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Abstract

Land reforms have been reported to impact agriculture, economic performances and indicators of countries along with water users and allocations. However, little is known about how land fragmentation (consolidation) in land-reform processes affects water availability. This research investigates a question "how the number of water users is related with irrigation water allocation in land reforms," hypothesizing that an increase in the number of water users through land fragmentation poses negative threats on the water allocation through a mediation of irrigation types. We conduct empirical analyses for irrigation water demand and availability, utilizing panel data for 25 years from 13 districts in Sugd province, Tajikistan. Two main results are obtained: First, the irrigated areas are main drivers that increase irrigation water demand in comparison to any other factors, and the impact by pump irrigated areas is approximately 1.6 times as large as that by gravity irrigated areas. Second, the increasing number of water users under land fragmentation in Tajikistan tends to reduce irrigation water availability, and the magnitude in reduction under pump irrigation is more significant than that under gravity irrigation. Overall, this research establishes that irrigations and the number of water users through land reforms matter for a change in the water allocation, and the interactions particularly pose the idiosyncratic threats on the irrigation water availability. Thus, it is advisable to reconsider ongoing land-reform policies considering possible negative externality of land fragmentation as well as irrigation for food security and water sustainability in agriculture.

Key Words: Land reform; irrigation water; number of water users; pump irrigation; gravity irrigation; Tajikistan

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1 Introduction

In early 1990s, a land reform in the transitioning period from centralized economy to market-based economy was a top-priority agenda for many countries, such as the former-Soviet, Central Europe, Eastern Europe and Asian ones. The objective of such land reforms was ensuring rural employment, food security and economic growth by restructuring and privatizing large state and collective farms. The reforms have had different methods and orientations of land redistribution across countries depending on historical ownership, collective farm members, land availability and auctions. In some cases, land has been returned to the pre-collectivization owners, and consequently, land fragmentation is reported to occur along with some side effects on water allocations (Swinnen, 1999, Rembold, 2003). Land reforms are generally known to impact not only agriculture but also economic growth in countries spanning agricultural development, crop diversification, occupational choices, technological advancements and demographics through a change in the number of land users and allocations (Lerman, 2008, Hartvigsen, 2014, Ciaian et al., 2018, Adamopoulos and Restuccia, 2020, Wang et al., 2020). In particular, the land fragmentation through agricultural reforms in these countries is expected to have significantly affected water users and water availability. This paper addresses relationship between a number of water users and irrigation water availability (IWA) in land-reform fragmentation processes.

In the last few decades, land reforms have been studied in social science and interdisciplinary studies, using various methods of both qualitative and quantitative approaches. Specifically, these researches focus on examining land reforms' performances by implementing case-method studies, modeling methods, policy reviews, quantitative approaches, scoping studies and socio-ecological analyses, identifying the causalities and relationships with economic growth, agricultural productivity, diversification, employment and rural development (Lerman, 1998, Swinnen, 1999, Rembold, 2003, Vitikainen, 2004, Margaret and Patricia, 2006, Ghatak and Roy, 2007, Deininger et al., 2009). In literature, two common concepts associated with the land reforms are land consolidation and land fragmentation. Land consolidation generally involves the redistribution of land titles from individuals to groups and/or communities at large and considered one of instruments to ensure sustainable land management and reducing agricultural production costs (Crecente et al., 2002, Haldrup, 2015, Hartvigsen, 2015, Jiang et al., 2022). Land fragmentation generally involves the redistribution of land titles from a group or a community to individuals and considered one of instruments to allow individual land ownership through finely partitioning the areas (Gorton, 2001, Pottier, 2006, Sklenicka, 2016, Ntihinyurwa et al., 2019).

A group of studies have shown positive impact of land fragmentation in land reforms on some economic performances and indicators (Lerman and Sedik, 2008, Deininger et al., 2009). Lerman (2008) studies the impact of land reforms on agricultural growth and productivity using time series analysis, identifying that countries with a land reform tend to have a high agricultural efficiency. Lerman and Sedik (2009) examine agricultural productivity in relation to land sizes via econometric analysis and find that small-sized farms are more productive than large-sized corporate farms in Tajikistan and Uzbekistan. Nguyen (2012) analyzes the impact of the land tenure in a land reform on agricultural productivity by taking a sample of 320 farms from Northern Uplands of Vietnam, finding that land productivity tends to increase when chemical fertilizer use is reduced in the reform process. Ciaian et al. (2018) investigate relationship between land fragmentation and production diversification by interviewing farm households in Albania, and identify that land fragmentation promotes the diversification of agricultural productions. Ntihinyurwa et al. (2019) conduct literature reviews on land fragmentation and consolidation issues, claiming that each type of the land reforms can have positive or negative impact, depending on local political, socioeconomic and environmental conditions.

Another group of literature has shown some negative impact of land reforms on economic performances and indicators, especially when land is fragmented due to policy changes or development processes (Gorton, 2001, Niroula and Thapa, 2007, Pavsakarnis and Maliene, 2010, Manjunatha et al., 2013, Hiironen and Riekkinen, 2016, Postek et al., 2019, Wang et al., 2021). Rahman and Rahman (2009) study relationship between land fragmentation and rice production using farm level survey data, and demonstrate that land fragmentation reduces rice production in Bangladesh. Nhundu and Mushunje (2010) examine the effect of a fast-track policy with land fragmentation in Zimbabwe using gross margin analysis, identifying a decline in not only irrigation funding but also crop production and increasing conflicts in shared irrigation infrastructures. Hartvigsen (2014) studies the impact of a land reform in Central and Eastern Europe by developing some conceptual framework for economic growth, finding that land fragmentation tends to be further advanced with rural and agricultural development. He also suggests that such a tendency should be considered to formulate land-reform policies for avoiding the adverse effects. Jürgenson (2016) conduct a comparative analysis of the land reform in Estonia based on archival maps using geographic information system, identifying that the land reform in post-1990 has higher land fragmentation than that in pre-1940. He concludes that the fragmentation in post-1990 constrains agricultural production and rural development. Wang et al. (2020) evaluate the impact of land fragmentation on irrigation management by conducting a questionnaire survey with 3895 households in China and reveal that the fragmentation is negatively associated with irrigation collective actions.

