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The Impact Of Dams on Agricultural Productivity In Indonesia

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ABSTRACT

The construction of dams plays a crucial role in water resource management, including irrigation, energy, and consumption, and is believed to contribute to overall welfare improvement. Several previous studies have highlighted the positive impact of large dams on agricultural productivity, particularly in terms of irrigation efficiency. However, the distribution of these benefits among local communities remains unclear. Some studies suggest that residents living near dams often receive fewer benefits. This study aims to evaluate the impact of large and small dams on agricultural productivity, measured by the frequency of rice harvests at the household level, using data from the Indonesia Family Life Survey (IFLS) 2007 and 2014, as well as spatial data on dams in Indonesia. The findings indicate that the presence of large dams tends to be negatively associated with the frequency of rice harvests for households near the dams. Conversely, small dams exhibit a different trend, where their presence is associated with increased agricultural productivity. This study employs a unique approach by considering the distance of households from dam locations to provide more accurate predictions of changes in agricultural productivity in areas near large dams compared to those farther away.

INTRODUCTION

Dams play a critical role in water resource management (WCD, 2000). Several studies have shown that the construction of dams positively impacts agricultural productivity (see Duflo & Pande, 2007; Strobl & Strobl, 2011; Blanc & Strobl, 2014). However, it remains unclear who truly benefits from dam construction and whether these benefits are equitably distributed across regions (Duflo & Pande, 2007). Duflo & Pande (2007), in their study in India, found that dam construction only increases agricultural production in downstream areas, while regions near the dam site do not benefit. Similar findings were observed in Africa by Strobl & Strobl (2011). However, these studies focused solely on large dams, with limited research on small dams.

Therefore, this study aims to explore the impact of both large and small dams on agricultural productivity, measured by the frequency of rice harvests at the household level.

Dam construction policies, aimed at increasing irrigation water supply, electricity, and drinking water, have long been a strategic choice in many countries (Chen et al., 2016). The widespread belief that dam construction positively impacts economic growth and poverty reduction has motivated many nations to prioritize dam construction in their development policies (Nguyen et al., 2017; Yigzaw et al., 2019). Globally, dams contribute 19% of electricity supply and 30% of irrigation water for the 271 million hectares of irrigated land. They also reduce the risk of natural disasters and support river transport development, recreational activities, tourism, and fish farming (WCD, 2000). Additionally, dam construction creates job opportunities (Siciliano et al., 2018; Mettetal, 2019). Constructing dams along river flows has become vital for population growth and technological innovations, particularly in water resource management (Poff & Hart, 2002).

However, dam construction sometimes creates significant trade-offs both geographically and sectorally. Dams may concentrate benefits and/or costs among specific groups (e.g., local landowners may gain significantly from new irrigation-driven agricultural productivity, while others may lose homes or livelihoods tied to seasonal water flow) (Jeuland, 2020). Furthermore, dams have environmental and social downsides. Large dams typically have extensive impacts on rivers, watersheds, and aquatic ecosystems (WCD, 2000). Dam construction has displaced over 40 million people worldwide, leading to global shifts in farming patterns and increased salinity (soil salinization) and waterlogging, which can degrade soil fertility in dam-construction areas (WCD, 2000; Poff & Hart, 2002).

As one of seven countries with more than 2,000 km² of water resources, along with Brazil, Russia, Canada, China, the United States, and Colombia, Indonesia has significant potential to meet its growing water demand due to population growth (Chen et al., 2016). Climate change, driven by global warming, has prompted many countries, including Indonesia, to secure future water needs not only for agriculture but also for household consumption (SPANCOLD, 2015). Consequently, efforts to utilize watersheds through infrastructure for electricity, flood control, and irrigation have intensified (Yüksel, 2010). In Indonesia, water infrastructure is crucial for maintaining and enhancing agricultural productivity, as 70% of the rural labor force works in agriculture (Yamamoto et al., 2019). Therefore, the Indonesian government has continued to prioritize dam construction through the National Strategic Project (PSN) policy to secure future water resilience.

Research on the impact of dams on socio-economic aspects, particularly on the frequency of rice harvests at the household level in Indonesia, is relatively scarce. Most dam-related studies focus on their impact on the welfare of people relocated from dam construction sites (Nakayama et al., 1999; Sisinggih et al., 2013). This study is significant as it seeks to mitigate socio-economic risks, especially for farmers and rural communities, from dam construction projects, given that previous research indicates socio-economic issues resulting from dam construction are often overlooked (Legese et al., 2018). The study employs a household distance-to-dam variation concept to evaluate the impacts, offering more accurate predictions of changes in agricultural productivity in areas close to and farther from dams. Zhao (2013) used distance estimations to analyze land conversion during dam construction and operation phases, highlighting potential land conversion and its socio-economic impacts on households within a 10-kilometer radius of dam sites.

