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Original Research Article

The Relationship between Water Pollution and Economic Growth in Central Asian Countries: A Causal Analysis Using Difference-in-Difference (DID) Model

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Abstract: The biggest problem facing the Central Asian countries is water pollution, which undermines environmental security and slows down further economic development. This study examines the relationships between Water pollution, Agricultural production, Aquaculture production, Improved water source, Industry, Surface temperature anomaly, Urban and Rural population growth, and economic growth in Central Asian countries after the transition economics with a Difference-in-differences (DID) for panel-data model, and Heterogeneous effects and reports some findings tried to explain using the diagnostic graphs and tests, using 1990 to 2017 database. According to the survey, agriculture is the main cause of water pollution. Studies have also shown that water pollution increases with the growth of the economy and population in these countries. The results of this study will help to understand the impact of not only water pollution, but also various environmental regulations on pollution control, and will also help formulate future policies.

Keywords: Water pollution; Central Asia; Difference-in-Difference (DID); Heterogeneous effects; Environmental Economics.

1. INTRODUCTION

Central Asia consists of the former Soviet republics of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. Central Asia covers an area of 4 million square kilometers and has a population of 60 million people and a population density of just 15 people/square kilometer. It has a varied topography characterized by vast deserts, grassy steppes, and high, glaciated mountain ranges. Major river systems of the region include the Amu Darya and the Syr Darya. The Major water bodies are the Aral Sea, Lake Balkhash, and Issyk Kul Lake, which are part of the west-central Asia endorheic basin that also includes the Caspian Sea (Figure 1). Most of the surface and ground waters in Central Asia are polluted and do not meet drinking water quality standards. The water quality is very low due to untreated and insufficiently treated wastewater from industrial areas and industrial pollution. In addition, the main reason for water pollution is an increase in the number of breaks and leaks in drinking water pipelines in some regions and a decrease in the uninterrupted operation of water supply services. The use of agricultural irrigation, manure, and fertilizers contaminate surface and groundwater with chemical elements such as salinity, nitrates, and phosphorus. More than a third of Central Asia's population uses unsanitary drinking water, and in some regions, the rate exceeds 50 percent (Yu *et al.*, 2021). In addition, about 55 percent of settlements receive water from pipelines in less than 6 hours a day, and only 10 percent have access to clean water. Water supply services do not provide the required level of security, and many rural communities use drinking water from irrigation canals (Toernqvist *et al.*, 2011). Thus, the search for ways to reduce water pollution is one of the main objectives of research in the field of environmental economics, and there is a need to develop environmental policy and protect the health of the population and ecosystems in Central Asia. In addition, water quality in Central Asia is important in many ways, including drinking water supply, domestic use, irrigation, fisheries, and ecosystem resilience. The novelty of this study lies in the fact that it opens up the possibility of developing water pollution throughout the aquifer of Central Asia and provides scientifically based results in the fight against water pollution caused by agriculture. Only a few panel studies have included Central Asian countries in their water pollution analysis. To the best of our knowledge, there has not been a panel data study investigating the causal relationship between water pollution and economic growth in Central Asia. This is incongruous because Central Asia represents an important case in this regard. As a natural resource-rich country, Central Asian countries have been characterized by a considerable achievement in economic growth and it has been passed through different development stages (Feng *et al*., 2021; Karthe *et al*., 2015; Karthe *et al*., 2017; Liu *et al*., 2020; Toernqvist *et al*., 2011; Yu *et al*., 2021; Zhupankhan *et al*., 2018). For example, Feng *et al*., (2021) showed that nitrogen fertilizer application contributed over 60% to total nitrogen input and was mainly responsible for a 42.9% increase of total grey water footprint from 101.5 to 145.0 billion cubic meter from 1992 to 2018. Water pollution levels increased from 0.55 in 1992 to 2.41 in 2018 and the pollution assimilation capacity of water systems has been fully consumed just by nitrogen load from agriculture since 2005. Greywater footprint intensity and greywater pollution–efficiency types in all Central Asian countries have improved in recent years except for Turkmenistan. Nitrogen fertilizer application and agricultural economy development were the main driving factors that induced nitrogen pollution. Results were validated by riverine nitrate concentrations and the estimates from prior studies. The purpose of this article, then, is to study investigating the causal relationship between water pollution (unsafe water) and economic growth (GDP) in Central Asia. In this study, the unsafe water source in Central Asian countries are based on the relationship between Water pollution, Agricultural production, Aquaculture production, Improved water source, Industry, Surface temperature anomaly, Urban and Rural population growth, and economic growth, with a Difference-in-differences for panel-data model, Heterogeneous effects, unit root tests, and reports some findings tried to explain using Difference-in-differences diagnostic graphs and tests. The article is divided into six sections. Following this introduction in Section 1, there is a review of related literature in Section 2. Section 3 discusses the methodology and data. Section 4 examines the data analysis. Section 5 is the discussion of the findings, while Section 6 concludes with some recommendations and suggestions for future research.

2. LITERATURE REVIEW

The existing empirical literature is presented to have an idea of past empirical findings on the relationship between water pollution and economic growth for different individual countries. The empirical literature abounds with studies that investigate the environmental effects of energy use and economic growth for both developed and developing countries using different datasets, model specifications, methodologies, and functional forms. The existing literature related to this research is reviewed under the following four categories: (I) relationship between water pollution and economic growth, using the different variables (II), the studies on causal effect using the difference-in-difference model, (III) the studies of water pollution in heterogeneous effects, and (IV) Water pollution in Central Asia. A more detailed analysis is presented in the following categories.

