water

Article

Urbanization Impacts on Rice Farming Technical Efficiency: A Comparison of Irrigated and Non-Irrigated Areas in Indonesia

Mohammad Rondhi [1,*], Stefani Jessica Herlyana Suherman [1], Clement Billy Hensie [1], Shohibul Ulum [1], Anik Suwandari [1], Rokhani [2], Yasuhiro Mori [3] and Takumi Kondo [4]

[1] Department of Agribusiness, Faculty of Agriculture, University of Jember, Jember 68121, Indonesia; 181510601002@mail.unej.ac.id (S.J.H.S.); 181510601052@mail.unej.ac.id (C.B.H.); shohibul.students@mail.unej.ac.id (S.U.); anik.faperta@unej.ac.id (A.S.)
[2] Department of Agricultural Extension, Faculty of Agriculture, University of Jember, Jember 68121, Indonesia; rokhani@unej.ac.id
[3] Department of Sustainable Agriculture, Rakuno Gakuen University, Ebetsu 069-8501, Hokkaido, Japan; y-mori@rakuno.ac.jp
[4] Research Faculty of Agriculture, Hokkaido University, Sapporo 060-8589, Hokkaido, Japan; kondot@agr.hokudai.ac.jp
* Correspondence: rondhi.faperta@unej.ac.id; Tel.: +62-81291495040

Abstract: By 2050, the world population is expected to double, with the majority living in urban areas. Urbanization is a result of population pressure, often emphasized in developing countries. It has various impacts on all economic sectors, among which is agriculture through irrigation, which plays an important role in the production and sustainability of farming. This paper aimed to analyze the effect of urbanization on farm performance using a sequential mixed method. The data of approximately 80,053 farmers were extracted from the Indonesian Rice Farm Household Survey (SPD) dataset. A stochastic frontier was employed to analyze technical efficiency (TE) and its determinants, which consist of farmers' age, education level, climate change, land ownership, membership status, and pest infestation. The estimation results showed that the mean technical efficiency in both irrigation and non-irrigation rice farming was 64.7% and 66.2%, respectively. Although TE's achievement in non-irrigated rice farming areas was greater than in irrigated ones, rice productivity in irrigated areas was greater than in non-irrigated. All technical efficiency determinants have significant effects on technical efficiency. The estimation results also showed that rice farming in urban areas tends to decrease technical efficiency.

Keywords: irrigation; technical efficiency; urbanization; rice productivity; stochastic frontier analysis

check for updates

Citation: Rondhi, M.; Suherman, S.J.H.; Hensie, C.B.; Ulum, S.; Suwandari, A.; Rokhani; Mori, Y.; Kondo, T. Urbanization Impacts on Rice Farming Technical Efficiency: A Comparison of Irrigated and Non-Irrigated Areas in Indonesia. *Water* **2024**, *16*, 651. https://doi.org/10.3390/w16050651

Academic Editors: Elahi Ehsan and Guo Wei

Received: 30 November 2023
Revised: 23 January 2024
Accepted: 29 January 2024
Published: 22 February 2024

1. Introduction

In developing countries, including Indonesia, urbanization introduces threats relating to food insecurity, malnutrition, and the vulnerability of food systems. As a result, food systems in developing countries face significant pressure as urbanization occurs in areas with the most productive agricultural land [1,2]. These urbanization-mediated challenges are receiving increasing attention, both nationally and internationally, as they are a key component of sustainable development [3]. In particular, the importance of urbanization for the social and economic situation of a country has become an emphasized topic within the frameworks of the Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs).

Urbanization has affected the agriculture sector, especially irrigation. The impacts of urbanization can be identified according to the quantity and quality of irrigation water. The reduced amount of water flowing through irrigation canals reduces distribution efficiency and increases irrigation water losses. Urbanization also causes the fragmentation of irrigated agricultural land and water distribution networks, as well as the disruption of the operation and maintenance of irrigation areas [4]. In addition, a crucial problem arising from urbanization is the handling and management of waste [5]. In developing countries, urban communities do not have access to proper sewerage systems, which results in pollution [6]. In addition, many urban residents intentionally or unintentionally exacerbate soil and water pollution due to improper waste management and handling.

Several studies have identified the impact of urbanization on water quality and quantity, and recent studies reinforced this [7,8]. There are three important aspects of the impact of urbanization on the use of water resources. The first aspect is the impact of urbanization on the use of water resources. Several studies have found that urbanization causes an increase in total water use, and the impact is linear [9]. However, several other studies have shown that the impact of urbanization on the use of water resources has a non-linear threshold effect [10]. In addition, the impact of urbanization varies according to the type and level of water consumption [11].

The second aspect is the impact of urbanization on the efficient use of water resources. Several studies show that urbanization increases water use efficiency [10,12]; however, Ref. [13] found that population and land urbanization have a negative impact on the efficiency of industrial water use. Moreover, several other studies have found that the relationship between urbanization and water use efficiency follows an inverted N-shaped pattern, which means that urbanization increases water use efficiency in one group and reduces it in other groups. The third aspect is the impact of urbanization on the structure of water use. Most studies show that urbanization decreases the proportion of agricultural water use and increases the proportion of industrial water use and household water use [14]. These results indicate that urbanization will increase competition in the use of agricultural irrigation water in urban areas.

Water usage in certain areas in Indonesia is threatened by urbanization. Green open spaces in many new urban areas in Indonesia decreased over time. This has led to a decline in water absorption areas, which in turn degrades water capacity [15]. The declined water capacity had a significant impact on rice farming and other agricultural aspects within urban areas. The development of technology related to water management or water usage in Indonesian rice farming has thus become a primary policy of the Indonesian government [16]. The awareness of people living in surrounding areas is also necessary to manage water shortage [17].

As one of the water usage methods in the agriculture sector, irrigation has an important role in improving rice productivity. In Indonesia, the role of irrigation in rice farming is indicative of its ability to increase the income and quality of life among farmers. Rice farmers in Indonesia also require accessible water from irrigation canals to cultivate rice farming [18]. The rice farmland area in Indonesia comprises 4.1 million hectares of irrigated rice farmland, 3.3 million hectares of rain-fed rice farmland, and 1.1 million hectares of other rice farmland [19]. Therefore, irrigated rice farmland holds a significant role within the Indonesian agricultural sector.

Paddy or rice commodity is a staple food for Indonesian people, and the government strives to maintain the availability and stability of this commodity [20]. Among the substantial efforts taken by the government is the import of rice from countries such as China, Thailand, Myanmar, Vietnam, India, Pakistan, the United States, etc., which annually imported 928,610.9 during 2016–2020 [21]. The import policy was made due to the lack of rice maximum productivity, which was characterized by the leveling-off phenomenon [22]. The input usage in rice farming is a main presumption behind the low rice productivity or potential production [23].

