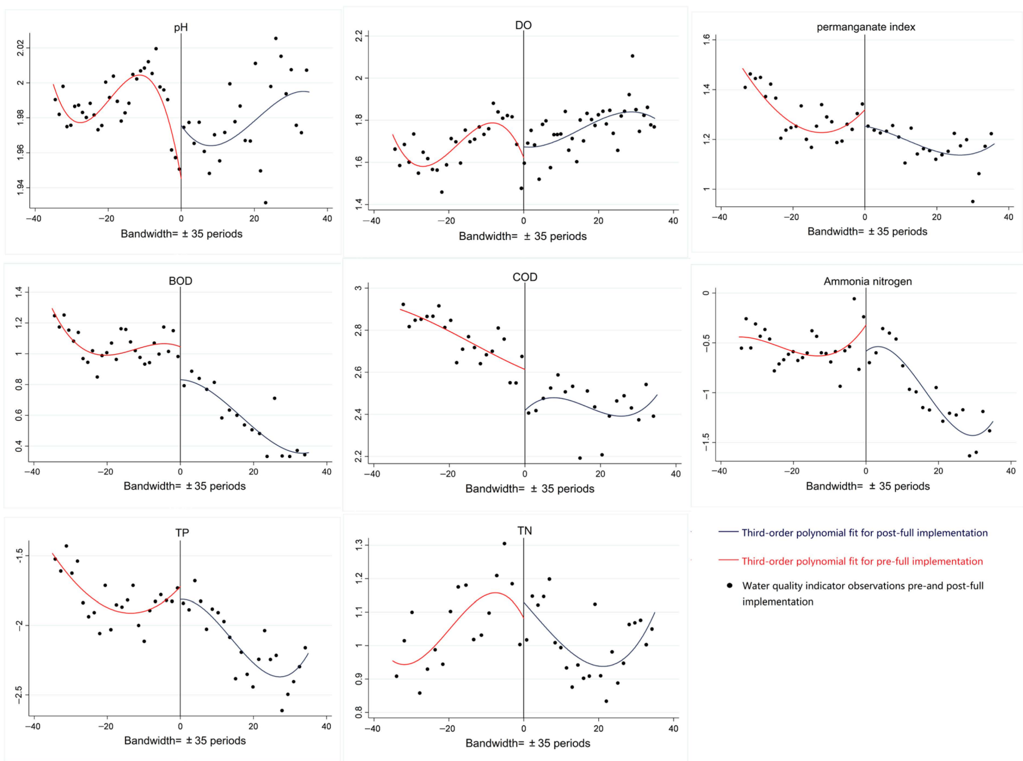

Figure 2. Third-order polynomial fitted curves for eight water quality indicators in rivers flowing into the sea before and after RCS's full implementation in 13 coastal cities of Guangdong Province (over 35 periods).

In this study, the bandwidth was selected as the date distance from the discontinuity point. The shorter the bandwidth, the lower the requirements for the control variables. Within a narrower time window, other indicators that may affect the dependent variables are less likely to change drastically, thus providing a better solution to the problems of omitted variables. However, by choosing a narrower time window, a larger number of sample observations will be lost, causing errors in the estimation results. Therefore, in this study, we first used the 30 periods before and after the RCS's full implementation as the bandwidth and set it as the benchmark regression. In terms of the polynomial around time t, this study used the approach in Lee and Lemieux by using the AIC criteria to select the order of the polynomial regressions [31], and the final analysis employed a third-order polynomial regression model.

Table 3 presents the results of the RDD method (30 periods before and after) when the time trends were fitted with a third-order polynomial regression, including the interaction term of the discontinuity dummy variable with the time polynomial and a series of influences of climate change and human economic and social activities. The results show that water quality indicators, such as DO, COD_{Mn}, BOD, NH_3-N, COD, and TP, were significantly different before and after the full implementation of the RCS. When controlling for the other variables, the RCS's full implementation resulted in an increase of approximately 6% in DO, a decrease of approximately 11.1% in COD_{Mn}, a decrease of approximately 13.8% in BOD, a decrease of approximately 21.8% in NH_3-N, a decrease of approximately 16.2% in COD, and a decrease of approximately 15.3% in TP, with correlation coefficients passing the test of significance at the level of 10% and above. Among the significant water quality indicators, NH_3-N showed the largest decrease. This result may be closely linked with the evaluative indicator system for the RCS in Guangdong Province and local special remediation campaigns of "comprehensive eradication of the black-odor waters". However, for TN, the coefficient of the effect of the RCS had a negative sign but was not significant in the discontinuity estimation. This insignificant result may infer that the RCS's full implementation failed to bring positive and significant effects to the improvement of TN in rivers. In the joint analysis of the effect of the RCS's full implementation and the polynomial cross-term coefficient, we found statistical significances in DO, COD_{Mn}, BOD, NH_3-N, COD, and TP, while the test of the cross-term coefficient of TN was not significant. This result further indicates the RCS's full implementation has not yet brought about a significant policy effect on TN in the river management.