The first category of existing literature on the effect of water pollution and economic growth in Nigeria (Joshua *et al*., 2020) and comparative regional studies combined a set of similar income countries, such as Chinese provinces water pollution studies (Fan and Fang, 2020; Sheng and Tang, 2020; Shi *et al.*, 2020), and others, see (Cai *et al*., 2020; Wan and Wang, 2021; Zhai *et al*., 2021). For example, Joshua *et al*., (2020) guide environmental engineers in identifying the pollution sources and developing appropriate strategies in mitigating them. This study aimed to systematically analyze published literature to identify the interaction of the nature and regional distribution of pollution sources in Nigeria in the domain of surface water, groundwater, and rainwater quality. The scope of the analysis was on published literature on the subject in the last two decades. Regional distribution was observed to affect pollution sources for surface water, groundwater and rainwater in Nigeria as differences were observed in each geopolitical zone. Several research questions were raised which became the focus of the literature analysis. The major sources of surface water, groundwater, and rainwater pollution in Nigeria were identified as industrial effluent (18% of research output), hydrogeology (25% of research output), and roof type (31%) respectively. Cai *et al.*, (2020) investigate the relationship between water pollution discharge–wastewater, chemical oxygen demand, and ammonia nitrogen and economic growth–per capita Gross Domestic Production, based on a comparison of the results from two variable coefficient panel data models- a Locally Weighted Smoothed Regression Estimator and Smoothing Scatterplots Model (SSURM) which is a nonparametric model, and a Semi-parametric Seemingly Unrelated Regression Model which considers the contemporaneous correlation of water pollutants that most previous studies have ignored. The empirical results indicate that there exist differences that can be represented by the characteristics of different Environmental Kuznets Curve (EKC) types or different turning points under the same EKC type and that the SSURM may be more conducive to reflecting the real relationship between water pollution and economic growth.

The second category of the several studies was conducted using the difference-in-differences (DID) model (Chen *et al*., 2018; Dendir *et al*., 2019; Paula and Albert, 2018; *Qiping et al.*, 2021; Yeon *et al*., 2020; Zhou *et al*., 2019; Zhu *et al.*, 2020). For example, Chen *et al*., (2018) found that Hazard Analysis Critical Control Points (HAACP) implementation does not affect the flow of the United States seafood imports, while the estimates of the other key variables are consistent across the models seen in previous work. Thus, we find evidence that non-tariff measures like HACCP had a net null effect on imports, though the distribution of imports shifted. Yeon *et al*., (2020) conducted a difference-in-differences technique in comparing the performance of hotels in New York and

Washington D.C. Results show that the regulation had a positive ripple effect on the performance of lower-scale hotels. Zhou *et al*., (2019) conducted an empirical analysis, using the decomposition and difference-in-differences approach. The main conclusions are as follows: (1) Overall, China's emission trading pilots have driven a significant decline in the carbon intensity, resulting in an average annual decline of approximately 0.026tons/10,000 yuan in the pilot provinces. (2) In the sample period, emission trading pilots had a sustained and stable effect on carbon intensity with no time lag. (3) Emission trading pilots reduce the carbon intensity by adjusting the industrial structure. In contrast, energy structure and energy intensity channels have not yet been realized.

The third category of the literature investigates the several studies were conducted using the heterogeneous effects (Donghai *et al*., 2019; Pan and Tang, 2021; Qing *et al*., 2019; Varekar *et al*., 2021; Vu and Papavassiliou, 2019; Yoosuk *et al*., 2010). For example, Pan and Tang (2021) show that both the National Key Ecological Functional Areas Policy (NKEFAP) and Transfer Payment of Ecological Functional Areas Policy (TPEFAP) can reduce water pollution, but the reduction effect is higher for the TPEFAP than for the NKEFAP. For underlying mechanisms, the NKEFAP and TPEFAP reduce water pollution mainly by controlling the industrial waste discharge, rather than by controlling agricultural and domestic pollution. Heterogeneity analysis reveals that counties with higher initial pollution levels and higher economic levels have a greater water pollution reduction effect. They were found to contribute to the understanding of the effect of heterogeneous environmental regulations on pollution control and are conducive to future policymaking. For India, Varekar *et al*., (2021) presented a study that proposes an innovative semi-empirical approach of Seasonal Export Coefficients (SECs) for the estimation of diffuse pollution loads, especially for tropical countries like India. This seasonal heterogeneity is then tested for its possible impact on the rationalization of water quality monitoring locations for the Kali River basin in India. The SECs are estimated for the available water quality dataset of 1999 and 2000. The resulting SECs for Kali river basin are: 2.03 (agricultural), 1.44 (fallow), and 0.92 (settlement) for monsoonal nitrate; while for non-monsoonal nitrate, SECs are 0.51 (agricultural), 0.23 (fallow), and 0.10 (settlement). The monsoonal phosphate SECs for land use classes agricultural, fallow, and settlement are 1.01, 0.68, and 0.25, while non-monsoonal phosphate SECs are 0.27, 0.14, and, 0.03 respectively. The seasonal variation of diffuse pollution sources is effectively captured by SECs. The proposed approach, by considering both point and diffuse pollution, is found efficient in determining optimum locations and the number of monitoring sites where seasonal variations are found evident during experimental years.

The fourth category of the literature explores water pollution in central Asian countries (Karthe *et al*., 2015; Karthe *et al*., 2017; Liu *et al*., 2020; Toernqvist *et al*., 2011; Zhupankhan *et al*., 2018). For example, Liu *et al*., (2020) showed the existing problems related to the utilization of groundwater resources in the transboundary aquifers in this region, they propose developing strategies for on-demand water abstraction, enhancing the ecological protection of transboundary aquifers, and strengthening international cooperation. This paper summarizes the distribution of 34 transboundary aquifers in Central Asia and analyzes the status and potential of groundwater resource uses in this transboundary aquifer. Zhupankhan *et al*., (2018) empirically investigated the Central Asian economies are developing under increasing water deficiency, resulting in developmental problems. The main reasons for this are increasing political tensions and worsening ecological and socio-economic conditions. Kazakhstan was the first country in Central Asia to develop the pre-requisites for a transition towards integrated water resources management. Therefore, Kazakhstan has the potential to lead the development of transboundary water integration between all Central Asian states. A scenario for successful regional cooperation on water management in Central Asia involves establishing legal mechanisms for water management following international water law, assistance by international agencies and donors, and integrated social, economic, and environmental methodology.