Previous studies have primarily focused on examining whether the goals of land reforms, such as rural employment, food security and economic growth, are achieved or not. However, little is known about how land fragmentation (consolidation) in land-reform processes affects water availability or about externality of land reforms on water allocations. Given this paucity in the literature, we examine how the land reform influences an irrigation water allocation through a temporal change in the number of water users by taking a case of Tajikistan land reforms. To this end, we conduct empirical analyses to address the relationship between the number of water users and irrigation water demand (IWD) as well as IWA in a land reform, utilizing the panel data for 25 years from 13 districts of Sugd province. This research seeks to pose answer a question: How is the number of water users related with irrigation water allocation in land reforms? Specifically, it is hypothesized that an increase in the number of water users through land fragmentation poses negative threats on the irrigation water allocation through a mediation of irrigation types. Answering the question and hypothesis shall be useful for the development of land policies on irrigation water allocations in not only Tajikistan but also other nations facing similar contexts in consideration to

Sustainable Development Goals (SDGs).

2 Land reform and water availability in Tajikistan

The agricultural sector is one of the leading sectors in the economy of Tajikistan, forming about 24 % of the gross domestic product (GDP) and employing about 46 % of the working population (World Bank, 2021). The agricultural sector is the largest water user in the country, which accounts for around 90 % of extracted water resources. More than 80 % of agricultural production is produced in irrigated land (NDS, 2013). The critical factor in the country's socio-economic development is the agricultural sector contributing to the national development strategy for 2030 and the national development program for 2016 to 2020. Sustainable development of agricultural and irrigation sectors plays an essential role in economic growth, social development, food security, poverty reduction and prevention of migration through employment in the country.

Following the economic reform to increase agricultural output based on the rational use of natural resources in mountainous areas, such as land and water resources, Tajikistan's government has started a land reform since 1995. To develop high-income and profitable farm production, freedom of product prices, liberty to plant crops and ensuring food security, in 1996 president decree was enacted. The agricultural reform program from 2012 to 2020 aimed to strengthen agricultural production and improve the export environment (Babu and Akramov, 2022). Along with the land reform, the former collective and state farms were reorganized and agricultural land was redistributed to households, individuals or groups of farms and agricultural enterprises. As a result, the number of land users in irrigated land had increased from 11 500 in 1996 to 187 220 in 2020 (SCLMG, 2020). Accordingly, the irrigation sector has also been gradually transferred to the self-sufficiency principle by introducing irrigation service fees. Irrigation water supply at the off-farm level is the responsibility of the Agency for Land Reclamation and Irrigation (ALRI) and its district departments. To ensure water conservation, efficient operation and maintenance of the on-farm irrigation system, the Water User Associations (WUAs) were established. However, the volume of annual supplied irrigation water in Tajikistan has decreased from 8 billion m^3 to 4 billion m^3 over the last 25 years wherein the irrigated land area remains unchanged (ALRI, 2020). In addition, irrigation water management organizations have been facing several problems, such as debts, electricity, wages and operation-maintenance costs in the systems.

The water-sector reform program in Tajikistan from 2016 to 2025, which was approved by the government on December 30, 2015, aims to introduce advanced and sustainable institutional and legal mechanisms for water management. The main goals are to sustain water supply, to achieve economically and environmentally sustainable water allocations under the integrated resource management. To achieve these goals, the government has initiated amendments in legal frameworks and implemented development programs as well as institutional changes. According to the Tajikistan's Water Code, water resource is the state property. Ensuring sustainable management and rational use of water resources is regulated by the water legislation of the Republic of Tajikistan (Water Code, 2020). Specifically, the authorities of the recognized state bodies are in charge of regulating water allocation, water usage plans, water supply and development of new irrigated land (Water Code, 2020). It implies that Tajikistan's water allocation with its supply and demand is not driven by the market. Rather, it is the responsibility of the state organizations in Tajikistan.