Table 3. Estimation of the effects of the RCS's full implementation on water quality indicators (breakpoint policy effects with time-varying trends).

	pH	DO	COD_{Mn}	BOD	NH_3-N	COD	TN	TP
RCS's full implementation	−0.041 (0.051)	0.060 ** (0.030)	−0.111 * (0.059)	−0.138 ** (0.066)	−0.218 *** (0.045)	−0.162 *** (0.052)	−0.054 (0.064)	−0.153 * (0.080)
Population	−0.008 (0.026)	−0.018 (0.027)	−0.024 (0.035)	−0.025 (0.049)	0.261 *** (0.092)	−0.025 (0.040)	−0.035 (0.031)	−0.119 *** (0.024)
Temperature	−0.002 (0.003)	−0.008 *** (0.003)	0.003 (0.003)	0.004 (0.005)	−0.024 *** (0.008)	−0.000 (0.004)	−0.014 *** (0.004)	−0.003 (0.003)
Rainfall	−0.001 *** (0.000)	−0.000 *** (0.000)	−0.000 * (0.000)	−0.000 * (0.000)	0.000 * (0.000)	−0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
GDP	0.092 *** (0.007)	−0.605 *** (0.092)	0.505 *** (0.128)	0.584 *** (0.146)	1.102 *** (0.262)	0.013 (0.015)	0.447 *** (0.088)	0.403 *** (0.153)
Arable land area	−0.114 *** (0.020)	−0.005 (0.134)	0.234 *** (0.025)	0.169 *** (0.036)	0.512 *** (0.065)	0.246 *** (0.026)	0.318 *** (0.028)	0.134 *** (0.023)
Urban-construction land area	−0.098 *** (0.027)	−0.013 (0.024)	0.070 * (0.036)	0.184 *** (0.042)	0.194 ** (0.077)	0.185 *** (0.038)	0.321 *** (0.028)	0.167 *** (0.031)
Secondary industry outputs	0.005 (0.064)	0.249 *** (0.081)	−0.392 *** (0.131)	−0.551 *** (0.141)	−0.999 *** (0.255)	−0.226 ** (0.115)	−0.280 *** (0.083)	−0.390 ** (0.152)
Yearly Effects	yes	yes	yes	yes	yes	yes	yes	yes
Regional Effects	yes	yes	yes	yes	yes	yes	yes	yes
Constant	7.887 *** (0.267)	5.331 *** (0.421)	−2.100 *** (0.439)	−2.570 *** (0.516)	−8.974 *** (0.923)	0.781 * (0.435)	−3.388 *** (0.341)	−1.434 *** (0.444)

Table 3. *Cont.*

	pH	DO	COD_{Mn}	BOD	NH_3-N	COD	TN	TP
Policy effect with polynomial interaction coefficient test (prob > F)	0.279	0.005	0.003	0.002	0.009	0.005	0.213	0.002
Adjusted R^2	0.165	0.216	0.215	0.274	0.231	0.211	0.259	0.147
Sample size	780	780	780	780	780	780	780	780
Polynomial order	3	3	3	3	3	3	3	3

Note: Values in parentheses are heteroskedasticity-robust standard errors of the regression coefficients; *, **, and *** indicate significance levels at 10%, 5%, and 1%, respectively.

4.2. Robustness Test

Our empirical evidence suggests significant enhancements in water quality indicators, such as DO, COD_{Mn}, BOD, NH_3-N, COD, and TP, attributable to the RCS's full implementation in Guangdong Province. However, the impact on TN levels in the river appears to be statistically insignificant, indicating a lack of a discernible policy effect in this specific domain. Because the validity of the regression discontinuity design may be affected by other conditions and factors, further robustness testing is needed.