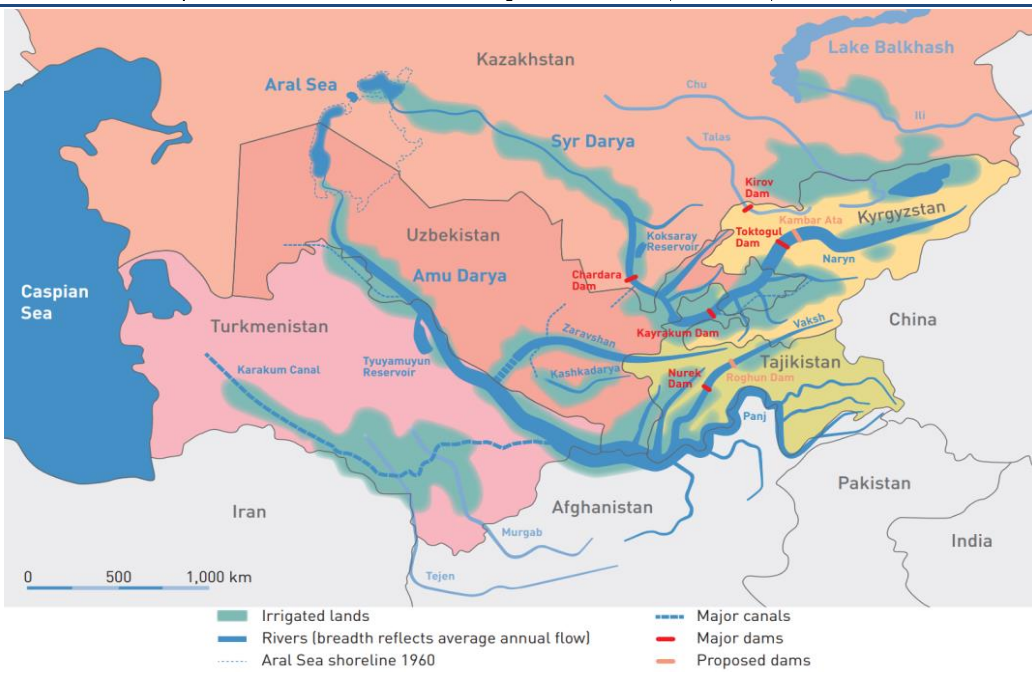

Figure 1: Water resource use in Central Asia
Source: Zoï Environment Network, 2018

3. METHODOLOGY AND DATA

3.1. Source of Data and Model

The present article follows from this literature on Water pollution. It seeks to extend knowledge on this topic and underline the roles of economic growth and Water pollution, using a broad range of the latest data. The purpose of this section is to examine the relationship between Water pollution, Agricultural production, Aquaculture production, Improved water source, Industry, Surface temperature anomaly, Urban and Rural population growth, and economic growth in Central Asian countries. It adopted the Difference-in-differences (DID) Model, Heterogeneous effects, the Robustness test, unit root test, and reports some findings. This paper is focused on economic activities. The key contribution of the present research to the existing literature will be to shed light on and quantify the impact of Water Pollution and Economic Growth of hazardous water pollutants in Central Asia. This study collected data from official sources, including the World Development Indicators (WDI), Food and Agriculture Organization (FOA), Institute for Health Metrics and Evaluation (IHME) database, Organization for Economic Cooperation, and Development (OECD) National Accounts, electronic files and web site. The author used the average Unsafe water source (*lnUWS*) levels at the Central Asian countries level from 1990 to 2017, as reported in the official database, to measure the dependent variables of water pollution. Water pollution data from five countries were collected concerning unsafe water data yearly. The study uses Deaths from Unsafe water (*lnDUW*), Agricultural land (*lnAGL*), Aquaculture production (*lnAQP*), Improved water source (*lnIWS*), Industry (*lnIND*), Surface temperature anomaly (*lnSTA*), Gross Domestic Product (*lnGDP*), Urban population growth (*lnUPG*), and Rural population growth (*lnRPG*) as independent variables. For the estimates of the coefficient of the variables, the following empirical model is formulated. Stata 17.0 econometrics software was used for the analysis.

3.2. Unit Root tests

This section shows graphically the overall statistics of quantitative data in the survey. The different axes show the different units of measure of the variables, and the graphs for each are converted to natural logarithmic values. The simplest study of data properties begins with a study of relative averages and variances of the data. The descriptive statistics and correlation matrix in Table 1 show the logarithmic variable data. Table 2 presents the overall mean values and units of measure for the 28 years of the survey between 1990 and 2017. The author performed unit root test using the variables included in the Fisher-type unit root test based on the Augmented Dickey-Fuller (ADF) test at a significance level of 1% (shown in Table 3).

3.3. Difference-in-differences for panel-data model

The author uses the DID model in this paper because it is powerful to circumvent the endogenous problems that typically arise (Meyer, 1995). The DID model can control the systematic differences between the treatment and control groups and isolate the changes in the outcomes over time between the samples that were and were not affected by the policy. The DID approach can remove the biases that could be the result of trends caused by other factors. Difference-in-differences Modeling the Outcome: The outcome Y_i is modeled by the following equation:

$$Y_{i,t} = \alpha + \beta T_{i,t} + \gamma t_{i,t} + \delta(T_{i,t} \cdot t_{i,t}) + \varepsilon_{i,t} \;\ldots\ldots (1)$$

In the Equation (1), where, the coefficients given by the Greek letters α, β, γ and δ are all unknown parameters and ε_i is a random error term, unobserved "error" term which contains all determinants of $Y_{i,t}$ which this model omits. where, α is a constant term, β is treatment group specific effect (to account for average permanent differences between treatment and control), γ is time trend common to control and treatment groups, and δ is true effect of treatment. $T_{i,t}$ is dummy variable of time, $t_{i,t}$ is a grouped dummy variable (regional dummy variable), $T_{i,t} \cdot t_{i,t}$ is the interaction term between the grouped dummy variables and dummy variables of time. First, the author used the DID model to estimate the average effects of the dependent variable on Unsafe water (water pollution). The proposed DID model can be defined as follows:

$$UWS_{i,t} = \alpha + \beta T_{i,t} + \gamma t_{i,t} + \delta(T_{i,t} \cdot t_{i,t}) + \varphi X_{i,t} + \varepsilon_{i,t} \quad \ldots\ldots\ldots\ldots.. (2)$$