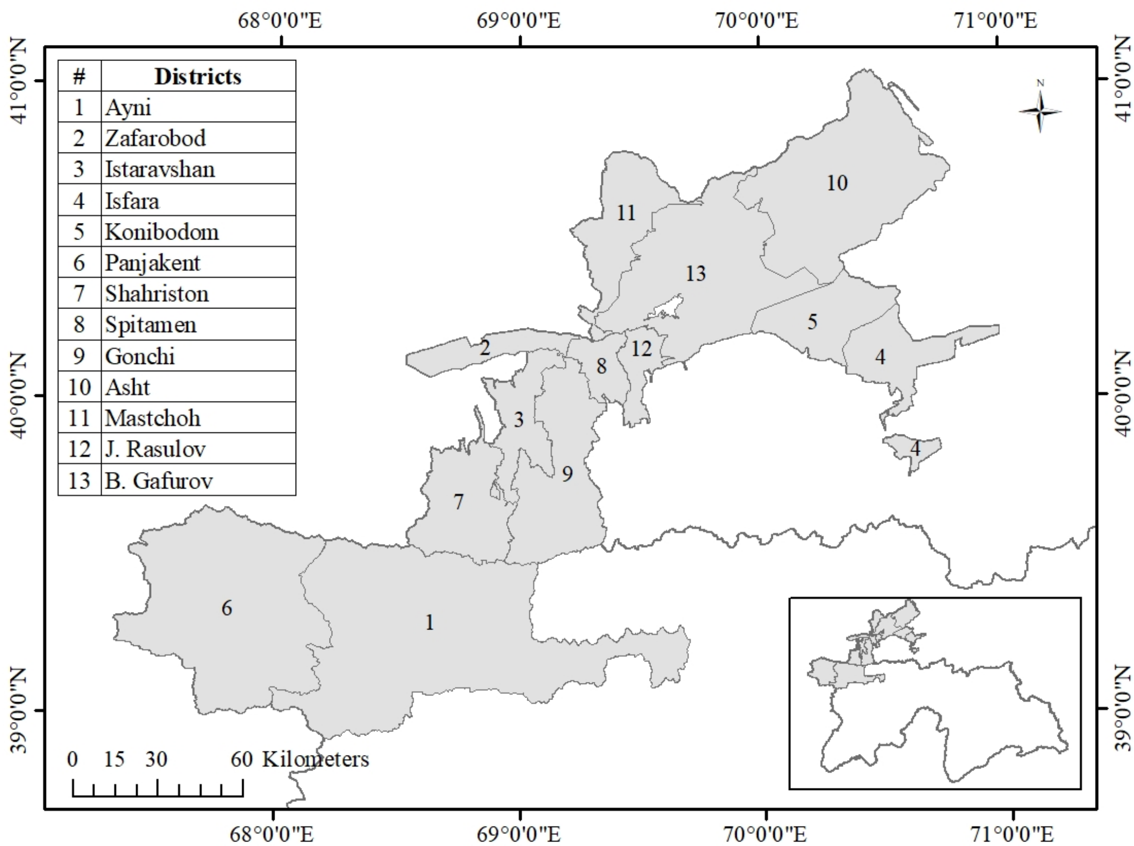
Despite the governmental efforts on implementing a series of state-funded programs and strategies, subsidies, substantial amount of loans and grants in both agriculture and water sectors, the quality of irrigation services in Tajikistan has been declining. Due to the severe economic conditions, the implemented reforms tend to focus only on short-run economic performances without considering medium- and long-run sustainable irrigation water supply at individual and society levels. Consequently, irrigation service providers face various problems with respect to water supply shortage, operation, maintenance of the irrigation system, collection of irrigation service fees and accumulation of the debts. For instance, the WUAs still face challenges on financial, technical, operational and management capacity to fulfill their responsibilities (Sehring, 2007, Balasubramanya et al., 2016, Shenhav et al., 2019). Development of the appropriate irrigation system and land reforms according to a temporal change in the number of water users are necessary and urgent. To this end, it is essential to study and understand the externality of land reforms on the irrigation water allocation, especially when the number of water users change over time in the reform processes.

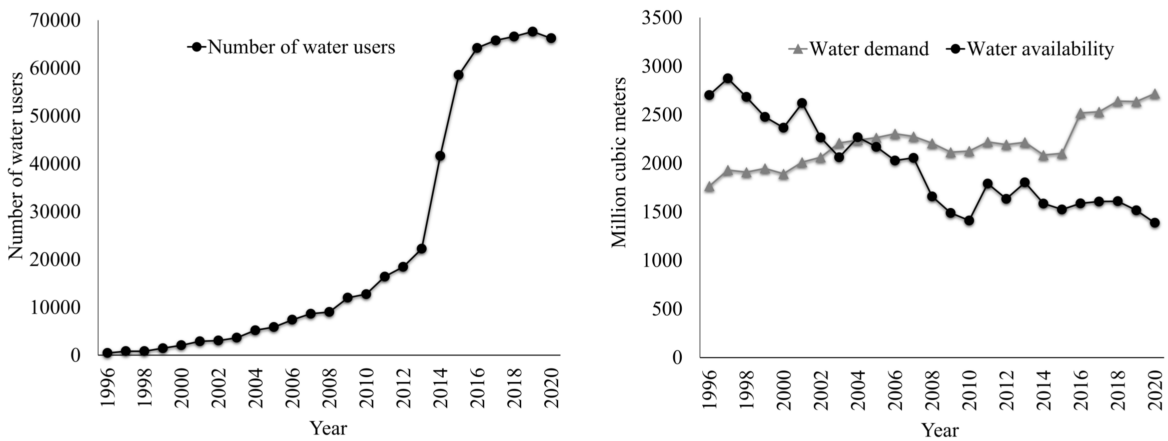
3 Methodology

The study areas include 13 districts of Sugd province, which are located in the northern part of Tajikistan (figure 1). These areas are considered continental with relatively cold winters and dry-hot summers. The annual average precipitation in these areas varies from 150 mm to 300 mm and the maximum temperature in summer reaches to 47 °C. Due to limited precipitation in the vegetation period, the irrigation facilities are important to maintain soil moisture and create favorable conditions for full potential of agricultural crops production. Irrigated areas in the Sugd province are around 290 000 ha including more than 60 % of pump irrigation facilities and remaining areas are gravity irrigation facilities. Pump stations were constructed during the Soviet period to irrigate mountainous and hilly areas and lift water several times as cascades. In 2020, an irrigated area per capita accounted for 0.1 ha in Sugd province, which is the smallest among Central Asian countries. However, one third of the Tajikistan's irrigated land belongs to this province, contributing to 40 % of the country's agricultural production.

During the land reform from 1996 to 2020, the state and the collective farms were reorganized as well as distributed to individual small-sized farms in Sugd province. Figure 2(a) presents that the number of irrigation water users has increased from 1500 to 60 000 in this period. The irrigation and drainage systems, which were constructed during the Soviet period under the assumption that farming is conducted in the large-sized plots, remain unchanged after the land fragmentation. Therefore, the increase in a number of irrigation water users creates challenges to the irrigation water facilities. For instance, figure 2(b) demonstrates that IWA has decreased from 2.8 billion m^3 to 1.5 billion m^3 from 1996 to 2020. On the other hand, IWD has increased from 1.7 billion m^3 to