There are two main strategies that have been implemented in Indonesia via the Food Directorate of the Ministry of Agriculture to alleviate low rice productivity, which are intensification and extensification [24]. In fact, these strategies are still unable to increase rice production, even though rice productivity in Indonesia tends to experience leveling off [25]. Another strategy is the Special Efforts Program (UPSUS Program), which had been implemented by the local government of East Java to achieve a self-sufficient rice and food sector as well [26]. The fluctuation in rice productivity has become a serious problem within the Indonesian food sector because it is heavily correlated with the retail price of rice [27].

Irrigation networks across Indonesia are the key to improving rice productivity. The SPD dataset showed that irrigated rice field areas are estimated to comprise roughly 49.36% of the total, while the remaining 50.64% of areas are non-irrigated. However, irrigated areas located in urban and countryside areas have thus far been underutilized. The usage of irrigation networks around urban areas has been obstructed by land conversion [28]. On the other hand, the deterioration of irrigation networks in rural or rural areas contributes to the low productivity of agricultural commodities. In general, national irrigation networks are potentially under-utilized or inefficient, as there are 3.3 million ha, or 36% of irrigated areas, in bad conditions or not functioning at all [29]. This condition has affected farming technical efficiency.

Farming efficiency within irrigation networks is a primary indicator of how irrigation affects agricultural farming along irrigation canals. The efficiency level of farming has been affected by irrigation networks, the formal education level of farmers, the non-formal education level of farmers, land ownership status, and farmer membership status [30,31]. Other factors that allegedly contribute to the technical efficiency level of farming include the amount of fertilizer and irrigation in risky environmental conditions [32].

The decline in the quantity and quality of irrigation water due to urbanization will reduce agricultural productivity in urban areas and their buffer zones. This condition will increase the vulnerability of the food system in urban buffer areas, which will in turn increase food insecurity in urban areas. In addition, the use of water contaminated with urban waste will increase the risk of food safety and the emergence of food-related diseases. Thus, the main objectives of this article were to determine technical efficiency within rice farming on irrigated and non-irrigated cropland. In order to capture the effect of urbanization on technical efficiency, this article included the attributes of urban or rural farmers. These factors can provide detailed explanations related to technical efficiency based on location.

2. Materials and Methods

This research was designed as a mixed-method study, indicating an integration of quantitative and qualitative approaches. The mixed method entails collecting and analyzing data using qualitative and quantitative approaches [33]. The sequential method is an example of a mixed method employed in this study, which means that qualitative data were collected after the determination or estimation of quantitative results. The sequential mixed method can be defined as a type of investigation in which the phases of the research occur in a consecutive order [34].

2.1. Sampling

The main source of data in this article was extracted from the 2014 Rice Farm Household Survey (SPD) dataset. There were 87,730 observations (households) in total. All of the observations practiced rice farming, or at least had rice farmland. However, this article only used 80,053 eligible households after dropping roughly 7000 observations which were categorized as non-rice-field farmers. Alongside the chosen observations, another key informant was needed to verify the quantitative results. Therefore, there were two informants who conducted in-depth interviews in Jember Regency, East Java Province, Indonesia; The informants represented urban and rural areas that had experienced irrigated and non-irrigated areas

BPS or the Indonesian Statistical Agency stated that the sampled farmers were interviewed during the Agricultural Census in 2013. The collected data were categorized within the 2014 Rice Farm Household Survey (SPD) dataset, which was published the following year. This study only utilized information related to the demography, membership of farmer association, type or harvest area, rice production, production cost, and natural disaster, including pest infestation from the dataset.

2.2. Data Analysis

Technical efficiency can defined as the degree to which the actual output of a production unit approaches its maximum [35]. The common tool used to measure maximum output is the production function or relationship between the input and output [36], and can be measured using deterministic or stochastic models, for example, least-squares econometric production model, total factor productivity indices, data envelopment analysis, and stochastic frontier [37]. Stochastic frontier analysis (SFA) was employed to determine the technical efficiency level among farmers. The SFA method was developed by Aigner to estimate a production frontier that assumed a functional form to represent the relationships among the inputs. The Cobb–Douglas production function was selected as the functional form in this study because it is first-order flexible to provide the first-order differential approximation of an arbitrary function at a single point and parsimony of parameters [37,38]. The following equations are representative of SFA in this paper:

$$\ln Y_{IR} = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + v_i - \mu_i \quad (1)$$

$$\ln Y_{NI} = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + v_i - \mu_i \quad (2)$$

There are two models which will be estimated by the SFA. Model (1) is the Cobb–Douglass production function for irrigated farming, while model (2) is used for non-irrigated areas. The estimation occurs separately in FRONT4.1 software. The Y symbol denotes rice production in kg; β_0 is a constant or the intercept; the β_1–β_4 coefficient denotes each production variable as follows: X_1 = harvest area (square meters), X_2 = chemical manure (kg), X_3 = seed (kg), and X_4 = labor (work days). The v_i is the noise effect and μ_i the inefficiency effect. The models consist of three main parts: deterministic effect, noise effect, and inefficiency effect. In this study, the SFA was used mainly because it can separate technical efficiency from random error [39]. It assumed that the observed outputs tend to lie below the deterministic part of the frontier.

SFA theory assumes there is an inefficiency effect in the SFA model. In this paper, the inefficiency effect was modeled using a separate equation. Because there were two production or Cobb–Douglass functions, there were also two inefficiency models described in this paper. Each inefficiency model represents irrigated and non-irrigated rice farming. The following equations were the inefficiency models used in this study:

$$\mu_{IR} = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 + \delta_7 Z_7 + \varepsilon \quad (3)$$

$$\mu_{NI} = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 + \delta_7 Z_7 + \varepsilon \quad (4)$$

where μ denotes the technical efficiency index, while δ_0 and δ are the constant and coefficient, respectively. ε represents a random variable that is defined such that μ_i is the non-negative truncation of the $N(\delta Z_i, \sigma_u)$ distribution. The technical efficiency determinants consist of demographic conditions (Z_1,Z_2), farming effect (Z_3,Z_4), institutional involvement (Z_4,Z_5), and climate effect (Z_6,Z_7). The production (frontier) and technical efficiency (effect) models were estimated using an MLE estimator in a single-step manner. Table 1 shows the data type and description of every variable in the technical efficiency model.

Table 1. Independent variables of the irrigated and non-irrigated stochastic frontier model.

Expected Sign	Description	Type	Notation	Variable
−	Age of farmer in year units	Scale	Z_1	Age
+	Educational level of farmer in year units	Scale	Z_2	Education
−	1 for urban area 0 for rural or countryside area	Dummy	Z_3	Area
−	1 for owned land 0 for rented/non-owned land	Dummy	Z_4	Land ownership
−	1 for member of a farmer's association 0 for non-member of a farmer's association	Dummy	Z_5	Membership status
−	1 for no climate change impact 0 for climate change impact	Dummy	Z_6	Climate change
−	1 for no pest infestation 0 for pest infestation existed	Dummy	Z_7	Pest infestation

3. Results

3.1. Descriptive Statistics

The SPD dataset showed that most rice farming can be found on non-irrigated farmland. Irrigation water had a significant impact on agricultural production, especially in rice field farming [40]. Despite the availability of irrigation water, good irrigation water management practices also contributed to the productivity and sustainability of rice farming. This subsection describes the differences between irrigated and non-irrigated rice farming based on the Rice Farm Household Survey (SPD) data. Clear differences can be observed for the harvest area and input–output percentage. The graph below shows the distribution of the average harvest area in rice farming across Indonesia.