In the Equation (2), where, $UWS_{i,t}$ is the water pollution in central Asian country i in year t. Therefore, the parameter of interest is $\alpha, \beta, \gamma, \delta$, and φ; which represents the estimator of DID and measures net impacts of the independent variables on water pollution in central Asian countries. A negative and significant $\alpha, \beta, \gamma, \delta$, and φ shows that the variables reduces water pollution, while a positive and significant $\alpha, \beta, \gamma, \delta$, and φ means that the variables increases water pollution. $T_{i,t}$ is dummy variable of time, $t_{i,t}$ is a grouped dummy variable (regional dummy variable), $T_{i,t} \cdot t_{i,t}$ is a dummy variable that equals 1 in the years after county i has initiated the independent variables and 0 otherwise. $X_{i,t}$ represents a series of control variables that will influence water quality, including dependent variables, and ε_i is a random error term. Second, the author examines the DID dynamic effect of the variables on water pollution. The author includes a set of dummy variables in the benchmark regression of Equation (1), which can be denoted as:

$$UWS_{i,t} = \alpha + \beta T_{i,t} + \gamma t_{i,t} + \sum_{j=1}^{n} \delta(T_{i,j} \cdot t_{i,j}) + \varphi X_{i,t} + \omega_i + \mu_t + \varepsilon_{i,t} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

In the Equation (3), where, $\sum_{j=1}^{n} \delta(T_{i,t} \cdot t_{i,t})$ represents the interaction term between the dummy variable of the central Asian counties implemented the independent variables and the time length after implementing the independent variables. When $j = 1, 2, 3, \ldots, n$, it means 1, 2, 3,… years after the independent variables are implemented. ω_i is vectors of the county dummy variables that indicate county fixed effects. μ_t is vectors of the year dummy variables that indicate year fixed effects. The remaining variables are the same as in Equation (1) and (2).

3.4. Heterogeneous effects

This empirical analysis above suggests that the independent variables have a statistically significant impact on the water environment. In this section, the author explores whether the impact of the independent variables on water pollution is heterogeneous across different initial pollution levels. Third, to find out how the independent variables led to the reduction of water pollution, the author further explores the impact mechanisms of the independent variables on water pollution:

$$\text{effect}lnUWS_{i,t} = \alpha + \beta T_{i,t} + \gamma t_{i,t} + \delta_1(T_{i,t} \cdot t_{i,t}) + \varphi X_{i,t} + \omega_i + \mu_t + \varepsilon_{i,t} \quad \ldots\ldots\ldots\ldots (4)$$

In Equation (4), effect$lnUWS_{i,t}$ is the water pollution indicators represent different heterogeneous effects mechanisms. The parameter of interest is δ_1, which measures the net effects of the independent variables on different heterogeneous effects mechanism indicators. The remaining variables are the same as in Equation (1), (2) and (3).

3.5. Difference-in-differences diagnostic graphs and tests

An important prerequisite for adopting the DID method is the parallel trend. It is common to complement the regression analysis with graphical diagnostics and tests that provide evidence of whether an estimated effect can be given a causal interpretation. As discussed in DID intro, the author would like to observe that the treated and control groups had mean outcomes that evolved similarly to each other over time before the treatment. This is usually referred to as a parallel-trends or common trends assumption. The author would also like to ascertain that neither the control nor the treatment group changed their behavior in anticipation of the treatment. Also, the author tests the strategy to observe if the treatment group and the control group meet the same trend assumption.

4. RESULT

4.1. Unit Root Tests Result

The descriptive statistics of the variables are provided in Table 1, respectively. A look at the descriptive analysis shows that the investigated variables display some insignificant variances in the statistics. For dependent variables, the average and standard deviation values of *lnUWS* are 0.6834 and 1.5001 respectively. The average and standard deviation values of *lnDUW* stand at 1.1960 and 1.3257 respectively. *lnAGL*, *lnAQL*, and *lnIWU* use have mean values of 4.0647, 6.2418, and 4.5513 respectively, while the respective standard deviations are 0.3100, 2.1126, and 0.0379 respectively. The large standard deviations of the variables are indications of large variations of the values around their averages, hence, large disparities. To test the distribution properties of these variables, the study uses Jarque-Bera, Skewness, and Kurtosis as indicators. In a normal distribution Kurtosis is 3, and skewness is 0. In what follows, more properties of these variables are presented.

Table 1: Descriptive statistics of variables

	Mean	Std. Dev.	Min	Max	Variance	Skewness	Kurtosis	Jarque-Bera
lnUWS	-0.6834	1.5001	-3.5065	1.8870	2.2503	-0.1844	1.9887	0.0341
lnDUW	1.1960	1.3257	-1.4591	3.3536	1.7577	-0.3134	2.0259	0.0200
lnAGL	4.0647	0.3100	3.4637	4.4083	0.0961	-0.8810	2.4535	4.9e-05
lnAQP	6.2418	2.1126	2.4849	10.8676	4.4631	0.1549	2.0956	0.0696
lnIWU	4.5513	0.0379	4.4897	4.5991	0.0014	-0.5493	1.8078	4.7e-04
lnIND	3.4257	0.3246	2.5004	4.1984	0.1053	0.3164	2.9944	0.3108
lnSTA	-0.4969	1.0971	-4.6051	1.5390	1.2037	-1.6464	2.2306	1.1e-27
lnGDP	23.4757	1.3093	21.4873	26.0015	1.7143	0.2662	1.8488	0.0092
lnUPG	0.4666	0.6635	-3.1964	1.4026	0.4403	-2.3163	1.1327	1.2e-96
lnRPG	0.1894	0.6571	-2.0174	1.2265	0.4318	-1.0783	2.0309	1.9e-07

Notes: All variables are expressed in their logarithms, Std. Dev.=standard deviation, Min=minimum, and Max=maximum. Source: Compiled by the author based on WDI, IHME, FOA, and OECD database (1990-2017).

The correlation coefficient between *lnUWS* and *lnDUW* is 98.73, implying that the relationship between ln*UWS* and ln*DUW* is 98.73% in a positive direction. The relationship between *lnUWS* and *lnGDP* is approximately 77.42%. The relationship between *lnSTA* and *lnGDP* is approximately strongly by 13.74%, while the relationship between *lnAGL*, *lnIND*, and *lnSTA* is 31.21% and 14.27%. The relationship between *lnGDP*, *lnAQL*, and *lnIWU* is approximately 37.71% and 38.74%. The relationship between *lnRPG* and *lnDAP* is approximately 12.90%. The relationship between *lnDUW*, *lnURG*, and *lnRPG* is approximately strongly by 16.75% and 33.91%. The correlation matrix of all variables is shown in Table 2.