Figure 1: Study areas in Tajikistan





(a) Number of water users

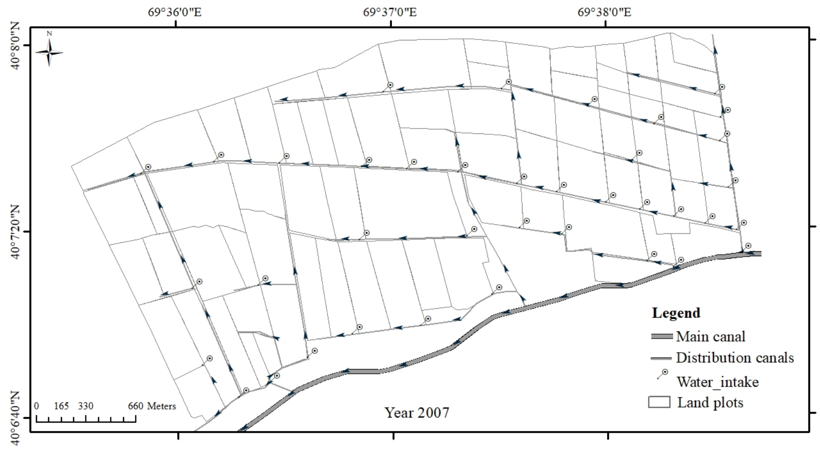
(b) Irrigation water demand and irrigation water availability

Figure 2: Changes in the number of water users, IWD and IWA from 1996 to 2020 in Sugd province

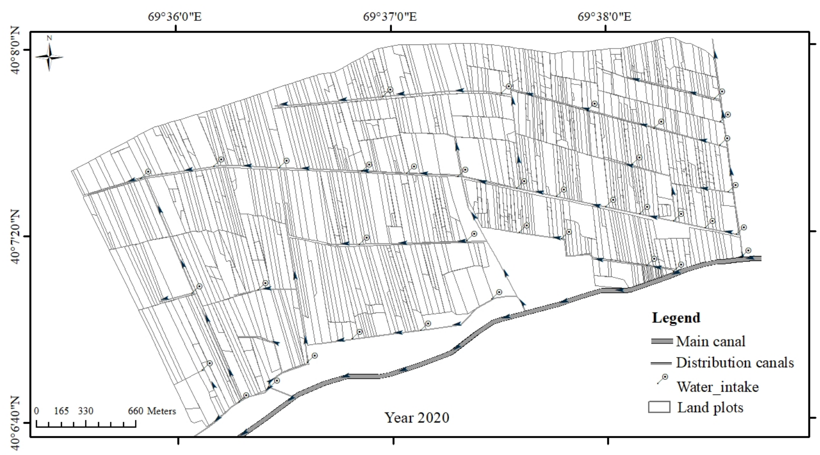
2.5 billion m^3 during the period.

Figure 3 illustrates the land fragmentation in the reform process in B. Gafurov district of Sugd province from 2007 to 2020. For instance, figure 3(a) shows that 650 ha consisted of 74 plots with an average size of 8.7 ha, being part of one collective farm in 2007. Figure 3(b) visualizes that the area becomes so fragmented in the reform process with an increase in the number of plots up to 917 with an average size of 0.7 ha in 2020. At the same time, figure 3(c) suggest that irrigation systems have unchanged including main canals, distribution canals and water intakes during the reform period. While each plot had direct access to a water intake point in 2007, it is sharply declined in 2020 and only 25 plots currently have access to a water intake point. Overall, it is evident that the plot sizes become approximately 12 times as small as those in the pre-land reform period under the same irrigation systems.

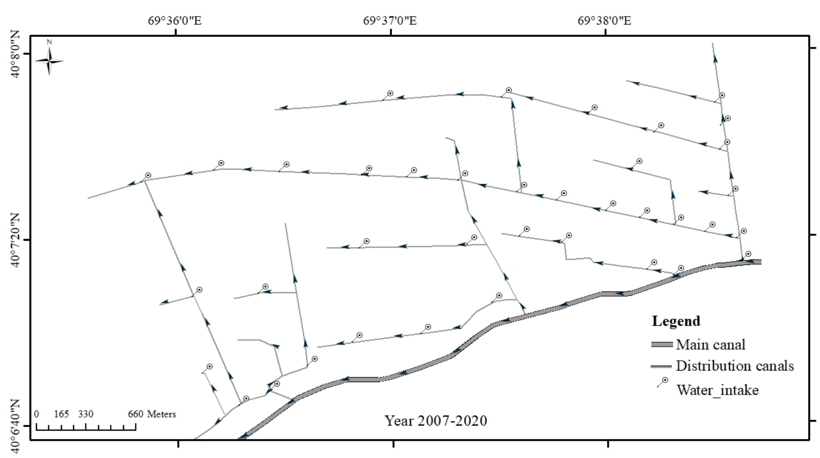
This study uses panel data from 1996 to 2020 that consist of IWD, IWA, number of water users, gravity irrigated areas, pump irrigated areas and payment fraction in Sugd province, Tajikistan (See table 1 for the description of the variables). Out of the 15 administrative bodies in Sugd province, 13 farming districts are selected as cross-sectional units, because agricultural and irrigation activities are carried out in these districts. We apply the panel-data regression models to investigate the relationship between the number of water users in the land reform and IWD as



(a) Land plots in 2007



(b) Land plots in 2020



(c) Irrigation system from 2007 to 2020

Figure 3: Comparison of land plot sizes between 2007 and 2020. Source: Google earth images for B. Gafurov district

Table 1: Description of the variables

Variables	Units	Description
IWD	Thousand cubic meters per year	Irrigation water demand (IWD) calculated by crop types and area
IWA	Thousand cubic meters per year	Irrigation water availability (IWA), volume of received irrigation water
Waterusers	Number of water users	Number of farmers in irrigated land
Gravityareas	Hectares per year	Gravity irrigated areas
Pumpareas	Hectares per year	Pump irrigated areas
Paymentfraction	% of collected payment	Percentage of collected irrigation service fees

well as IWA along with irrigation areas. In the analyses, both time-specific factors and regional differences are considered. To control time-specific factors, we consider year-fixed effects in the regression models, such as deterioration and rehabilitation of irrigation infrastructure, agricultural practices, policies and institutional changes which may affect IWD and IWA by including year-fixed dummy variables. To control the regional differences, we consider the regional-fixed effects, such as geography, climate and demography by including region-fixed dummy variables.