Figure 1 visualizes the average productivity of rice or paddy, mainly concentrating on Sumatra and Java. In general, the average productivity in irrigated areas was higher compared with non-irrigated areas. The higher irrigated average rice productivity in urban areas can be found in Java, the eastern part of Sumatera, and the southern part of Celebes, while non-irrigated urban areas can be found in eastern Java and the south of Sumatera. Higher irrigated productivity in rural or countryside areas can be found in eastern and western Java, northern Sumatra, and south Celebes, while the higher non-irrigated productivity in rural areas can only be found in eastern Java and southern Sumatera.

Table 2 showed that all input usage on non-irrigated farmland was relatively greater than that on irrigated farmlands. However, in terms of output, irrigated farming still produced a greater yield than non-irrigated farming. Chemical manure consists of urea, TSP/SP36, ZA, NPK, KCL, and other manure compounds. Irrigated farming used greater amounts of chemical manure compared with non-irrigated farming. Rice or paddy seed in non-irrigated farming (53%) was greater than that in irrigated farming (47%). The labor force used in non-irrigated farming was still greater compared with that in irrigated farming.

Table 3 shows that the average age of farmers in irrigated areas is 50.2 years and 48.8 years for non-irrigated areas. The education variables clearly show that irrigated farmers spend 6.4 years in education and higher compared with non-irrigated farmers, who only spend 5.8 years. In terms of urban and rural status, irrigated farmers in urban (57%) areas have a higher status than rural farmers (43%), while non-irrigated farmers in rural areas (54.2%) tend to have a higher status than irrigated farmers (45.8%). Self-owned farmland was higher among non-irrigated farmers (52.2%) compared with irrigated farmers (47.8%), while rented or no self-owned land was higher among irrigated farmers (53.1%) compared with non-irrigated farmers (48.9%), Most farmers who had a farmer's association membership were irrigated farmers (53.7%); otherwise, most non-irrigated farmers (55.7%) were not a member of a farmer's association. Irrigated farmers (56.1%) acknowledged the climate change impact on their farming. Non-irrigated farmers did not acknowledge the climate change was higher (64.2%) compared with irrigated farmers (35.9%). Pest infestation perceptions were higher among non-irrigated farmers.

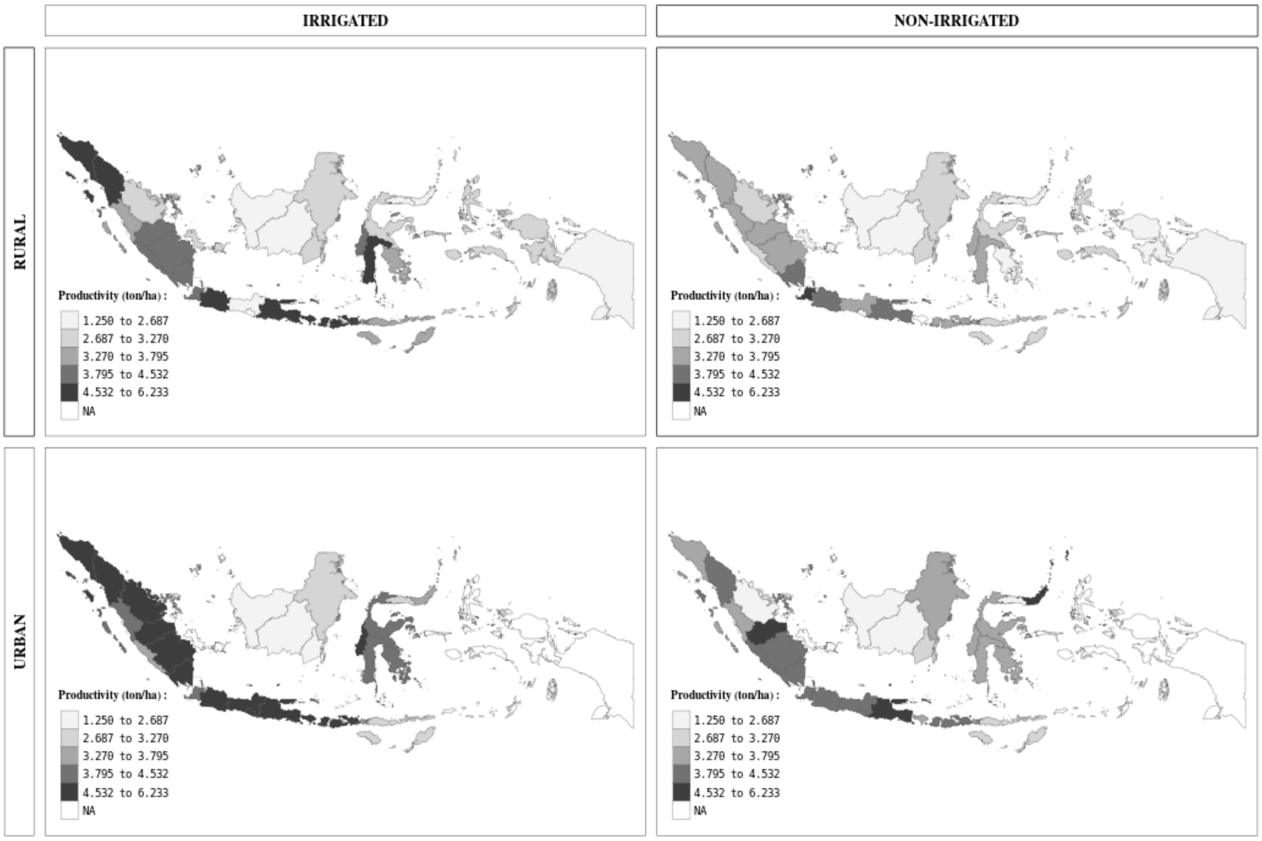

Figure 1. Distribution of average rice farming productivity across Indonesia irrigated urban areas, non-irrigated urban areas, irrigated rural areas, and non-irrigated rural areas.

Table 2. Percentage and units of average yield and input usages in irrigated and non-irrigated farmland.

Description	Non-Irrigated (Percent) (Units)	Irrigated (Percent) (Units)
Yield	47.8 (1620.1 kg)	52.2 (1811.6 kg)
Chemical manure	49.9 (139 kg)	50.1 (143.2 kg)
Seed	53.3 (23 kg)	46.6 (31 kg)
Labor	53.5 (36 days)	46.5 (32.2 days)

Table 3. Percentage and average of technical efficiency determinants.