Table 2: Correlation matrix of variables

	lnUWS	***lnDUW***	***lnAGL***	***lnAQP***	***lnIWU***	***lnIND***	***lnSTA***	***lnGDP***	***lnUPG***	***lnRPG***
lnUWS	1.0000									
lnDUW	0.9873	1.0000								
lnAGL	-0.5778	-0.5018	1.0000							
lnAQP	-0.1954	-0.2578	0.0886	1.0000						
lnIWU	-0.5980	-0.6143	0.0744	0.5219	1.0000					
lnIND	0.0475	0.0862	0.3121	-0.2801	-0.5452	1.0000				
lnSTA	-0.3006	-0.2904	0.1427	-0.0105	0.2087	-0.0607	1.00000			
lnGDP	-0.7742	-0.7621	0.6261	0.3771	0.3874	0.2498	0.1374	1.0000		
lnUPG	-0.0915	-0.1675	0.1290	0.1233	-0.1148	0.0238	-0.0083	0.1913	1.0000	
lnRPG	0.3955	0.3391	-0.4464	0.0568	-0.1583	-0.0276	-0.2286	-0.3171	-0.0311	1.0000

Notes: All variables are expressed in their logarithms. Source: Compiled by the author based on WDI, IHME, FOA, and OECD database (1990-2017).

Table 3 results of the Fisher-type unit root test based on the Augmented Dickey-Fuller (ADF) test showed that each variable is stationary at the significance level of 1%. After the stationarity of each variable was tested, the next step was to test if there was a problem of multicollinearity between independent variables. Using several independent variables in research can lead to a misleading and unrealistic valuation of contributions of individual independent variables when trying to explain the dependent variable. This problem can occur when high collinearity exists between two or more independent variables. Multicollinearity can cause unrealistically high standard error estimates of regression coefficients and in the end, can cause false conclusions about the significance of independent variables in the model is evaluated.

Table 3: Fisher-type unit root test

VAR	Inverse chi-squared		Inverse normal		Inverse logit		Modified inv. chi-squared	
	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value
lnUWS	21.7971	0.0162	-2.3048	0.0106	-2.3702	0.0123	2.6379	0.0042
lnDUW	35.8172	0.0001	-4.0165	0.0000	-4.3877	0.0001	5.7729	0.0000
lnAGL	33.3479	0.0002	-3.5924	0.0002	-3.9248	0.0002	5.2208	0.0000
lnAQP	28.3099	0.0016	-3.3517	0.0004	-3.4199	0.0009	4.0942	0.0000
lnIWU	19.4643	0.0126	-2.2900	0.0110	-2.4237	0.0116	2.8661	0.0021
lnIND	71.0149	0.0000	-6.9809	0.0000	-8.9134	0.0000	13.6433	0.0000
lnSTA	47.4124	0.0000	-5.2226	0.0000	-5.9306	0.0000	8.3657	0.0000
lnGDP	18.6380	0.0451	-1.9617	0.0249	-1.9429	0.0309	1.9315	0.0267
lnUPG	26.2058	0.0035	-2.5103	0.0060	-2.6943	0.0058	3.6237	0.0001
lnRPG	46.6484	0.0000	-5.0745	0.0000	-5.8117	0.0000	8.1948	0.0000

Notes: All variables are expressed in their logarithms. Based on augmented Dickey–Fuller tests Source: Compiled by the author based on WDI, IHME, FOA, and OECD database (1990-2017).

4.2. Difference-in-differences regression result

Water quality in Central Asia varies with climate, geological environment, and human activities. Table 4 shows the DID regression of water pollution in Central Asia. Column (1) of the table shows the regression results without adding control variables. Because there are many independent variables in this study, columns (2) to (9) yielded regression results for each of the control variables, one after the other, based on the baseline model. Column (10) represents the regression result that includes all control variables and is defined as the complete model. The average variance of the results of this model is only about 2 units, which is below the threshold of 10. In fact, for all of the parameters discussed below, the DID regression coefficient ranges from -0.267 to 0.0646 and is at least 1%. The national economies of Central Asia are dominated by agriculture and animal husbandry. Agricultural industries, including cotton, are developed in Kazakhstan, Tajikistan, Uzbekistan, and Turkmenistan, while in Kyrgyzstan the focus is on livestock. Thus, as *lnAGL* activity increases, the 1% ratio becomes significantly negative, which is the main indicator of water pollution due to the agricultural sector. Surface contamination from agriculture and animal husbandry affects not only the quality of surface water but also the quality of groundwater. Central Asia is also rich in natural resources. For example, Kazakhstan, Uzbekistan, and Turkmenistan are rich in oil and gas, while Tajikistan and Kyrgyzstan are rich in non-ferrous metals and coal. The use of these natural resources affects the groundwater environment, especially as a result of oil spills, waste accumulation, wastewater treatment, and other unjustified exploitation and exploitation phenomena. In addition, the full DID regression results show that the coefficients of the *lnDUW*, *lnAGL*, *lnGDP*, and *lnUPG* variables in Central Asia are quite positive at 1%, indicating that the higher these values, the higher the water pollution in these countries. Another interesting finding is that, despite economic growth (*lnGDP*), water pollution is expected to increase accordingly.