Figure 4 displays a conceptual framework for our empirical analysis, being developed on the basis of the fact that IWD and IWA in Tajikistan are not driven by markets but controlled by the government. Specifically, the variables except IWD and IWA in the framework are determined by the central agencies, and water users respond to the changes in the variables through IWD and IWA. Therefore, an empirical framework for market demand and supply in economic theory cannot be directly applied to our study on water allocations in Tajikistan. Given this state of affairs, the conceptual framework is believed to be one of the comprehensive views for understanding the complex relations among different factors, variables and interactions that affect IWD and IWA in the study. The panel-data regressions shall estimate parameters β_i^Ks for $i = 1, 2, 3, 4, 5, 6$ and $K = \{\mathrm{IWD}, \mathrm{IWA}\}$ in figure 4, each of which corresponds to the relationship between IWD (or IWA) and a key variable, after the effects of all other independent variables are netted out (Wooldridge, 2010). In particular, we focus on reporting the relationships "how IWD and IWA are related to the number of water users and irrigation types" that correspond to $\beta_2^K, \beta_3^K, \beta_5^K, \beta_6^K$ according to the

Figure 4: A conceptual framework that describes the relationships between the variables (the number of water users, irrigation types, irrigation service fees, the interactions, time and regional specific factors) and irrigation water demand (IWD) or irrigation water availability (IWA) by β_i^Ks for $K = \{\text{IWD}, \text{IWA}\}$ and $i = 1, 2, 3, 4, 5, 6$, respectively
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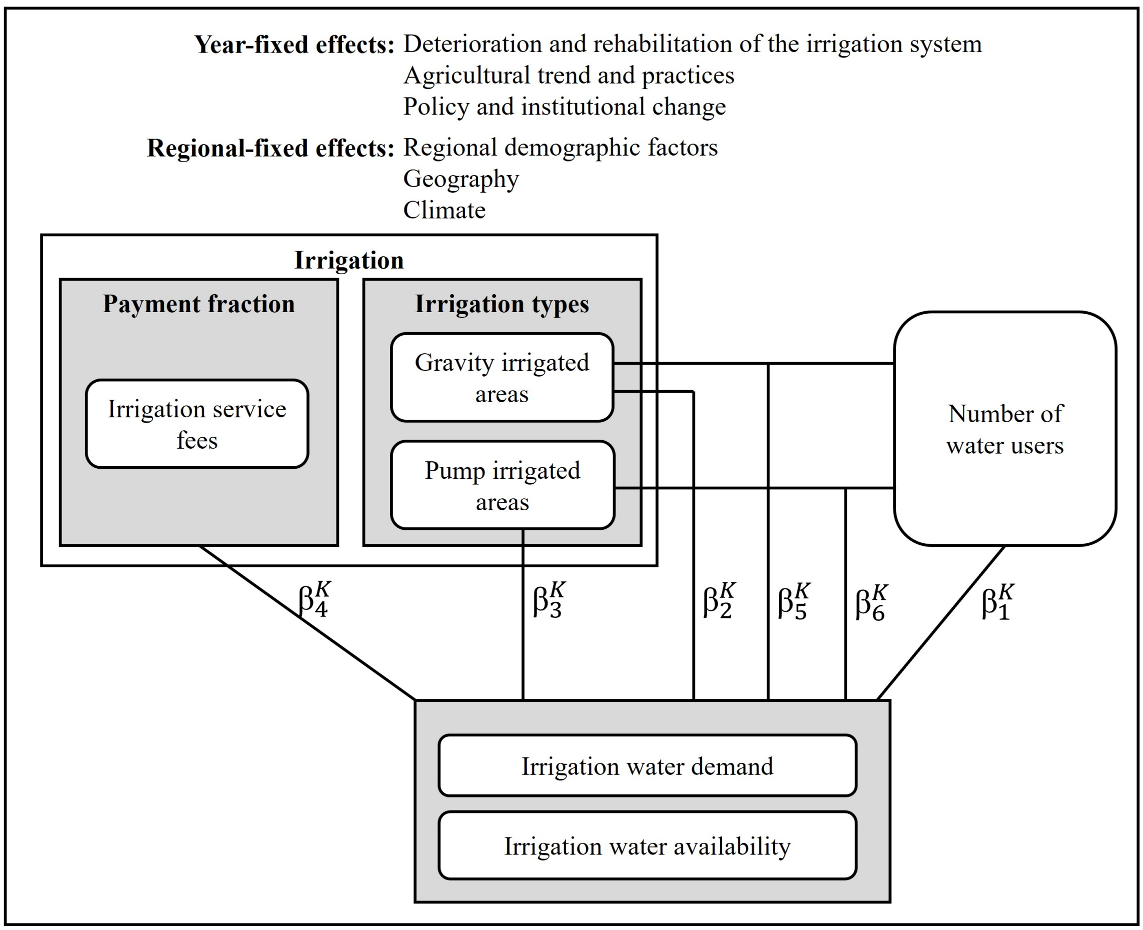


research question and hypothesis. The regression specifications are expressed as

$$\begin{aligned} Y_{it}^K = \beta_0^K + \beta_1^K \boldsymbol{WU}_{it} + \beta_2^K \boldsymbol{GA}_{it} + \beta_3^K \boldsymbol{PA}_{it} + \beta_4^K \boldsymbol{PF}_{it} \\ + \beta_5^K \boldsymbol{WU}_{it} \cdot \boldsymbol{GA}_{it} + \beta_6^K \boldsymbol{WU}_{it} \cdot \boldsymbol{PA}_{it} + \varepsilon_{it}^K \end{aligned} \tag{1}$$