Average		Percentage		Category	Description
Non-Irrigated	**Irrigated**	**Non-Irrigated**	**Irrigated**		
48.8	50.2				Age (years)
5.84	6.4				Education (years)
		43	57	Urban	Area
		54.2	45.8	Rural	
		52.2	47.8	Self-owned	Land ownership
		46.9	53.1	Rented	
		46.3	53.7	Member	Membership status
		55.7	44.3	Non-Member	
		43.9	56.1	No-Impact	Climate
		64.2	35.8	Impact	
		50.4	49.6	No Pest Infest	Pest Infestation
		50.7	49.3	Pest Infest	

3.2. Analytical Results

In this study, the stochastic frontier model (SFA) was developed from the Cobb–Douglas production function. The Cobb–Douglas function is widely used to determine causal relationships among production and input. The stochastic frontier model was estimated using the software Frontier 4.1c. The SFA was designed to determine the efficiency level achievable by farmers. There are four inputs in the SFA model: harvest area (X_1), chemical manure (X_2), seed (X_3), and labor (X_4). Chemical manure can be divided into several types, including urea, TSP/SP36, ZA KCL, and NPK. SFA in the Cobb–Douglas form is estimated employing maximum likelihood estimation (MLE). Table 1 shows the estimation results based on irrigated and non-irrigated farmland.

Table 4 outlines that all variables had a significant effect on rice production in irrigated and non-irrigated farming. These variables, excluding labor, were significant at a 99% confidence interval, while labor was significant at a 90% confidence interval based on the irrigated model. The sigma-squared parameter (σ^2) indicates that there was an inefficiency effect in the models. This was confirmed by the Gamma (γ) parameter, which was equal to 0.97 for irrigated and 0.94 for non-irrigated farmland, indicating that 97% and 94% for both frontier models were affected by inefficiency, respectively. The existence of an inefficiency effect on these models was also detected using an LR test of the one-sided error. The irrigated model had an LR test result of 12.796 and the non-irrigated model 9.787; these values indicate the presence of an inefficiency effect on both models.

Table 4. Estimation results of the stochastic frontier model based on irrigated and non-irrigated farming.

Non-Irrigated			Irrigated			
t-Ratio	**S.E**	**Estimated**	**t-Ratio**	**S.E**	**Estimated**	**Variable**
0.17×10^{2} *	0.23×10^{-1}	0.39	0.45×10^{1} *	0.19×10^{-1}	0.88×10^{-1}	Constant
0.34×10^{3} *	0.26×10^{-2}	0.88	0.41×10^{3} *	0.23×10^{-2}	0.94	Harvest area (m^2)
0.13×10^{2} *	0.15×10^{-2}	0.19×10^{-1}	0.78×10^{1} *	0.15×10^{-2}	0.12×10^{-1}	Chemical manure (kg)
-0.53×10^{-1} *	0.39×10^{-2}	-0.20×10^{-1}	-0.75×10^{1} *	0.31×10^{-2}	-0.24×10^{-1}	Seeds (kg)
-0.62×10^{1} *	0.36×10^{-2}	-0.23×10^{-1}	-0.18×10^{1} ***	0.29×10^{-2}	-0.24×10^{-1}	Labor (man days)
0.24×10^{2} *	0.54×10^{-1}	0.13×10^{1}	0.20×10^{2} *	0.66×10^{-1}	0.13×10^{1}	Sigma-squared (σ^2)
0.43×10^{3} *	0.22×10^{-2}	0.94	0.65×10^{3} *	0.15×10^{-2}	0.97	Gamma (γ)
		−35,651			−30,097	Log-likelihood function (OLS)
		−30,758			−23,698	Log-likelihood function (MLE)
		9787			12,796	LR test of the one-sided error

Notes: *** Significant at the 0.01 confidence interval level. * Significant at the 0.1 confidence interval level.

The SFA result can be divided into irrigated and non-irrigated models; all independent variables had a significant effect on rice production in Indonesia. Two of the four variables had a positive effect, and two other variables had a negative effect. The variable of harvested area and the amount of chemical manure had a positive effect on rice production. A percentage increase in the two variables will cause an increase in the percentage of rice production. The variables rice seeds and labor had a negative effect so that the percentage increase in these variables decreased the percentage of rice production.

It can be seen that the coefficient estimated between the irrigation and non-irrigation models was not much different. In addition, the sign of the coefficient between the two models was also quite similar. Therefore, it can be concluded that the input–output relationship of the rice field with irrigation and non-irrigation was identical according to the Cobb–Douglas model. The constant in the Cobb–Douglas production function is one of efficiency in farming. Table 4 shows the non-irrigated model had a higher level of efficiency because it had a constant of 0.39 greater than the non-irrigated one which was only 0.088. Irrigated farming area had a higher positive impact equal to 0.94 compared with the non-irrigated counterpart, which had 0.88. An increase in the amount of chemical manure input in non-irrigated farming provided a higher percentage increase toward rice production of 0.019% compared with irrigated farming, which had 0.012%. Both the amount of seeds and labor force had relatively small estimated coefficient differences between irrigated and non-irrigated farming. Non-irrigated farming had an advantage in terms of seed and labor usage because it had a lower estimated coefficient compared with irrigated farming. The results of the analysis also showed that a one-percent increase in seeds will reduce rice production by 0.0024% in irrigated farming and 0.02% in non-irrigated farming. On the other hand, a one-percent increase in the labor force will reduce rice production by 0.024% in irrigated farming and 0.023% in non-irrigated farming. The return to scale or the sum of anti-log coefficients for the irrigation and non-irrigation models showed 6.9 and 23.6, respectively. These two models indicated an increasing return-to-scale position. However, the non-irrigation model had a higher return-to-scale compared with the irrigation one.

The level of technical efficiency in irrigated and non-irrigated rice farming in Indonesia is influenced by three main factors: the demographic characteristics of the farmers, membership status at the farmer association, and climate change or natural disaster factors. Farmers' demographic characteristics comprised age, education, region dummy, and land status. On the other hand, climate change or natural disasters comprised several variables related to the perception of climate change and natural disasters, including pest infestation.

The technical efficiency model employed in this study was estimated using the maximum likelihood estimation (MLE). This article employed a single-step estimation procedure that involved the production frontier model to determine the coefficients for each parameter within the technical efficiency model. The practical aspects related to the estimation of all parameters of the SFA were achieved using FRONT4.1 software. Table 4 shows the estimation results of an irrigated and non-irrigatedrice field farmland technical efficiency model in Indonesia.

Tables 5 and 6 show all variables have a significant effect at the 99% confidence level on the technical inefficiency of irrigated rice field farming in Indonesia. These variables include farmers' age, education, region, land status, farmer group participation, climate change and natural disasters, and pest infestation.

The technical efficiency model of irrigated rice farming showed that all coefficients, except land ownership status, have a negative effect on technical efficiency. Overall, the estimation results are not in line with the expectations, as previously mentioned in Table 1. The estimated negative coefficients in the model indicate that variables tend to decrease technical efficiency or increase technical inefficiency. The area variable, i.e., urban or rural, was the main focus of this study, although other variables were also discussed.