This study adopts a different approach from Duflo & Pande (2007) and Strobl & Strobl (2011), who used upstream and downstream concepts. The approach in this research aims to answer how dams affect rice harvest frequency, particularly the impact on farmers living near dam locations. Among the socio-economic issues arising from dam construction, this study focuses on analyzing its impact on agricultural productivity, measured by rice harvest frequency at the household level near dam sites. Rice harvest frequency is a relevant and accurate indicator of agricultural productivity in the context of irrigation infrastructure, including dams (Aribowo & Yudhistira, 2021). The variation in household distance from dam locations is considered to provide more accurate predictions of changes in agricultural productivity. Secondary data are used to analyze whether areas closer to dams experience more significant land conversion than farther areas. Thus, it is assumed that households near dams will undergo socio-economic changes as the dams become operational.

LITERATURE REVIEW

Agricultural productivity is defined as the yield obtained from a unit of land or labor within a specific period. Agricultural productivity can be measured using several indicators. One commonly used indicator is crop yield, which is calculated based on production per unit of land area, for example, in tons per hectare (Duflo & Pande, 2007; Takeshima, 2018). Additionally, agricultural productivity can also be measured through the economic value of crop yields, which is calculated based on the total income earned by farmers from their harvests (Ersado, 2005; Blanc & Strobl, 2014). In this study, rice harvest frequency is chosen as a proxy for agricultural productivity because this indicator is contextually relevant, easy to measure, and directly reflects the impact of dam infrastructure on agricultural productivity in Indonesia (Aribowo & Yudhistira, 2021).

Based on Cobb-Douglas production theory, this study aims to explain the relationship between production inputs and the resulting output, specifically the frequency of rice harvests. This relationship can be expressed in the production function Q = f (L, K, T), where Q represents the quantity of output produced (rice harvest frequency), L indicates the amount of labor, K represents capital inputs (such as tools and agricultural infrastructure), and T reflects the technology or production methods applied. This study focuses primarily on the role of irrigation infrastructure, particularly large and small dams, as part of the capital input variables that have the potential to increase rice harvest frequency.

Research on the impact of dams on rice harvest frequency in Indonesia, particularly based on variations in household distance from dams, remains limited. This study follows the approach of Zhao (2013), who found that dam construction influences land-use patterns, primarily through land conversion during the land acquisition, construction, and operational phases of a dam. The impact of this conversion is most evident within a 10-kilometer radius of the dam, with the greatest effect occurring at a distance of 800–1000 meters and diminishing as the distance increases. Meanwhile, the impact of reservoir filling tends to decline up to 5,000 meters from the river, then gradually increases again up to 10,000 meters. The conversion of agricultural land and forests due to dams can reduce the available rice field area, potentially lowering the productivity of staple crops such as rice.

A previous study by Duflo and Pande (2007) in India found that large dams increased agricultural productivity in downstream areas but led to higher poverty levels in upstream regions. This study employed panel analysis and instrumental variable (IV) methods, incorporating variables such as the number of dams, the irrigated area, agricultural production, and poverty ratios. The results indicated a 0.77% increase in poverty in upstream districts, while downstream districts experienced a decline in poverty, highlighting an unequal distribution of dam benefits. Strobl and Strobl (2011) reinforced these findings in their study in Africa, showing that agricultural productivity was higher in downstream areas than in upstream regions of dams. Their study utilized satellite data on Net Primary Production (NPP) as a proxy for land productivity, along with environmental variables such as rainfall and temperature. Using an instrumental variable (IV) approach, the results showed that large dams increased land productivity in downstream areas but did not provide significant benefits for land near the dam itself. Research on small dams, conducted by Ersado (2005) in Ethiopia, found that villages near dams experienced increased productivity and income but also faced a rise in disease incidents such as malaria due to water stagnation, reducing some of the economic benefits generated by these dams.