where subscripts $i = 1, \ldots, 13$ and $t = 1996, 1997, \ldots, 2020$ denote the district and year, respectively, Y_{it}^K indicates a dependent variable where $Y_{it}^{\text{IWD}} = \textit{IWD}_{it}$ and $Y_{it}^{\text{IWA}} = \textit{IWA}_{it}$ for $K = \{\text{IWD}, \text{IWA}\}$, $\textit{WU}_{it}$, $\textit{GA}_{it}$, $\textit{PA}_{it}$, $\textit{PF}_{it}$, $\textit{WU}_{it} \cdot \textit{GA}_{it}$ and $\textit{WU}_{it} \cdot \textit{PA}_{it}$ represent the number of water users, gravity irrigated areas, pump irrigated areas, payment fraction and the corresponding interaction terms, respectively, and ϵ_{it}^K is an error term in district *i* and at year *t*.

The conceptual framework in figure 4 and regression specifications in equation (1) enable us to identify the key determinants for addressing the research question and hypothesis in our study. To this end, we proceed with taking the following steps for estimating the parameters. First, we apply panel unit root tests for our variables to confirm that they are stationary at the level or not by the Levin-Lin-Chu test (Levin et al., 2002), indicating that they are stationary. Second, we apply the Hausman test (Hausman, 1978) to determine whether a fixed-effects or random-effects model is appropriate for this analysis, suggesting the fixed-effects model. Third, we estimate four different regression models for robustness check: Model 1 includes only the number of water users along with an intercept as independent variables. Model 2 includes the number of water users, irrigation types and irrigation service fees along with an intercept. In models 3 and 4, we additionally introduce the interaction terms between the number of water users and irrigation types along with year-fixed and region-fixed dummy variables.

4 Results

Table 2 reports the summary statistics of the variables in our analysis, indicating that 325 (300) observations are collected for the IWD, IWA, gravity irrigated areas, pump irrigated areas and payment fraction (for the number of water users). The minimum and maximum values of the

Table 2: Summary statistics

Variables	Obs	Mean	Median	SD	Min	Max
IWD	325	169 624	167 750	78 266	12 214	370 080
IWA	325	151 321	122 900	127 303	1400	587 700
Waterusers	300	1884	700	2728	7	14 627
Gravityareas	325	10 686	7485	9748	0	36 089
Pumpareas	325	13 152	9965	10 645	0	38 027
Paymentfraction	325	67	70	33	0	300

IWD (IWA) variable are 12.2 million m^3 (1.4 million m^3) and 370.1 million m^3 (587.7 million m^3), respectively. These differences highlight the substantial diversity in IWD (IWA) among the districts in our panel-data set. The number of water users ranges from 7 to 14 627 across the 13 districts, while the mean is 1884 and the median is 700. The minimum value of 0 for the gravity irrigated areas (pump irrigated areas) indicates that those districts solely rely on pump irrigation (gravity irrigation). Regarding the payment fraction, a minimum value of 0 indicates that water users do not pay the irrigation service fees for a given year, while a maximum value of 300 implies that water users paid irrigation service fees for the overdue years. Overall, the extensive gaps between the minimum and maximum values of the variables demonstrate that the Tajikistan agricultural and water systems are highly heterogeneous due to the wide range of crops and diversity in geography as well as climatic conditions.

4.1 Irrigation water demand

Table 3 reports the estimated coefficients and their respective standard errors of the independent variables on IWD along with their statistical significances in four regression models. Models 3 and 4 include the marginal effects for an interpretation of the relationships between our independent variables and their interactions with IWD. We find that the coefficients of gravity irrigated areas and pump irrigated areas on IWD are positive and statistically significant at the 1 % level in model 2. These findings remain consistent after incorporating interaction terms between the number of water users and irrigation types in model 3 and a year-fixed dummy variable in model 4. We mainly focus on reporting marginal effects in model 4 which is considered a full specification of our regressions. The marginal effect in model 4 indicates that IWD tend to increase by 4970 m^3 (7851 m^3) with a one additional hectare in gravity irrigated areas (pump irrigated areas), holding other independent variables fixed at their sample means. Overall, a rise in IWD is estimated to be 1.6 times larger in pump irrigated areas than that of gravity irrigated areas. The result can be attributed to the fact that farmers tend to grow specific crops(cotton and vegetables) with high water requirement in pump irrigated areas due to the local geography and environment as compared to those in gravity irrigated areas in Tajikistan.

4.2 Irrigation water availability

Table 4 shows the estimated coefficients, marginal effects and their respective standard errors of the independent variables on IWA along with their statistical significances. We find that the coefficients and marginal effects of the number of water users are statistically significant with negative sign at the 1 % level in a robust manner, irrespective of the models. This relationship holds true even when interaction terms between the number of water users and irrigation types are included in model 3 and a year-fixed dummy variable is included in model 4. In model 4, the marginal effect indicates that IWA tends to decrease by approximately 3246 m^3 when the number of water users increases by one, holding other independent variables fixed at their sample means. Overall, this finding suggests that the increasing number of water users through the land fragmentation processes in Tajikistan poses negative threats on the IWA.