Table 4: Difference-in-differences regression

VAR	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
time	-1.172***	0.434***	0.272***	0.301***	0.327***	0.313***	0.320***	0.0535	-0.0494	-0.0614
	(0.400)	(0.0451)	(0.0552)	(0.0538)	(0.0567)	(0.0545)	(0.0558)	(0.0700)	(0.0812)	(0.0769)
Treated	-0.776**	0.0456	0.142*	0.105	0.162**	0.194***	0.194***	0.268***	-0.0563	-0.172
	(0.384)	(0.0964)	(0.0732)	(0.0725)	(0.0619)	(0.0612)	(0.0616)	(0.0544)	(0.108)	(0.107)
DID	0.00828	-0.184*	-0.217**	-0.232***	-0.224***	-0.267***	-0.266***	-0.242***	0.0142	0.0646
	(0.425)	(0.108)	(0.0862)	(0.0834)	(0.0856)	(0.0780)	(0.0783)	(0.0734)	(0.102)	(0.0945)
lnDUW		0.221***	0.198***	0.202***	0.207***	0.204***	0.204***	0.182***	0.193***	0.199***
		(0.00644)	(0.00788)	(0.00830)	(0.0111)	(0.0108)	(0.0108)	(0.0120)	(0.0118)	(0.0113)
lnAGL			-0.0130***	-0.0118***	-0.0114***	-0.0141***	-0.0142***	-0.0269***	-0.0200***	-0.0195***
			(0.00173)	(0.00175)	(0.00181)	(0.00238)	(0.00236)	(0.00256)	(0.00322)	(0.00333)
lnAQP				6.59e-06**	3.95e-06	3.55e-06	3.51e-06	5.31e-07	2.08e-06	5.08e-06*
				(3.20e-06)	(2.82e-06)	(2.59e-06)	(2.52e-06)	(2.99e-06)	(2.42e-06)	(2.75e-06)
lnIWU					0.0140	0.0238*	0.0247*	-0.0198	-0.0161	-0.0224
					(0.00958)	(0.0139)	(0.0141)	(0.0170)	(0.0156)	(0.0162)
lnIND						0.00564	0.00571	0.00203	-0.000433	-0.00171
						(0.00371)	(0.00372)	(0.00336)	(0.00325)	(0.00337)
lnSTA							-0.0273	-0.0281	-0.0153	-0.0187
							(0.0226)	(0.0194)	(0.0191)	(0.0192)
lnGDP								0***	0***	0***
								(0)	(0)	(0)
lnUPG									0.108***	0.160***
									(0.0329)	(0.0359)
lnRPG										-0.0710**
										(0.0315)
Constant	2.174***	-0.439***	0.561***	0.446***	-0.977	-1.898	-1.961	3.243*	2.460	3.066*
	(0.358)	(0.0467)	(0.162)	(0.167)	(1.043)	(1.424)	(1.446)	(1.833)	(1.691)	(1.739)
R-squared	0.203	0.966	0.974	0.975	0.975	0.976	0.976	0.981	0.982	0.983

Notes: *** shows significance at 1%; ** shows significance at 5%; * shows significance at 10%. The dependent variable is the score on the *lnUWS*. “time” is a dummy variable indicating that the *lnUWS* was taken as a TIME. “Treated” is a dummy variable indicating that the water pollution in Central Asia. All regressions included class fixed effects. All variables are expressed in their logarithms.
Source: Compiled by the author based on WDI, IHME, FOA, and OECD database (1990-2017).

4.3. Heterogeneous effects result

In the previous section of this study, empirical analysis of DID regression showed that the independent variables had a statistically significant effect on water pollution in Central Asia. However, Table 5 in this section shows that the effect of the explanatory variables in this study differs from the high and low levels of pollution in Central Asia using the heterogeneous effects test. According to columns 4 (1) and (3) of Table 4, the variables *lnAGL* and *lnGDP* have high initial levels of water pollution, on average 0.0911 units and 8.89e-11 units, which is almost three times higher than the calculated low pollution levels. In contrast, the impact of *lnAGL* and *lnGDP* in parts of Central Asia with low water pollution levels is not statistically significant. As shown in columns (2) and (5) of Table 5, the *lnAGL* and *lnGDP* coefficients are insignificant in regions with low water pollution, while the coefficients in regions with high initial pollution levels are negative and significant at 10%. These results can be explained as follows. Local governments in Central Asia face challenges between water security and economic growth. To control water pollution to some extent, it is necessary not to cut the local budgets of the Central Asian governments. This situation will greatly help low-pollution local governments to develop water pollution abatement strategies that are consistent with economic growth. However, in areas with high levels of primary pollution, various environmental pollution reduction measures are being implemented to avoid funding and taxes arising from environmental assessments. Consequently, states with a high level of primary pollution should be interested in protecting their aquatic environment. According to a study by Greenstone and Geyer (2009), if the impact of water pollution is negligible, the need for people to reduce water pollution is insufficient, and policies to reduce water pollution may be ineffective. In addition, Liang et al., (2018) believe that a high level of economic development will have a positive impact on environmental policies aimed at increasing the environmental performance of the region. As Kazakhstan is a major economic power in Central Asia, it is important to understand how a country's water management policies affect water availability in other Central Asian countries. In addition to water pollution, water scarcity is increasing in Central Asia, leading to further developmental problems. The main reason for this is the growth of political tension and the deterioration of the ecological and socio-economic situation. Kazakhstan is the first country in Central Asia to develop a preliminary plan for the transition to integrated water resources management. Therefore, it is possible to develop transboundary water integration between all countries of Central Asia, starting with Kazakhstan. In other low-GDP Central Asian countries, local governments need to focus on economic growth and water pollution as a secondary goal.

Table 5: Heterogeneous effects with different water pollution levels

	High water pollution levels			**Low water pollution levels**		
VAR	(1)	(2)	(3)	(4)	(5)	(6)
lnDUW	0.23***	0.161***	0.214***	0.0742	0.091**	0.0174
	(0.0745)	(0.0144)	(0.0157)	(0.0631)	(0.0371)	(0.108)
lnAGL	-0.0911***	-0.0396	-0.114**	-0.0821*	-0.0311	-0.142
	(0.0317)	(0.0357)	(0.0514)	(0.0483)	(0.0379)	(0.101)
lnAQP	-9.48e-06	-9.24e-07	5.62e-06	-7.99e-05	-8.37e-06	-4.99e-05
	(5.05e-05)	(6.20e-06)	(7.09e-06)	(6.24e-05)	(8.51e-06)	(4.61e-05)
lnIWU	0.566	-0.213	0.838***	-0.163	-0.0733	0.0714
	(0.856)	(0.131)	(0.255)	(0.186)	(0.389)	(0.0563)
lnIND	0.00736	-0.00569	-0.0547***	0.00152*	-0.0015	-0.00484
	(0.0127)	(0.00558)	(0.00947)	(0.000781)	(0.00275)	(0.00602)
lnSTA	0.108	-0.0176	0.0811**	-0.00487	0.000436	0.0172
	(0.104)	(0.0564)	(0.0358)	(0.0053)	(0.0222)	(0.014)
lnGDP	-8.89e-11*	0	-0***	7.53e-11	0	7.48e-11
	(0)	(0)	(0)	(8.55e-11)	(0)	(7.05e-11)
lnUPG	-0.147	0.0512	0.131*	0.297	0.0826	-0.231
	(0.243)	(0.0869)	(0.0697)	(0.337)	(0.069)	(0.189)
lnRPG	0.866**	0.126	-0.182	0.968	0.00292	-0.726
	(0.395)	(0.0895)	(0.112)	(0.337)	(0.0771)	(0.768)
lnUWS				-0.595***	-0.592***	-0.251
				(0.221)	(0.0786)	(0.237)
Constant				35.9	13.41	-18.2
				(36.33)	(8.264)	(17.06)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

Notes: ***shows significance at 1%; **shows significance at 5%; * shows significance at 10%. All variables are expressed in their logarithms. Source: Compiled by the author based on WDI, IHME, FOA, and OECD database (1990-2017).