Unlike previous studies that differentiated impacts based on upstream and downstream locations, this research adopts a more detailed approach to identifying the decline in rice harvest frequency among households located near dams. In this study, the criteria for large dams refer to the standards set by the International Commission on Large Dams (ICOLD), which defines a large dam as a structure with a minimum height of 15 meters from the foundation or a height of 5 to 15 meters with a storage capacity of at least 3 million cubic meters (WCD, 2000). Meanwhile, the Ministry of Public Works and Public Housing Regulation No. 27 of 2015 does not specifically define the criteria for large dams.

METHODS

This study uses secondary data to analyze the impact of dams on agricultural productivity, measured through household rice harvest frequency. The primary data source is the Indonesia Family Life Survey (IFLS) to measure harvest frequency, which is considered relevant for evaluating agricultural productivity (Aribowo & Yudhistira, 2021). Dam data were obtained from the Pusdatin Kemen PUPR, covering 228 dams classified into 128 large dams and 70 small dams based on the literature. Only dams located in areas within the coverage of the 2007 and 2014 IFLS surveys were included. Additional data sources, such as rainfall and elevation, were obtained from external datasets as control variables.

The selection of household samples was based on their residential locations derived from IFLS data, which were then matched with the positions of dams and administrative maps from BPS. The selected households are agricultural sector workers in sub-districts located within the influence radius of large and small dams. This process utilized geographic mapping methods referencing dam coordinates and the centroids of sub-districts. Buffers with a 10 km radius were created around each sub-district centroid to identify households located within the dams' influence area. These buffers provided information on the number and types of dams within the specified radius. Households in sub-districts within this influence radius were chosen as they are assumed to potentially experience the direct impact of the dams. The household sample data were grouped based on the number and type of dams in their vicinity. The analysis was conducted to understand the relationship between the presence of large or small dams and rice harvest frequency, aiming to evaluate the impact of dams on agricultural practices in the region.

In this study, the empirical model used to analyze the effect of the number of large and small dams on harvest frequency is a panel regression model with a fixed-effect approach. The fixed-effect model was chosen because this method allows for controlling variables that may vary across households but remain constant over time. Consequently, this model can eliminate bias arising from unobservable individual household characteristics. The empirical model equation used in this study is as follows:

$$Y_{it} = \alpha + \beta_1 X_{1it} + \beta_2 X_{2it} + \gamma Control_{it} + \delta_t + u_i + \epsilon_{it}$$

Where Y_{it} represents the harvest frequency for farmer household iii in period ttt, β_1 and β_2 are the coefficients of the main independent variables, X_{1it} denotes the number of large dams for farmer household i in period t, X_{2it} denotes the number of small dams for farmer household i in period t, γ represents the coefficients of the control variables, $Control_{it}$ includes a set of control variables for farmer household i in period t, δ_t captures year fixed effects, u_i represents individual fixed effects, and ϵ_{it} is the error term or random error.

RESULTS

According to the primary functions of dams, which include irrigation, power generation, and water supply for consumption, the construction of water infrastructure is theoretically expected to bring long-term benefits to society. However, these benefits may not be fully experienced by households living near the reservoir. This condition arises due to changes in river flow patterns, where water sources are diverted to maximize reservoir storage (Duflo & Pande, 2007). In this study, rice harvest frequency from IFLS 4 and 5 data is used as an indicator of agricultural productivity to test the proposed hypothesis. Harvest frequency, particularly for rice crops, is often used as a reference in cost-benefit analyses of dam construction (Zainuddin, 2012).

This study classifies regions into four clusters based on the variation in household distance from the dam: 0–2.5 kilometers, 2.5–5 kilometers, 5–7.5 kilometers, and 7.5–10 kilometers. This classification aims to analyze the impact of dams based on differences in the distance between farming households and the dam.