Table 5. Estimation results of an irrigated technical efficiency model.

t-Ratio	S.E	Estimation	Notation	Variable
0.98×10^{1} ***	0.13	0.13×10^{1}		Constant
-0.82×10^{1} ***	0.34×10^{-1}	-0.28	Z_1	Age of farmers
-0.15×10^{2} ***	0.14×10^{-1}	-0.20	Z_2	Education
-0.21×10^{2} ***	0.76×10^{-1}	-0.16×10^{1}	Z_3	Area
-0.33×10^{1} ***	0.19×10^{-1}	0.65×10^{-1}	Z_4	Land ownership status
-0.10×10^{2} ***	0.16×10^{-1}	-0.17	Z_5	Membership status
-19×10^{2} ***	0.35×10^{-1}	-0.69	Z_6	Climate change and natural disasters
-19×10^{2} ***	0.53×10^{-1}	-10×10^{1}	Z_7	Pest infestation
64.78				Mean TE
2.576				T-table (α = 0.01)

Note: *** Significant at the 0.01 confidence interval level.

Table 6. Estimation results of the non-irrigated technical efficiency model.

t-Ratio	S.E	Estimation	Notation	Variable
0.88×10^{1} ***	0.14	0.13×10^{1}		Constant
-0.79×10^{1} ***	0.36×10^{-1}	-0.29	Z_1	Age of farmers
-0.16×10^{2} ***	0.13×10^{-1}	-0.21	Z_2	Education
-0.23×10^{2} ***	0.56×10^{-1}	-0.13×10^{1}	Z_3	Area
-0.16×10^{1} ***	0.19×10^{-1}	0.32×10^{-1}	Z_4	Land ownership status
-0.75×10^{2} ***	0.17×10^{-1}	-0.13	Z_5	Membership status
-19×10^{2} ***	0.32×10^{-1}	-0.64	Z_6	Climate change and natural disasters
-19×10^{2} ***	0.43×10^{-1}	-0.76	Z_7	Pest infestation
66.29				Mean technical efficiency
2.576				T-table (α = 0.01)

Note: *** Significant at the 0.01 confidence interval level.

Similar estimation results can also be found in the non-irrigated rice farming model. All technical efficiency variables, except land ownership status, had a negative impact on the technical efficiency level. This article will pay more attention to the area or urban–rural area variable. Although there was a similarity in terms of the estimated coefficient between the irrigation and non-irrigated models, there were still differences in the magnitude of each coefficient. Therefore, each variable in the technical efficiency model still had a specific impact on technical efficiency, even though it was an identical model. Table 6 shows the distribution of the achieved technical efficiencies grouped by irrigation and urban–rural status.

The Table 7 indicates more farmers in technical and non-technical irrigation in urban areas compared to rural areas. In general, the technical efficiency index of all sampled farmers was in the range between 50% and 75%. The technical efficiency of the sampled farmers was in an increasing mode. There was a relative comparison in terms of the number of farmers among categories. For example, the efficiency index of urban–irrigated farmers was greater than that of non-irrigated farmers, although the percentage of non-irrigated–urban farmers was higher than irrigated–urban farmers. A further interpretation of the technical efficiency results will be explained in the discussion section.

Table 7. The distribution of the achieved technical efficiencies among farmers.

Non-Irrigated		Irrigated		Technical Efficiency (%)
Urban Areas	**Rural Areas**	**Urban Areas**	**Rural Areas**	
570 (3.1%)	2345 (11%)	623 (2.6%)	1472 (9.5%)	0–25
2239 (12.3%)	6039 (28.3%)	2775 (11.4%)	4324 (28.1%)	25–50
6240 (34.3%)	8515 (40%)	7552 (31.2%)	5531 (35.6%)	50–75
9140 (50.2%)	5435 (25.5%)	13,209 (54.7%)	4044 (26.3%)	75–100
18,189	21,334	24,159	15,371	Total

4. Discussion

4.1. Stochastic Frontier Estimation of Irrigated and Non-Irrigated Rice Farming

Figure 1 depicts the average productivity on irrigated rice fields (4.5 ton/hectares) was higher than on non-irrigated fields (3.6 ton/hectares). The average rice productivity in urban areas was also higher (4.7 ton/hectares) compared with rural (3.4 ton/hectares). Although irrigated rice farming had higher productivity, its technical efficiency (64.8%) was lower compared with non-irrigated rice farming (66.3%), allegedly due to the utilization of farming input and factors related to technical efficiency. Table 2 shows that non-irrigated rice farming had a higher usage of seed and labor inputs, while irrigated farming had a higher usage of chemical manure. This section intends to give further explanations related to the input used and technical efficiency factors.

Both the irrigated and non-irrigated models emphasize the need for a new method to improve rice production based on the combination of available inputs. Rice productivity could be improved either by increasing the input or using a new technology [41]. The coefficient value of the land area variable is positive, so a one-percent increase in land area will increase production by one percent. This result is in line with [38,42–48]. The combination or substitution of land-use variables may be a reason for the positive value of its coefficient. Table 4 suggests that a substitution or combination of land use and chemical manure can increase rice production.

The chemical manure variable had a significant positive effect on production, indicating that a one-percent increase in fertilizer will increase production by one percent. The estimation result is confirmed by the result of [43,47–53]. The estimation results suggested that rice farmers have used the optimal amount of chemical manure as an input. On the other hand, another result showed that the usage of chemical manure under optimal conditions led to a decrease in production [50].

The seeds or seeding variable has a negative influence on rice production. It can be interpreted that an increase in the use of seeds by one percent will reduce production by one percent. This result is in line with previous research conducted by [51,53]. However, these results contradicted another research, which concluded that a certain, good method or procedural seeding could increase production [44]. The labor input usage also had a negative value, which means that the addition of labor by one percent will reduce production by one percent. The negative coefficient of labor input is confirmed by [50,51,53].

Based on the results of the analysis, the technical efficiency of irrigated and non-irrigated rice farming was influenced by the demographic factors of farmers, farmer group membership, and climate change. All technical efficiency determinants had a statistically significant effect on technical efficiency. However, the coefficient values of educational and land ownership status variables were different from the theoretical framework, as mentioned in Table 1. In order to improve the technical efficiency of irrigated and non-irrigated rice farming, farmers can take any action relating to these factors. The coefficient value of the age variable was negative, meaning that the technical efficiency decreases as farmers get older. However, the results of this study are not in accordance with the others, which showed that the older the farmer, the more efficient the cultivated farm. This is because the ability of farmers to make decisions is improved with age [54]. In addition, the age factor is positively correlated with farming experience, whereby farming experience increases with age [42].

The coefficient of the education variable was negative, which reduced the level of technical efficiency. The result is in line with [43–45,51,55,56]. The negative coefficient of the education variable probably indicated that farmers tend to overuse production inputs, resulting in a production decrease, as well as a decrease in technical efficiency [57]. In contrast, other researchers showed that technical efficiency will increase, as well as farmers' education [42,44,54].