Based on Lee and Lemieux's study, this study adjusted the bandwidth further, for bandwidth sensitivity tests to accurately estimate the treatment effects at neighboring discontinuities. Table 4 lists the bandwidth sensitivity tests for 12, 20, and 36 periods before and after the RCS's full implementation in Guangdong Province. In the bandwidth of 12 periods before and after the RCS's full implementation, the policy effect was not significant, with only water quality indicators such as NH_3-N and COD showing statistically significant decreases, while other indicators were not significant. This may be due to the complexity of local water pollution problems that arises from an extensive network of rivers, the high density of these waterways, the sophisticated development of regional water systems, and the variability of pollution sources across different regions. Concurrently, the management of rivers and lakes represents an enduring and time-consuming task. The lag in significant outcomes underscores the fact that improvements in water quality were not realized instantaneously after the RCS's full implementation. Instead, the effectiveness of the RCS's full implementation became progressively apparent over time, indicating a gradual yet significant enhancement in water quality indicators. The results of 20 and 36 periods before and after the full implementation are shown in Table 3, with a significant increase in DO and a significant decrease in water quality indicators such as COD_{Mn}, BOD, NH_3-N, COD, and TP, while TN appears to be insignificant for the RCS policy effect under the estimation of different bandwidths.

Table 4. Bandwidth sensitivity test.

	pH	DO	COD_{Mn}	BOD	NH_3-N	COD	TN	TP
Before and after 12 Periods (First-Order)								
The RCS's full implementation	−0.012 (0.058)	0.022 (0.050)	−0.035 (0.077)	−0.012 (0.015)	−0.011 * (0.006)	−0.014 * (0.007)	−0.007 (0.014)	−0.009 (0.017)
Adjusted R^2	0.359	0.335	0.354	0.389	0.327	0.329	0.395	0.278
Climate factors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample size	312	312	312	312	312	312	312	312
Before and after 20 Periods (Second-Order)								
The RCS's full implementation	−0.035 (0.044)	0.033 * (0.017)	−0.054 * (0.028)	−0.076 ** (0.038)	−0.125 ** (0.029)	−0.098 ** (0.047)	−0.033 (0.028)	−0.079 * (0.041)
Adjusted R^2	0.205	0.275	0.263	0.311	0.278	0.278	0.308	0.197
Climate factors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample size	520	520	520	520	520	520	520	520

Table 4. *Cont.*

	pH	DO	COD_{Mn}	BOD	NH_3-N	COD	TN	TP
Before and after 36 Periods (Excluding Guangzhou and Shenzhen, Third-Order)								
The RCS's full implementation	−0.040 (0.077)	0.063 ** (0.032)	−0.129 * (0.068)	−0.142 ** (0.068)	−0.232 *** (0.041)	−0.181 *** (0.054)	−0.057 (0.058)	−0.160 * (0.077)
Adjusted R^2	0.124	0.192	0.187	0.205	0.197	0.184	0.207	0.115
Climate factors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample size	792	792	792	792	792	792	792	792

Note: Values in parentheses are heteroskedasticity-robust standard errors of the regression coefficients; *, **, *** indicate significance levels at 10%, 5%, and 1%, respectively.

To address the concerns of unobservable and time-varying factors that still have an impact on the improvement in water quality change, virtual breakpoint-timing testing was incorporated. The virtual breakpoint time in Table 5 was set to six months in advance (six periods). If there were significant changes in water quality indicators before and after the virtual breakpoints, it suggests that water quality changes may be influenced by other unobservable factors, and the policy effect of the RCS remains uncertain. The virtual breakpoint test results show that the coefficients of pH, DO, and TN were positive, and the coefficients of the remaining indicators were negative after including virtual breakpoint times, but the water-quality improvement effect captured by virtual breakpoint times was not significant and nor was the cross-term coefficient test.

Table 5. Virtual breakpoint-time test.

	pH	DO	COD_{Mn}	BOD	NH_3-N	COD	TN	TP	pH	DO
The RCS's full implementation	−0.192 (0.203)	−0.255 (0.215)	-	-	-	-	-	-	-	-
Virtual breakpoint (six periods ahead)	-	-	0.004 (0.012)	0.013 (0.042)	−0.012 (0.022)	−0.025 (0.038)	−0.003 (0.003)	−0.009 (0.012)	0.004 (0.003)	−0.002 (0.012)
Socioeconomic variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	792	792	792	792	792	792	792	792	-	-
Polynomial order	3	3	3	3	3	3	3	3	3	3

Note: Values in parentheses are heteroskedasticity-robust standard errors of the regression coefficients.

5. Conclusions and Discussion

5.1. Research Findings

This study used the RDD method to systematically and empirically evaluate the policy effectiveness of the RCS on water environment quality. The analysis was based on monthly water-quality-monitoring sectional data collected from 25 water-quality monitoring stations in rivers flowing into the sea across 13 prefecture-level cities in Guangdong Province, spanning January 2015 to March 2022. The results show that the RCS can improve water quality to a certain extent. Statistically significant changes in several water quality indicators were found after the RCS's full implementation in Guangdong Province, particularly, a significant increase in DO and noticeable decreases in COD_{Mn}, BOD, NH_3-N, COD, and TP. Meanwhile, the pH levels consistently remained within the required thresholds of the water-quality standard limit throughout the monitoring period. Among all the indicators, NH_3-N showed the greatest reduction.