Table 1. Estimation Results of Rice Harvest Frequency

	Rice Harvest Frequency				
	(1) 0-2.5 km	(2) 2.5 – 5 km	(3) 5 – 7.5 km	(4) 7.5 – 10 km	(5) 0 – 10 km
Number of Big Dams	-0.891*** (0.241)	-0.083 (0.145)	0.076 (0.089)	0.121** (0.060)	0.089* (0.046)
Number of Small Dams	0.477* (0.247)	-0.234*** (0.080)	-0.084 (0.116)	-0.227*** (0.067)	-0.172*** (0.044)
Land Area	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Water Source:					
1. Rainwater	0.000 (.)	0.000 (.)	0.000 (.)	0.000 (.)	0.000 (.)
2. Irrigation	0.452*** (0.036)	0.442*** (0.036)	0.451*** (0.036)	0.430*** (0.036)	0.430*** (0.036)
3. Well/Pump	0.405*** (0.091)	0.404*** (0.090)	0.407*** (0.090)	0.410*** (0.089)	0.410*** (0.089)
5. Others	0.286*** (0.055)	0.282*** (0.055)	0.285*** (0.055)	0.262*** (0.055)	0.264*** (0.055)
Rice Variety	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)
Number of Household Members	-0.003 (0.006)	-0.004 (0.006)	-0.003 (0.006)	-0.004 (0.006)	-0.003 (0.006)
Tractor	0.262*** (0.077)	0.265*** (0.077)	0.262*** (0.077)	0.280*** (0.078)	0.276*** (0.077)
Other Agricultural Tools	-0.056 (0.059)	-0.046 (0.059)	-0.056 (0.059)	-0.067 (0.059)	-0.056 (0.058)
Average Rainfall	0.000***	0.000***	0.000***	0.000***	0.000***

	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Average Elevation	-0.000***	-0.000**	-0.000***	-0.000**	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
2007	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)
2014	0.115***	0.116***	0.113***	0.116***	0.117***
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
_cons	1.055***	1.049***	1.039***	1.076***	1.068***
	(0.110)	(0.110)	(0.110)	(0.111)	(0.111)
R-squared	0.156	0.153	0.151	0.161	0.161
Observations	3539	3539	3539	3539	3539

Source: Data Processed, 2025
*Notes: ***, **, * indicates statistical significance at 1%, 5%, and 10%*

The overall estimation results for households residing within 10 kilometers of large dam locations indicate a positive and significant correlation between an increase in the number of large dams and the frequency of rice harvests among the sampled farming households. Using distance variation, this study finds that the further the distance, the more positive and significant the correlation between large dams and the frequency of rice harvests. These findings suggest that agricultural productivity tends to be lower in districts or areas located closer to large dams (Duflo & Pande, 2007; Strobl & Strobl, 2011; Takeshima, 2018). In areas very close to large dams (0–2.5 kilometers), dam construction and operational activities can disrupt local ecosystems and agricultural activities. Land inundation for reservoirs can reduce the available agricultural land area, and population relocation can interfere with traditional farming practices, leading to a decrease in the frequency of rice harvests. At greater distances (7.5–10 km), large dams function as stable irrigation sources, providing year-round water supply. This enables farmers to increase planting intensity and rice harvest frequency, particularly in areas that previously depended on rainfall (Blanc & Strobl, 2013; Ashraf et al., 2007).

Interestingly, this result contrasts with the impact of small dams. The overall estimation results (column 5) show that small dams are negatively and significantly correlated with a reduction in rice harvest frequency. This may be because small dams are not as effective as large dams in providing consistent irrigation. They tend to have lower storage capacity and are more vulnerable to drought or climate variability (Ceuppens et al., 1997). Additionally, the presence of numerous small dams can lead to water flow fragmentation and potential conflicts among water users, which can disrupt irrigation schedules and reduce harvest frequency (Kahlown & Azam, 2002). At close distances (0–2.5 kilometers), small dams show a positive and significant correlation with rice harvest frequency, while at greater distances (7.5–10 kilometers), small dams may be less effective in distributing water to farther areas or may experience greater water loss.

Control variables such as water source, tractor use, and rainfall show a significant and positive impact on harvest frequency, highlighting the importance of water access, agricultural mechanization, and environmental conditions in supporting rice productivity. Tractor use has a significant positive effect across all models (coefficients around 0.262–0.280, $p < 0.01$), confirming that agricultural mechanization through tractor use can substantially increase harvest frequency (Blanc & Strobl, 2014). Rainfall also shows a highly significant positive effect ($p < 0.01$), reaffirming that the availability of natural water remains a crucial factor in determining agricultural productivity, particularly for rice crops (Ashraf et al., 2007). Conversely, elevation has a negative and significant effect ($p < 0.05$ or $p < 0.01$), indicating that areas with higher altitudes tend to have lower harvest frequency due to limited water access and geographical challenges. Meanwhile, variables such as land area, rice variety, and other agricultural tools do not show significant effects in this study.

This study also distinguishes between subdistricts that are only served by large dams and those that are only served by small dams to address potential overlapping effects of both dam types in the same subdistricts. The regression results after this separation show similar findings to the previous regressions. Detailed regression results can be found in the Appendix 1.