The positive coefficient of the land ownership status variable implied that farmers with self-owned land tend to be more efficient compared to farmers who rented land. The adoption level of technology may increase as extra income increases, eventually leading to an increase in technical efficiency [43]. The presence of disasters and the impact of climate change also produced a significant effect on the technical efficiency level. This result is in accordance with previous research by [58]. The farmer membership status variable had a negative coefficient value, meaning that being a member of a group of farmers will reduce technical efficiency. This result contradicts [59], who indicated that being part of a farmer or irrigation association should accelerate the problem-solving process related to irrigation and farming [60].

4.2. Technical Efficiency of Irrigated and Non-Irrigated Rice Farming

The frontier estimation result can be divided into two main categories: irrigated and non-irrigated rice fields. The two categories were then further divided into the following subcategories: urban and rural. Figure 2 shows irrigated farming in urban and rural areas, and non-irrigatedcategories which consists of non-irrigated urban and non-irrigated rural Figure 2 also shows that a clear difference in technical efficiency was achieved by farmers in irrigated and non-irrigated farming. Irrigated farming had lower technical efficiency indexes compared to the non-irrigated counterpart, with the technical efficiency of irrigated farming being below 50%, while non-irrigated farming was above 50% and even above 75%.

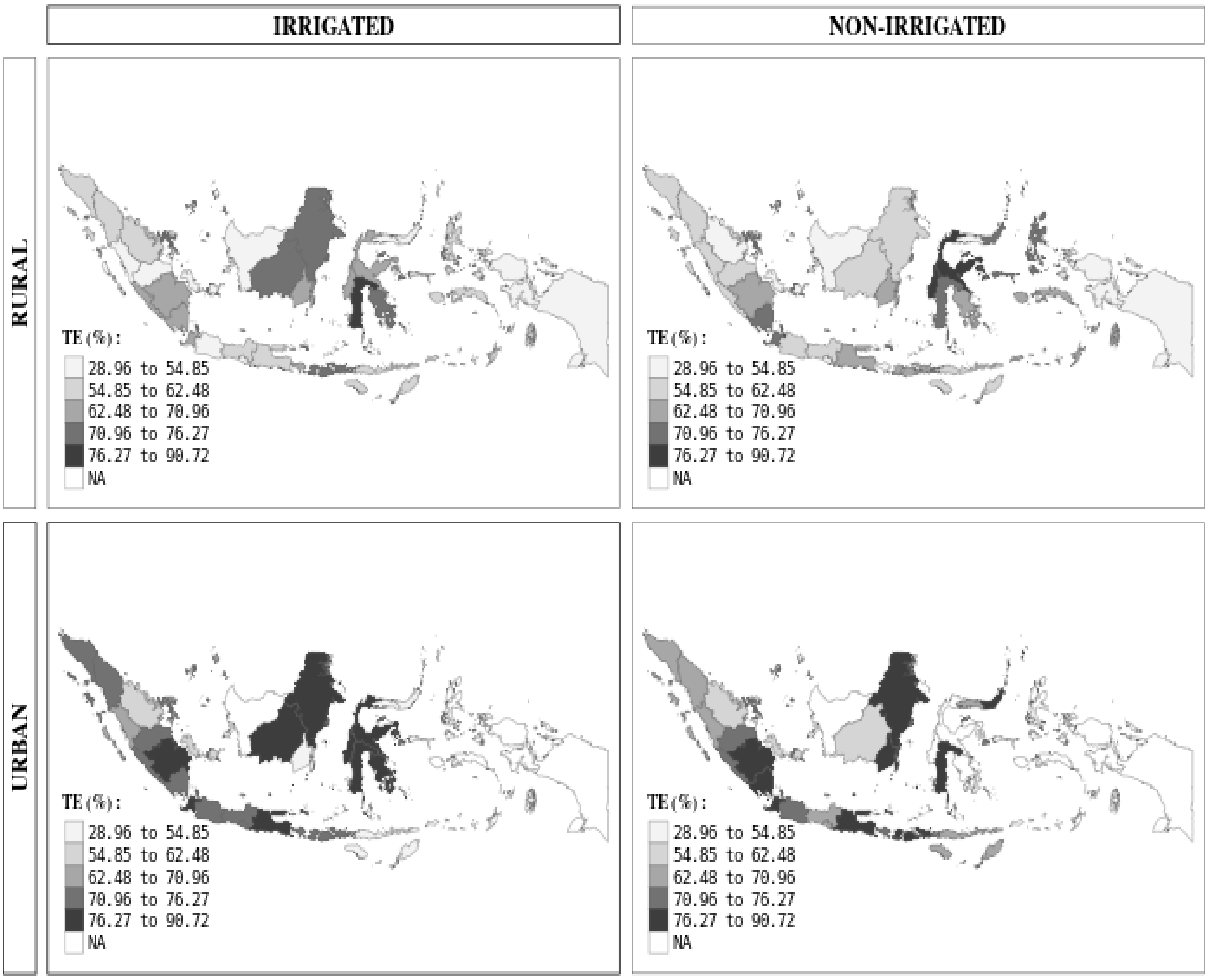

Figure 2. Rice farming technical efficiency of irrigated urban areas, non-irrigated urban areas, irrigated rural areas, and non-irrigated rural areas.

Differences can also be identified between rural and urban areas. It can be seen that urban areas have a higher technical efficiency index compared to rural areas. Tables 5 and 6 showed that the coefficient of the dummy variable of area in the non-irrigation model is higher than that in the irrigation model. It can be concluded that non-irrigated urban areas had a higher decrease in technical efficiency compared to irrigated rice fields in urban areas. These findings can be interpreted as a warning to the sustainability of rice production or productivity in urban areas. The technical efficiency of irrigated and non-irrigated rice farming located in urban areas was higher than that in the rural counterparts.

Population pressure is increasing over time, making urbanization uncontrollable. Moreover, the need for more space as urbanization increases caused increased threats to agricultural activities in urban areas. The most obvious impact of urbanization on agriculture is the drastic reduction in agricultural land in urban areas [60,61]. Agricultural production in areas adjacent to urban areas is declining [62]. Urbanization also threatens the segmentation or fragmentation of agricultural land around urban areas [63,64]. Other contributing factors related to urbanization include inappropriate government policies, private settlements of new towns, and the growth of private industrial complexes and infrastructure [65,66]. Ultimately, urbanization and these factors will have a major influence on food security [67].

Technical efficiency in urban areas was higher than in rural areas. It can be concluded that the use of production factors in urban areas was better than in rural areas. The existence of irrigation played an important role in the distribution of production factors in the farm or cropland area. Table 2 shows that the average use of chemical manure in irrigation farming was (143.2 kg) 50.1% or higher compared to the non-irrigated one, which was only (139 kg) 49.9%. Chemical manure as an input played an important role in terms of nutritional supplements for rice. It will be more effective if it is well distributed in the farm area. Therefore, a higher quantity of chemical manure in irrigated rice farming will increase production. The estimation results (Table 4) show a positive coefficient of the chemical manure variable, which means it increases the marginal production of rice.