After the RCS's full implementation in Guangdong Province, all-level governments across the province were motivated to work on the coordinated implementation of the "five-cleanings" initiative. The "five-cleanings" initiative encompassed multifaceted environmental cleanup operations, specifically, purging illegal sewage outlets, removing floating debris from water surfaces, purging sedimentary contaminants, clearing obstructions in rivers and lakes, and demolishing illegal structures encroaching on river and lake areas. In particular, the policy emphasized the need for targeted interventions focused on eliminating black-odor water bodies. For instance, Guangzhou Municipality delineated a clear priority for the remediation of 147 rivers that were identified as possessing black-odor water bodies and was committed to "comprehensive black-odor eradication" and "sustained environmental cleanliness" as pivotal governance objectives. Consistent with the objectives of the RCS, transparency, DO, NH_3-N, and COD_{Mn} have been established as the principal indicators for assessing the RCS's effectiveness in addressing the black-odor phenomena. Additionally, the main tasks of the river chiefs are to coordinate water and shore pollution control, to improve the sewage-discharge control mechanism, to strictly control pollution caused by industrial enterprises, and to optimize the layout of outlets for sewage dumped into rivers and lakes. In order to fulfill these tasks, many cities have upgraded their sewage discharge systems and treatment facilities and worked on the illegal discharges from small, scattered, and polluting enterprises. Furthermore, curbing agricultural nonpoint source (NPS) pollution was closely connected with the "five-cleanings" initiative and targeted evaluation indicators of NH_3-N and COD. In particular, county-level governments were motivated to conduct a series of special operations centered on scattered livestock- and poultry-raising farms that illegally discharged sewage into water bodies. For instance, according to official reports, after the RCS's full implementation in Shantou, municipal- and county-level governments closed and removed scattered and small swine farms, which raised a total of one million pigs per year. These farms discharged large amounts of high-concentration wastewater without treatment, leading to serious pollution [32]. These endeavors were evidenced by our findings of a significant reduction of COD_{Mn}, BOD, NH_3-N, COD, and TP.

However, statistically significant changes in TN were not found, indicating that the RCS may fall short of realizing the policy effects of comprehensive water pollution control. NH_3-N, as a significant form of nitrogen, is widely present in industrial wastewater and domestic sewage. Its high biological activity makes it readily utilized by microorganisms, leading to the rapid depletion of DO in water bodies. This process further promotes the decomposition of organic matter under anaerobic conditions, resulting in black-odor water bodies. Therefore, the NH_3-N indicator was strongly emphasized in addressing the problems of urban black-odor water bodies. Despite being a traditional pollutant, TN management has presented ongoing challenges, largely due to an emphasis on NH_3-N within the evaluative criteria of the RCS, neglecting TN in the surface-water-quality indicator system. If NH_3-N decreases but TN remains unchanged, this indicates that NH_3-N is converted to nitrate by the improved oxygen conditions, and there is no change in the eutrophication potential of nitrogen. Currently, there is a lack of stringent emission standards for TN in surface river waters and a deficiency in the development and deployment of technologies aimed at reducing TN levels. These obstacles are mirrored in our empirical evidence, which suggests the RCS's limited effectiveness in curtailing TN concentrations.

Our findings also point out the problem of the evaluation framework in the RCS remaining focused on the enhancement of short-term indicators, which involves challenges related to the scientific validity of these assessment indicators. The results show that the RCS had largely achieved the goals of eliminating black-odor water bodies, which often emphasized immediate outcomes rather than long-term ecological progress. Water environment governance and aquatic ecosystem restoration are long-term endeavors which cannot be adequately reflected through short-term assessment indicators. This situation inherently conflicts with the current assessment indicator system for local officials in the RCS. The existing water quality assessment indicators should authentically reflect the health status of river and lake ecosystems. Focusing on short-term effects is crucial for public perception, but long-term water environmental-quality enhancement also requires improvements in ecological diversity, biomass, and aquatic habitats. Furthermore, the current operational framework of the RCS, organized by administrative regions and characterized by a "jurisdiction-based management" approach within the administrative unit, inadvertently contributes to fragmentations in the organizational entities responsible for water governance. This segmentation is at odds with the integral and fluid characteristics of river ecosystems, generating an internal discord. The interjurisdictional factors, such as upstream–downstream and left-bank–right-bank dynamics, may lead to a "multiple strategies for one river" issue during the RCS implementation. Such a segmented protection and management approach is counterproductive to the holistic and collaborative governance and conservation of the river basin.