4.4. Robustness test

Difference-in-differences diagnostic test result

Although DID regression was used in the first part of the study, the explanatory variables were found to affect water pollution, but this was observed in a small number of variables. To test the robustness of the main results of this study, a resistance test using the Difference in Differences diagnostic test is used as follows. As a result, the variables *lnAGL* and *lnUPG* in the first study were confirmed as water-polluting variables in Central Asia (Table 6). A 1% increase in *lnAGL* contributes 1.905% to water pollution in the negative direction. Because Central Asia is entirely agricultural, the water required for irrigation of crops and the residual pollutants from it contaminate water to a large extent. In addition, as the economy of Central Asia grows, urbanization and urban population growth harm water quality. A 1% increase in Urban population growth (*lnUPG*) contributes 0.552% to water pollution in the negative direction. Additionally, Difference-in-differences diagnostic tests analysis shows that a 5% increase in *lnIND* contributes to a 2.913% rise in water pollution. As the Central Asian countries develop, industrialization develops, and as new facilities are built, water quality deteriorates. In addition, aquaculture, whose main activity is water, harms water quality. A 1% increase in *lnAQP* contributes 6.160% to water pollution in the negative direction. In most regions of Central Asia, groundwater has become an important source of water for irrigation of agricultural land and domestic use. However, the uncontrolled use of groundwater can lead to lower water levels and deterioration of water quality in some aquifers. Due to the difficult water security situation in Central Asia, it is necessary to develop surface and groundwater resources and prevent pollution.

Table 6: Difference-in-differences diagnostic test

VAR	*lnUWS*	*lnDUW*	*lnAGL*	*lnAQP*	*lnIWU*	*lnIND*	*lnSTA*	*lnGDP*	*lnUPG*	*lnRPG*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
lnUWS		4.194***	-0.528	-4,129	-0.302*	-2.282	-0.158	8.145e+09	0.0828	0.273
		(0.495)	(0.639)	(2,821)	(0.109)	(1.788)	(0.0919)	(7.057e+09)	(0.281)	(0.366)
lnDUW	0.185***		0.156	459.3	0.0709	1.643**	0.0450*	-1.072e+09	-0.0941	0.0111
	(0.0201)		(0.133)	(906.0)	(0.0363)	(0.442)	(0.0163)	(2.446e+09)	(0.0591)	(0.0926)
lnAGL	-0.0344	0.230		817.0	-0.0570*	-4.043**	-0.0257	5.913e+09	0.258**	-0.187***
	(0.0431)	(0.154)		(620.1)	(0.0213)	(1.234)	(0.0589)	(3.588e+09)	(0.0619)	(0.0390)
lnAQP	-7.39e-06	1.87e-05	2.25e-05		-1.29e-05***	0.000206	-9.71e-06	-366,836	-3.68e-05**	3.85e-05**
	(6.18e-06)	(3.52e-05)	(2.72e-05)		(1.32e-06)	(0.000159)	(5.55e-06)	(417,884)	(8.06e-06)	(1.19e-05)
lnIWU	-0.324*	1.727**	-0.939	-7,707		-10.13***	-0.408*	2.553e+10	-0.0937	0.489
	(0.145)	(0.588)	(0.682)	(4,211)		(2.036)	(0.186)	(2.319e+10)	(0.179)	(0.301)
lnIND	-0.00208	0.0340	-0.0566*	105.0	-0.00860**		0.00401	5.840e+08	0.0274**	-0.0179*
	(0.00306)	(0.0272)	(0.0263)	(52.92)	(0.00236)		(0.00533)	(3.295e+08)	(0.00823)	(0.00710)
lnSTA	-0.0212	0.137**	-0.0528	-725.6	-0.0509	0.588		5.101e+08	-0.0598	0.0377
	(0.0115)	(0.0374)	(0.132)	(353.5)	(0.0276)	(0.370)		(7.006e+08)	(0.0345)	(0.0427)
lnGDP	0	-0	0	-4.44e-08	0	1.39e-10**	0		-0*	0**
	(0)	(0)	(0)	(3.36e-08)	(0)	(0)	(0)		(0)	(0)
lnUPG	0.0287	-0.741	1.371**	-7,123**	-0.0303	10.42**	-0.155	-9.816e+09		0.706**
	(0.0942)	(0.548)	(0.346)	(1,935)	(0.0638)	(3.415)	(0.175)	(5.410e+09)		(0.201)
lnRPG	0.100	0.0930	-1.054**	7,904**	0.168	-7.227**	0.104	1.639e+10***	0.748***	
	(0.138)	(0.772)	(0.268)	(2,464)	(0.134)	(2.115)	(0.166)	(3.249e+09)	(0.102)	
DID	-0.188	0.405	-1.905**	-6,160*	-0.358	2.913**	-0.471	1.414e+10	-0.552*	0.134
	(0.115)	(0.462)	(0.550)	(2,516)	(0.251)	(1.049)	(0.272)	(1.032e+10)	(0.238)	(0.418)
Constant	32.78*	-175.8**	150.7*	681,676	97.65***	1,216***	40.59*	-2.787e+12	-6.466	-34.38
	(14.13)	(52.34)	(64.26)	(400,830)	(1.428)	(239.8)	(16.98)	(2.339e+12)	(18.45)	(29.65)

Note: Average treatment effect on the treated estimate adjusted for covariates, panel effects, and time effects. Robust standard errors in parentheses. *** shows significance at 1%; ** shows significance at 5%; * shows significance at 10%. All variables are expressed in their logarithms. Source: Compiled by the author based on WDI, IHME, FOA, and OECD database (1990-2017).