In model 4, the inclusion of a year-fixed dummy variable is crucial to account for unobserved factors that may vary over time during the land-reform processes. For instance, irrigation infrastructure conditions, agricultural practices, climate as well as policy and institutional modifications are unobserved factors that can be considered to change in a year-specific manner as year-fixed effects (see figure 4), and they are controlled by including the corresponding year-fixed dummy variable in the analysis. We find that the coefficient and marginal effect of gravity irrigated areas (pumps irrigated areas) exhibit statistical significances from 1 % to 5 % levels with positive sign in

Table 3: Estimation of the panel regression for the irrigation water demand (IWD) in Sugd province

	Model 1	Model 2	Model 3		Model 4	
	Coefficient	Coefficient	Coefficient	Marginal effect	Coefficient	Marginal effect
Waterusers	5.015***	1.907***	−7.502***	0.723	−7.990***	−1.123
	(0.659)	(0.539)	(1.439)	(0.475)	(1.424)	(0.691)
Gravityareas		6.537***	3.710***	4.787***	3.990***	4.970***
		(0.614)	(0.603)	(0.574)	(0.657)	(0.619)
Pumpareas		7.061***	8.757***	9.043***	7.680***	7.851***
		(1.078)	(1.028)	(0.994)	(1.028)	(0.995)
Paymentfraction		−1.706	40.543	40.543	15.84	15.284
		(48.049)	(41.549)	(41.549)	(48.264)	(48.264)
Waterusers × Gravityareas			0.0006***		0.0005***	
			(0.000 06)		(0.000 06)	
Waterusers × Pumpareas			0.0001**		0.000 09	
			(0.000 06)		(0.000 06)	
Constant	162 109.8***	3663.1	9500.7		18 104.9	
	(2063.7)	(13 631.3)	(12 487.8)		(13 815.7)	
Sample size	300	300	300		300	
Number of districts	13	13	13		13	
R-squared	0.17	0.55	0.67		0.73	
Year-fixed dummy	No	No	No		Yes	
Regional-fixed dummy	No	Yes	Yes		Yes	
Hausman test (χ^2)	0.15	103.15***	13.86**		21.63**	

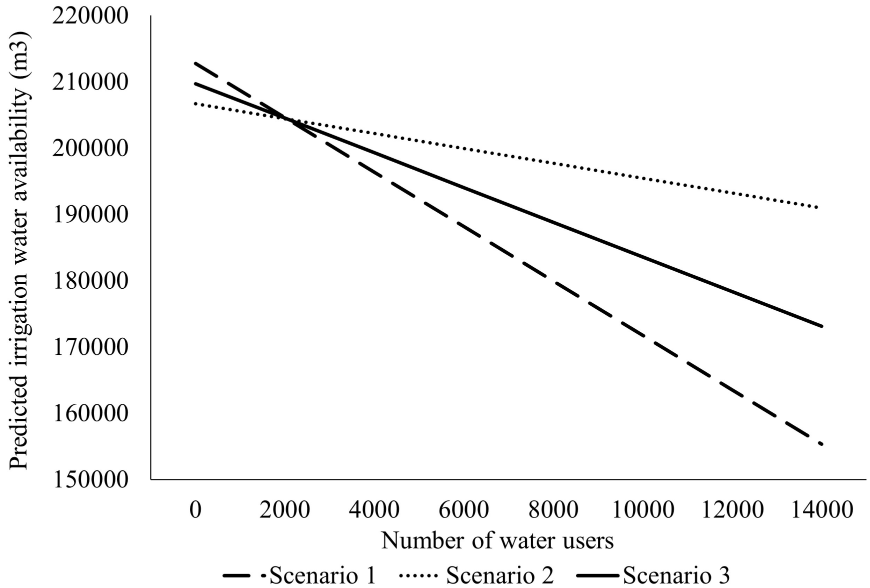
*** significant at the 1 % level
** significant at the 5 % level
* significant at the 10 % level
Standard errors are in parentheses

Table 4: Estimation of the panel regression for the irrigation water availability (IWA) in Sugd province

	Model 1	Model 2	Model 3		Model 4	
	Coefficient	Coefficient	Coefficient	Marginal effect	Coefficient	Marginal effect
Waterusers	−6.975***	−7.173***	3.535	−8.199***	11.600***	−3.246***
	(0.979)	(1.076)	(3.039)	(1.004)	(2.460)	(1.195)
Gravityareas		1.000	−2.394*	−2.548**	4.540***	3.807***
		(1.228)	(1.273)	(1.213)	(1.140)	(1.072)
Pumpareas		−3.023	4.773**	3.225	5.390***	3.874**
		(2.154)	(2.172)	(2.099)	(1.780)	(1.721)
Paymentfraction		125.417	224.888**	224.888**	109.170	109.171
		(95.988)	(87.739)	(87.739)	(83.460)	(83.460)
Waterusers × Gravityareas			−0.000 08		−0.0004***	
			(0.000 13)		(0.0001)	
Waterusers × Pumpareas			−0.0008***		−0.0008***	
			(0.000 12)		(0.0001)	
Constant	159 521.3***	180 156.9***	112 377.1***		83 885.2***	
	(3064.1)	(27 230.9)	(26 370.3)		(23 890.8)	
Sample size	300	300	300		300	
Number of districts	13	13	13		13	
R-squared	0.15	0.16	0.32		0.63	
Year-fixed dummy	No	No	No		Yes	
Regional-fixed dummy	No	Yes	Yes		Yes	
Hausman test (χ^2)	0.16	26.24***	8.48*		36.35***	

*** significant at the 1 % level
** significant at the 5 % level
* significant at the 10 % level
Standard errors are in parentheses

Figure 5: Predicted irrigation water availability (IWA) over the gravity and pump irrigated areas



model 4. Focusing on the marginal effect in model 4, the result implies that IWA tend to increase approximately by 3810 m^3 (3870 m^3) with an additional hectare in gravity irrigated areas (pump irrigated areas), holding other independent variables fixed at their sample means.

The interaction terms between the number of water users and irrigation types in models 3 and 4 are identified to be significant in a coherent manner, playing a crucial role in characterizing IWA. To quantitatively demonstrate these interactions, we have considered three scenarios and plotted the effects of the number of water users at different levels under varying proportions of irrigation types (holding other independent variables at their sample mean) based on the estimated results in model 4 of table 4. Scenario 1 assumes that 35 % is the gravity irrigated area and 65 % is the pump irrigated area. Scenario 2 assumes that 65 % is the gravity irrigated area and 35 % is the pump irrigated area. In scenario 3, we set an equal distribution of areas between the two irrigation types. Figure 5 shows the predicted IWAs over the number of water users under the three scenarios, demonstrating that the slopes are idiosyncratic by a mix of irrigation types. By comparing the slopes across the different scenarios, it becomes evident that increasing the proportion of pump irrigated areas leads to steeper slopes. This suggests that the magnitude in reduction of IWA through an increase in water users under pump irrigated areas is more significant than under gravity irrigated areas.