5.2. Policy Recommendations

Currently, the RCS in China is navigating a critical transition towards sustainable practices, marking a significant shift in river and lake management from traditional concentrated rectification and campaign-style approaches to sustainable and integrated governance models. This transition, informed by our findings on the RCS's effectiveness in Guangdong Province, highlights the urgent need for systematic enhancements in the RCS's institutional design. Such advancements are pivotal for securing a long-term, effective management-and-protection regime for river basins.

One of the key recommendations is the optimization of the existing water-quality indicator system, pivoting the focus towards the holistic health of rivers and lakes. Current achievements of the RCS can lay a foundation for the next phase of focus: promoting river ecological restoration and developing healthy river ecosystems. It is imperative to refine and improve the existing water-quality assessment indicators within the RCS, incorporating TN reduction and relevant control measures in the evaluative indicator system and integrating indicators related to hydrological resources, the physical morphology of rivers and lakes, water quality, aquatic biology, and the socio-service functions of these water bodies. It is recommended to establish a comprehensive assessment system for river and lake health, incorporating dynamic monitoring for their long-term health. This entails the establishment of sustained criteria and guidelines for continuous assessment and management, and it is recommended that the specific work of the RCS be divided into water resource protection, water shoreline protection, water pollution prevention and control, and aquatic ecosystem protection and social service function protection.

Second, the existing approach of fragmented "jurisdiction-based management" in water governance should be changed, to emphasize the holistic characteristics of rivers and establish the RCS regime based on a river-basin scale. The river basin is a complex ecosystem with unique regional heterogeneous characteristics and holistic functions. The complexity of river basin management lies in the fact that activities in the upper reaches can have downstream impacts, and conflicts of interest may arise among different administrative regions. Furthermore, there is an inherent inconsistency between the existing "jurisdiction-based management" approach and river basin characteristics. It is proposed to shift from a "jurisdiction-based management" approach to a governance system that delineates the river basin as the governance unit in order to promote the collaborative governance and coordination of upstream and downstream, left and right banks, and main and branch rivers within the basin. Such a shift may facilitate the coordinated development of resource, environmental, social, and economic factors within the basin and the realization of holistic governance in the RCS. It is also recommended that the basin-based cooperative mechanism for water environment management in cross-administrative regions be vigorously promoted. In addition, we recommend the establishment of a long-term mechanism for cross-border inspection, information sharing, and joint supervision of the basin to ensure the consistency and coherence of governance measures. Furthermore, incorporating river-basin health assessment indicators into RCS performance evaluation indicators and developing a performance assessment system based on river-basin health evaluation with designated weights are suggested, to ensure the accountability of river chiefs. At the same time, it is essential to consider the natural attributes of rivers, such as their natural flow direction, hydrological cycles, and biodiversity. These factors should be fully considered in governance measures to achieve effective comprehensive management.

Third, agricultural NPS pollution from crop farming and fertilizer use should be emphasized for the next phase of the RCS's focus. Although the proportion of agricultural production in local GDP amounts to less than 10% in the coastal cities for this study, agricultural NPS pollution appears to be a significant source of river pollution. Despite local governments' awareness of the harms of excessive fertilizer use, water pollution resulting from fertilizer use is not effectively addressed under the current RCS. It is highly recommended to implement more stringent regulations within the RCS to reduce fertilizer use and limit the nutrient loads entering water bodies.

Fourth, the successful implementation of the RCS also requires public participation and societal oversight. By educating the public about the importance of water environments and inspiring their active involvement in water conservation, the role of social forces in monitoring and safeguarding water environments can be leveraged. Additionally, the public can use social media, apps, or other platforms to report issues to the river chiefs, making the RCS implementation more transparent and democratic.

In this study, the RDD method was selected to empirically examine the policy effectiveness of the RCS's full implementation in Guangdong Province. Our analysis was based on the data of water quality monitoring of river sections entering the sea in Guangdong Province. However, our work still has some limitations. First, the data we employed were monthly monitoring data of water quality at the point where the river flows into the sea. Future research may benefit from the adoption of weekly or biweekly water-quality monitoring data, enabling a more accurate tracking of the trends in water environmental quality over time. Second, future research may integrate a broader spectrum of data and information pertaining to the conditions of rivers, social forces, and economic development, including adherence to the threshold limits for various indicators, shoreline management practices, ecological indicators, socioeconomic indicators, and the extent of public participation. The enrichment and refinement of these data will facilitate a more comprehensive and accurate evaluation of policy effectiveness, thereby furnishing a robust basis for future policy adjustments.

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