Difference-in-differences diagnostic graphs

Looking at the plotted observed means, the outcome trajectories in the control and treatment groups before the treatment are somewhat different (Figure 2). Water pollution has grown dramatically from 1990 to 2001 and has been moving up and down since 2002. A more formal way to assess whether the pretreatment trajectories are parallel is to perform a test on the linear-trends model coefficient that captures the differences in the trends between the treated group and the controls group. Thus, by testing this coefficient against 0, this study has a test of the null hypothesis that the pretreatment period trajectories are parallel. The author found that before the independent variables were implemented in 2002, the trends of water pollution in the treatment and control groups were the same, meeting the parallel trend assumption in Central Asian data.

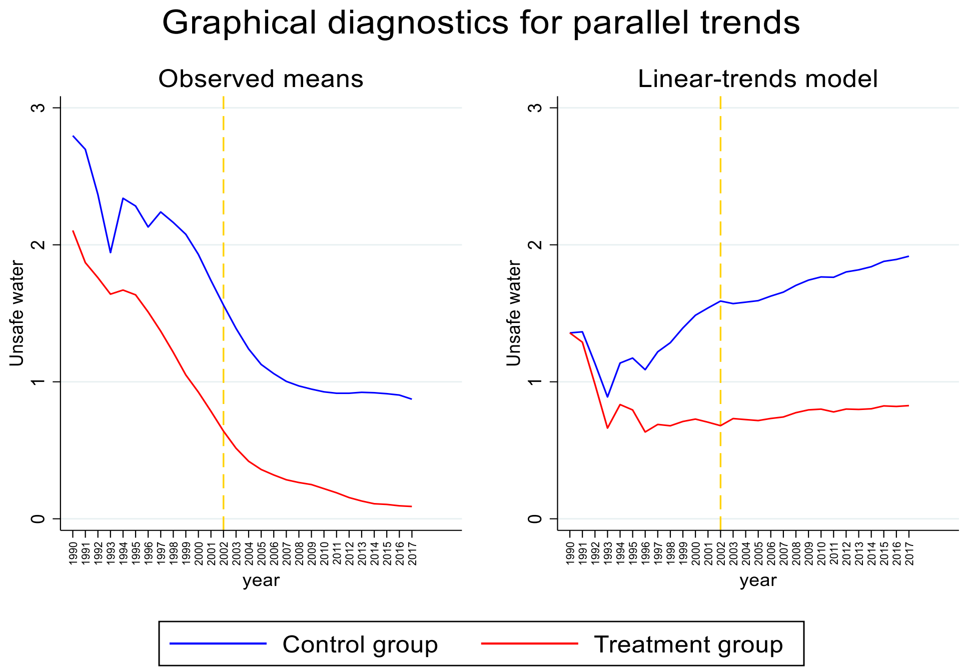

Figure 2: Graphical diagnostics for parallel trends

Source: Compiled by the author based on WDI, IHME, FOA, and OECD database (1990-2017)

5. DISCUSSION

Water pollution in Central Asia affects the drinking water supply of the entire population, household consumption, irrigation, fisheries, and ecosystem resilience. The main reason for water pollution is increasing disruptions and leaks of drinking water pipelines into populated areas, as well as a decrease in the uninterrupted supply of water. The countries of Central Asia, rich in agriculture, fuel, and minerals, make up the bulk of their gross domestic product, but water also plays an important role in their economies. In the mountainous regions of Kyrgyzstan and Tajikistan, hydropower is generated from the headwaters of rivers. In addition, the construction of new dams in these countries could significantly increase their export earnings. The lower reaches of the river irrigate agriculture and cotton fields in Uzbekistan and Turkmenistan. In particular, the use of large quantities of water in agriculture puts pressure on water supplies and pollutes water. The Central Asian countries must balance their limited resources fairly while balancing the origins of hydropower generation and downstream agriculture. Therefore, cooperation between these countries in terms of the availability and use of water is very important. The Central Asian government managed to turn the desert into fertile agricultural land, but it also completely dried up the Aral Sea, a huge lake that had previously dried up. Water pollution is the cause of water-related problems and the agricultural sector is a victim of it. Intensive agriculture also pollutes the rivers and soil of Central Asia. In these countries, irrigation infrastructure is failing and unsustainable green space projects are wasting huge amounts of water. In the future, as population growth and climate change put pressure on water scarcity and pollution in the region, these countries will need to work more closely together on water management. Not only about water pollution, but also about environmental protection, agriculture, water resources, health care, local government, municipalities, non-governmental organizations and industry, water quality and environmental issues, national action plans, and regional and local planning. There is a need to coordinate water management among the five countries to eliminate water pollution in Central Asia. Moreover, once the international legal environment and political will are in place, Central Asia can become a more effective independent organization that can better regulate water transactions with its powerful neighbors, Russia and China.

6. CONCLUSION AND RECOMMENDATIONS

Water pollution is a hot topic not only in Central Asia, but also in other parts of the world, and environmental standards are one of the factors for controlling water pollution. However, a small number of studies have examined the relative effectiveness of various regulations, environmental standards, and market environmental standards related to water pollution control. This study used annual data from the World Development Indicators (WDI), Food and Agriculture Organization (FOA), Institute for Health Metrics and Evaluation (IHME) database, Organization for Economic Cooperation and Development (OECD) National Accounts, electronic files, and web site for the period from 1990 to 2017. The unsafe water source in Central Asian countries are based on the relationship between Water pollution, Agricultural production, Aquaculture production, Improved water source, Industry, Surface temperature anomaly, Urban and Rural population growth, and Economic growth with a Difference-in-differences (DID) for panel-data model, Heterogeneous effects, unit root test, and reports some findings tried to explain using Difference-in-differences diagnostic graphs and tests. The results show that agriculture is the main cause of water pollution in Central Asia. Therefore, there is a need to reduce water pollution by controlling pollution from agricultural sources. Studies have also shown that water pollution increases with the growth of the economy and population in these countries. Based on the above findings, the following recommendations are made to improve the impact of agricultural regulatory policies on water pollution reduction. First, farmers need to improve their irrigation systems and change their traditional way of using canals as soon as possible. Therefore, policy support should be provided to farmers to introduce more sustainable technologies into agricultural production and to provide them with economic incentives to change their agricultural production patterns. This could significantly improve water quality if the Central Asian governments proposed concrete action plans to reduce water pollution from agriculture. Second, to improve the management of the partnership to improve the efficiency of treatment and reuse of wastewater used by the population and industry. Third, more attention needs to be paid to improving policy effectiveness in low-income, low-water pollution regions. Water pollution can be reduced by giving these regions more economic support.

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