Tables 5 and 6 clearly show the level of technical efficiency of rice farming in urban areas decreased drastically, allegedly due to greater domestic water use compared with irrigation. In addition, irrigation facilities or buildings were deteriorating or neglected due to the rapid conversion of agricultural land in urban areas. Deteriorated or neglected irrigation structures play an important role in terms of groundwater and land fertility [68]. Water use in urban areas is estimated to be scarce due to urbanization, climate change, and inappropriate urban planning [69,70]. Therefore, technical efficiency in rice farming in urban areas tends to decrease along with the reduced water supply for farming in urban areas. The problems of water scarcity or inappropriate irrigation management in urban areas should be solved through the efficient use of irrigation and better industrial water cycling [71]. Of course, support from the government and related agencies is needed in terms of good water management in urban areas [72,73].

Irrigation water supply in urban areas can still be met through wastewater or urban drainage flows. The existence of wastewater has considerable potential considering that 65% of irrigation canals are in the wastewater catchment area [74]. However, long-term use of wastewater in agricultural activities is detrimental to health [75]. In addition, the climate change phenomenon has an obvious impact on the quality of irrigation water. Urbanization and industrialization have a significant impact on water quality in terms of heavy metals, organic pollutants, and other hazardous materials [76].

5. Conclusions

Technical efficiency can be defined as the degree of actual output approaches the maximum output. In other words, technical efficiency is the ratio between the actual output and the maximum attainable output. The primary objective of this study was to determine technical efficiency in rice farming on irrigated and non-irrigated cropland. The urban and rural attributes of farmers were also included in the model, which consisted of farmers' age, educational level, land ownership status, climate change or natural disaster, and pest infestation. Then, stochastic frontier analysis (SFA) was employed to determine the technical efficiency index and the effects of the model on technical efficiency.

The analysis showed that all technical efficiency determinants in irrigated and non-irrigated rice farming have a significant effect on technical efficiency. The increasing age of farmers will reduce technical efficiency. Farmers' educational level has a negative effect on technical efficiency, meaning that technical efficiency decreases as farmers attain a higher educational level. The land ownership status variable has a significant impact on technical efficiency, with self-owned farmers having lower technical efficiency compared with rented-land farmers. The membership status variable had a negative coefficient, which means that farmers who became members of a group of farmers tended to have lower technical efficiency compared with non-member farmers.

The technical efficiency of non-irrigated farming was higher than that of irrigated farming. The analytical result also showed a higher decline in technical efficiency in urban areas compared with rural or rural areas. These findings indicate a threat to rice farming in urban areas with the long-term use of water. A potential cause of the higher decline in technical efficiency in urban areas is the overuse of water in domestic and industrial settings compared to irrigation purposes in urban areas. In addition, irrigation buildings or facilities in urban areas are deteriorating or neglected as a result of the rapid conversion of agricultural land.

Author Contributions: Conceptualization, M.R., Y.M., T.K., A.S. and R.; Data curation, S.J.H.S., C.B.H. and S.U.; Formal analysis, S.J.H.S. and C.B.H.; Methodology, M.R.; Project administration, R.; Resources, S.U.; Supervision, M.R., Y.M., T.K., A.S. and R.; Visualization, S.U.; Writing—original draft, M.R., S.J.H.S., C.B.H. and S.U.; Writing—review and editing, M.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research is funded by the Centre of Research and Community Service, Number: 2909/UN25.3.1/LT/2021—Professorship Scheme and KAKENHI JP21K14928.

Data Availability Statement: The data are not open source. The data presented in this study are available on request from the corresponding author.

Acknowledgments: In this section, we wish to acknowledge the helpful cooperation of key informants and the local water usage association (WUA).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Seto, K.C.; Güneralp, B.; Hutyra, L.R. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 16083–16088. [CrossRef] [PubMed]
2. D'Amour, C.B.; Reitsma, F.; Baiocchi, G.; Barthel, S.; Güneralp, B.; Erb, K.H.; Haberl, H.; Creutzig, F.; Seto, K.C. Future urban land expansion and implications for global croplands. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 8939–8944. [CrossRef]
3. FAO. The Future of Food and Agriculture: Trends and Challenges, 2014. Available online: http://www.fao.org/3/a-i6583e.pdf%0A (accessed on 22 June 2021).
4. Gooch, R.S. Editorial: Special issue on urbanization of irrigation systems. *Irrig. Drain. Syst.* **2009**, *23*, 61–62. [CrossRef]
5. Mesjasz-Lech, A. Municipal Waste Management in Context of Sustainable Urban Development. *Procedia-Soc. Behav. Sci.* **2014**, *151*, 244–256. [CrossRef]
6. Solgi, E.; Sheikhzadeh, H.; Solgi, M. Role of irrigation water, inorganic and organic fertilizers in soil and crop contamination by potentially hazardous elements in intensive farming systems: Case study from Moghan agro-industry, Iran. *J. Geochem. Explor.* **2018**, *185*, 74–80. [CrossRef]
7. Cerqueira, T.C.; Mendonça, R.L.; Gomes, R.L.; de Jesus, R.M.; da Silva, D.M.L. Effects of urbanization on water quality in a watershed in northeastern Brazil. *Environ. Monit. Assess.* **2020**, *192*, 65. [CrossRef]
8. Freeman, L.A.; Corbett, D.R.; Fitzgerald, A.M.; Lemley, D.A.; Quigg, A.; Steppe, C.N. Impacts of Urbanization and Development on Estuarine Ecosystems and Water Quality. *Estuaries Coasts* **2019**, *42*, 1821–1838. [CrossRef]
9. Shi, K.; Chen, Y.; Yu, B.; Xu, T.; Li, L.; Huang, C.; Liu, R.; Chen, Z.; Wu, J. Urban expansion and agricultural land loss in China: A multiscale perspective. *Sustainability* **2016**, *8*, 790. [CrossRef]
10. Wang, Z.; Zhang, S.; Peng, Y.; Wu, C.; Lv, Y.; Xiao, K.; Zhao, J.; Qian, G. Impact of rapid urbanization on the threshold effect in the relationship between impervious surfaces and water quality in shanghai, China. *Environ. Pollut.* **2020**, *267*, 115569. [CrossRef] [PubMed]
11. Arfanuzzaman, M.; Rahman, A.A. Sustainable water demand management in the face of rapid urbanization and ground water depletion for social–ecological resilience building. *Glob. Ecol. Conserv.* **2017**, *10*, 9–22. [CrossRef]
12. Bao, C.; Chen, X. Spatial econometric analysis on influencing factors of water consumption efficiency in urbanizing China. *J. Geogr. Sci.* **2017**, *27*, 1450–1462. [CrossRef]
13. Ding, X.; Fu, Z.; Jia, H. Study on urbanization level, urban primacy and industrial water utilization effciency in the Yangtze River Economic Belt. *Sustainability* **2019**, *11*, 6571. [CrossRef]
14. Ma, H.; Chou, N.T.; Wang, L. Dynamic coupling analysis of urbanization and water resource utilization systems in China. *Sustainability* **2016**, *8*, 1176. [CrossRef]
15. Tiurmauli, I.; Trigunasih, N.M.; Bhayunagiri, I.B.P. Aplikasi Sistem Informasi Geografis untuk Pemetaan Kerapatan Vegetasi dan Penutup Lahan Hubungannya dengan Daerah Resapan Air di Kawasan Pariwisata Ubud, Gianyar, Bali. *Nandur* **2023**, *3*, 105–113.
16. Rusmayadi, G.; Indriyani, I.; Sutrisno, E.; Nugroho, R.J.; Prasetyo, C.; Alaydrus, A.Z.A. Evaluasi Efisiensi Penggunaan Sumber Daya Air dalam Irigasi Pertanian: Studi Kasus di Wilayah Kabupaten Cianjur. *J. Geosains West Sci.* **2023**, *1*, 112–118. [CrossRef]