We summarize the estimation results associated with IWD and IWA in tables 3 and 4 and provide the answers to our research question (how is the number of water users related with irrigation water allocation in land reforms?) and hypothesis (an increase in the number of water users through land fragmentation poses negative threats on the water allocation through a mediation of irrigation types) in the introduction. As indicated in our conceptual framework in figure 4, it is found that IWD and IWA are characterized by the number of water users, irrigation types and their interactions as the main determinants in economically and statistically significant manners. The main difference between the two regressions is that the number of water users does not play a significant role in explaining IWD, while it emerges as an important predictor through an interaction with irrigation areas for IWA. Our research establishes that the increasing number of water users along with irrigation types through the land-fragmentation processes pose negative threats on irrigation water allocation in Tajikistan. While literature has identified both positive and negative impacts of land fragmentation on agricultural production and rural development (Lerman, 2008, Robinson et al., 2008, Lerman and Sedik, 2009, Hartvigsen, 2014, Jürgenson, 2016, Postek et al., 2019, Wang et al., 2020, 2021), our results appear to be on the “negative-impact” side.

Land fragmentation is an ongoing global event driven by market forces, such as population growth, or governmental decisions. Irrespective of driving forces behind land fragmentation, this research suggests that the decisions of land fragmentation must be carefully implemented along with the number of water users. Our negative-impact result shall be explained by whether or not an irrigation infrastructure or environment is suitable for the plot scales under land fragmentation that characterize farmers’ empowerment for water management, enabling individuals and organizations to effectively supervise and monitor the water allocation. In Tajikistan, we must admit that the current irrigation infrastructure and environment are not sufficiently suitable to allow an increase of water users through land fragmentation for maintaining water allocations, and nobody expected that such negative result would be realized when land fragmentation was adopted and started as a national policy. In other words, an increase in water users through land fragmentation exacerbates IWA, as demonstrated in this research, depending on infrastructures and environments. In particular, the negative impact shall be even worsened by particular environments, especially, semi-arid and arid regions, such as Tajikistan, where water is a bottleneck for not only agriculture but also many other economic activities.

Our research suggests some possible policy recommendations to improve irrigation water allocations through land-reform processes. One is to consolidate small-scale farms at the level of former collectivization parcels where at least one parcel should be shared by several farmers through creating community collaborative management, especially when a proper irrigation infrastructure (or an environment) for land fragmentation is not available. If they grow one type of crops in each parcel collectively, water availability, production, water supervision and monitoring will improve by land consolidation even in the absence of the proper infrastructure and environment. Another is to newly adopt a technically efficient and proper irrigation distribution system, such as a piped distribution system (PDS) for small-scale farms, when land fragmentation is moving forward or unavoidable due to the pressure from population growth or the general public. The PDS is reported to reduce the costs of land acquisition, operation, maintenance, supervision, water losses due to evaporation, seepage as well as water logging issues, and consequently, accurate volumetric irrigation water supply can be ensured. However, we must note that adopting such a system comes with a huge financial burden on the budget of developing nations. Given such a financial challenge, it is advisable to reassess the trade-off between promoting land consolidation and adopting a new irrigation infrastructure to accommodate small-sized plots. This reassessment should also consider the interaction between the number of water users and irrigation types for food security and sustainability in agricultural sectors, as demonstrated in this paper.

5 Conclusion

This study examines how the number of water users in land reforms is related to irrigation water in Tajikistan, hypothesizing that an increase in the number of water users through land fragmentation poses negative threats on water allocation through a mediation of irrigation types. We utilize panel data from 1996 to 2020 from 13 districts of Sugd province, collecting secondary data on IWD, IWA, gravity irrigated areas, pump irrigated areas and payment fraction. The analyses reveal that the irrigation type is a key determinant for IWD as compared to any other factors, and the impact under pump irrigated areas is approximately 1.6 times as large as that by gravity irrigated areas. The finding also shows that the increasing number of water users through land fragmentation in Tajikistan tends to reduce IWA, and the magnitude in reduction under pump irrigated areas is more significant than that under gravity irrigated areas. Overall, this research establishes that irrigation types and the number of water users through land reforms matter for a change in irrigation water allocations, and the interactions particularly pose the idiosyncratic threats on IWA. Our result implies that the decision of land fragmentation should be carefully evaluated and implemented in consideration to possible negative impacts on water availability along with an increasing number of water users, and the negative impact shall be highly dependent on infrastructure, i.e., irrigation types, as well as environment.

We note some limitations of our study and directions for future research. First, in this research, IWD is calculated with available information (mainly, crop types and areas), which is considered the best approximation we can make in the context of Tajikistan. However, future studies shall be able to collect and use a good-quality IWD data that incorporates irrigation system losses and other minute factors. Second, this research does not address the detailed processes of why the magnitude in IWA reduction under pump irrigation is more significant than that under gravity irrigation, when the number of water users increases. To clarify the details, future studies should consider water-use efficiency (or water balance) in regard to the farm-plot sizes and technical conditions under each irrigation type. To this end, water modeling approach with field measurements shall be recommended. Third, this research employs the secondary data without fully integrating the analysis with geoinformation. However, in future, it is desirable to collect primary data at each plot level and to conduct geoinformation system analysis with the data in a unified manner that enables us to clarify the details of water allocations. Finally, we admit that our research may have some other limitations, however, it is our belief that this study is one of the important first attempts to understand a relationship between the number of water users and IWA in land-reform processes, and further studies on the same issue will ensue in future.

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