DISCUSSION

Dams have long been a policy choice for many developing countries since the 20th century to enhance agricultural productivity (WCD, 2000). However, the effectiveness of large-scale water infrastructure development in improving the welfare of local populations remains uncertain due to several issues, including relocation (Kircherr & Charles, 2016), health problems (Mettetal, 2019), and unequal distribution of benefits (Duflo & Pande, 2007; Strobl & Strobl, 2011). Therefore, an evaluation of the policy choice between building large dams or small dams is necessary, considering time and cost efficiency. Large dam construction is associated with a higher risk of budget overruns compared to small dams (Ansar et al., 2014).

This study examines the impact of large and small dams operating in Indonesia on rice harvest frequency, particularly for households located relatively close to the dams. Rice harvest frequency is chosen as the research variable because 70% of Indonesia's workforce is employed in the agricultural sector, with rice being the main commodity (Yamamoto et al., 2019).

The analysis, using Ordinary Least Squares (OLS) regression with Fixed Effects, reveals differences in results between households near large dams and those near small dams. Statistically, large dams lead to a decrease in rice harvest frequency for households living close to the dam but have a positive impact on those living farther away. In contrast, small dams increase the rice harvest frequency for households located near the dam compared to those living farther away. These findings align with previous studies by Duflo & Pande (2007) in India and Strobl & Strobl (2011) and Takeshima (2018) in Africa, which indicate a decline in agricultural productivity for households near large dams. Conversely, Blanc & Strobl (2014) found that small dams positively affect agricultural land productivity in surrounding areas. Additionally, Ersado (2005) in Ethiopia found that small-scale dams enhance agricultural yields and income for households closer to the dam compared to those living farther away. Based on the estimation results, the research hypothesis stating that large dams negatively affect rice harvest frequency for nearby households, while small dams have a positive impact, is supported by the findings of this study.

This study also seeks to examine the heterogeneous effects of dams in Java and outside Java in the context of water resource management and their impact on agricultural productivity. Java, as a region with high population density and intensive economic activities, has greater irrigation needs and a more complex water management system compared to other regions. On the other hand, areas outside Java face different challenges, including more limited infrastructure distribution and varying geographical and climatic conditions. The findings indicate that large dams tend to be more effective in Java, particularly at medium to long distances, whereas small dams are more effective at shorter distances in non-Java regions. These varying effects offer valuable insights for policymakers in designing irrigation strategies that are better suited to the local conditions of each region to enhance rice harvest frequency. The complete results can be found in Appendix 2.

The estimation results indicate that policymakers should evaluate water management policies for large dams, particularly in areas within close proximity, to ensure a more equitable distribution of water and prevent a decline in rice harvest frequency. Local governments or relevant agencies may consider increasing the capacity or efficiency of small dam management, especially for irrigation systems in areas further from the dams. This could involve improving water management technology or providing additional infrastructure support. The use of tractors shows a positive and significant relationship with harvest frequency across all models, confirming that agricultural mechanization can enhance rice harvest frequency. Therefore, further support is needed in terms of providing or subsidizing agricultural machinery such as tractors, particularly for farmers in remote areas. Training programs on the use and maintenance of mechanical equipment could also help farmers optimize agricultural production.

The estimation results in this study still require refinement by incorporating additional factors that have not been included in the model but may influence rice harvest frequency. Studies by Duflo & Pande (2007), Mettetal (2019), and Strobl & Strobl (2011) utilized the average river gradient as an instrumental variable to address endogeneity issues, which could otherwise lead to biased and inconsistent coefficient estimates in regression analysis. However, this study does not employ such an instrumental variable due to the unavailability of nationwide river gradient data at the district level. Nevertheless, this study has applied the fixed effects approach to mitigate potential bias.

CONCLUSION

Using the Pooled Ordinary Least Squares (PLS) method with Fixed Effects, the findings indicate differences in the results between households living near large dams and those living near small dams. Statistically, large dams lead to a decrease in rice harvest frequency for households residing close to the dam area but have a positive impact on households living further away. In contrast, small dams increase rice harvest frequency for households living near the dam compared to those living further away. Thus, the research hypothesis stating that large dams have a negative effect on rice harvest frequency for nearby households, while small dams have a positive effect, is supported by the findings of this study.

LIMITATION

This study focuses on the impact of dams in Indonesia and does not include other water infrastructure, such as irrigation canals, which are still related to dams. This limitation is due to the difficulty in collecting comprehensive data regarding the number, specifications, and geographic coordinates of all water infrastructure. Nevertheless, this study has incorporated a control variable for water sources, which includes contributions from irrigation systems.

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