17. Yusuf, R.; Auliani, R. Peran Perencanaan Kota Berkelanjutan dalam Mengatasi Krisis Air Perkotaan: Integrasi Infrastruktur Hijau, Teknologi Pemantauan, dan Kebijakan Publik. *J. Multidisiplin West Sci.* **2023**, *2*, 770–779. [CrossRef]
18. Damayanti, L. Faktor-faktor yang Mempengaruhi Produksi, Pendapatan dan Kesempatan Kerja pada Usahatani Padi Sawah di Daerah Irigasi Parigi Moutong. *SEPA J. Sos. Ekon. Pertan. Dan Agribisnis* **2013**, *9*, 249–259.
19. Mulyani, A.; Mulyanto, B.; Barus, B.; Panuju, D.R.; dan Husnain, B.; Besar Litbang Sumberdaya Lahan Pertanian. Analisis Kapasitas Produksi Lahan Sawah untuk Ketahanan Pangan Nasional Menjelang Tahun 2045 Analysis of Rice Field Production Capacity for National Food Security By 2045. *J. Sumberd. Lahan* **2022**, *16*, 33–50.
20. Faradilla, C.; Marsudi, E.; Baihaqi, A. Analisis Statistik Ketahanan Pangan Terhadap Perubahan Harga Komoditas Pangan Strategis di Indonesia. *J. Agrisep.* **2021**, *22*, 53–62. [CrossRef]
21. BPS-Statistics Indonesia, Statistik Indonesia, 2021. Available online: https://webapi.bps.go.id/download.php?f=jxxf3cxpKaYpYsX9Rwc8CKD4sY8+SgNTbBnI1wiqJRsRaBVaftgro7sKiDwSnfcOGnxjW4yXuv4NNb64cAeEaDCw3DU4l9bWTkX1SuI5b3D90M+4OCSO49r13K0qPwbHpSNRoXEFSTgz8+8iLkjldztzzqEFxRzmlP1SeGdwKhcVc2t+Th2z2yc2cuhFJhSQMa9K7NpL2aYXee65JlsxJctvVbW4MMgCBGHn3aB4aap4Pthjq3kfybkXE0grUvmjM21IVQewg30dhSCRuexeLQ== (accessed on 14 May 2021).
22. Kementrian Pertanian Republik Indonesia, Data Lima Tahun Terakhir. 2019. Available online: https://www.pertanian.go.id/home/?show=page&act=view&id=61 (accessed on 22 June 2021).
23. Prabandari, A.; Sudarma, M.; WijayantiI, P. Analisis Faktor-faktor yang Mempengaruhi Produksi Padi Sawah pada Daerah Tengah dan Hilir Aliran Sungai Ayung (Studi Kasus Subak Mambal, Kabupaten Badung dan Subak Pagutan, Kota Denpasar). *E-J. Agribisnis Dan Agrowisata (J. Agribus. Agritourism)* **2013**, *2*, 89–98.
24. Direktorat Jenderal Tanaman Pangan, Petunjuk Teknis Pelaksanaan Kegiatan Budidaya Padi Tahun 2018. 2018. Available online: https://tanamanpangan.pertanian.go.id/assets/front/uploads/document/JUKNIS%20PADI%20%E2%80%93%202 2MAR18.pdf (accessed on 21 April 2021).
25. Kementerian Pertanian Republik Indonesia. *Arah, Kebijakan, Strategi dan Program Pembangunan Pertanian 2020–2024*; Kementerian Pertanian Republik Indonesia: Bogor, Indonesia, 2019.
26. Ratnawati, C. Mekanisasi Usahatani Padi Di Kecamatan Sananwetan Kota Blitar. *J. AGRI-TEK J. Penelit. Ilmu-Ilmu Eksakta.* **2020**, *21*, 20–28. [CrossRef]
27. Prihtanti, T.M.; Pangestika, M. Rice Productivity Dynamics, Retail Price of Rice (HEB), Government Purchase Price (HPP), and the Correlation between HPP and HEB. *J. Ilmu Pertan. Indones.* **2020**, *25*, 1–9. [CrossRef]
28. Sumaryanto, H.; Ariani, M.; Yoga, R.D.; Azahari, D.H. *Pengaruh Urbanisasi Terhadap Suksesi Sistem Pengelolaan Usahatani dan Implikasinya Terhadap Keberlanjutan Swasembada Pangan*; Kementerian Pertanian: Bogor, Indonesia, 2015.
29. Dirjen SDA. *Laporan Kinerja Direktorat Sumber Daya Air*; Dirjen SDA: Jakarta, Indonesia, 2018.
30. Baskoro, C.A. Efisiensi teknis Usahatani Padi Sawah Irigasi dan Non-Irigasi di Provinsi Jawa Timur. *IPB* **2020**, 1–42.
31. Abate, T.M.; Dessie, A.B.; Mekie, T.M. Technical efficiency of smallholder farmers in red pepper production in North Gondar zone Amhara regional state, Ethiopia. *J. Econ. Struct.* **2019**, *8*, 18. [CrossRef]
32. Gebregziabher, G.; Holden, S. Does Irrigation enhance and food deficits discourage fertilizer adoption in a risky environment? Evidence from Tigray, Ethiopia. *J. Dev. Agric. Econ.* **2011**, *3*, 514–528.
33. Creswell, J. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 4th ed.; SAGE Publications Inc.: Los Angeles, CA, USA, 2014.
34. Cronholm, S.; Hjalmarsson, A. Experiences from sequential use of mixed methods. *Electron. J. Bus. Res. Methods* **2011**, *9*, 87–95.
35. Fare, R.; Lovell, K.C. Measuring the technical efficiency of production. *J. Econ. Theory* **1978**, *19*, 150–162. [CrossRef]
36. Kalirajan, K.P.; Shand, R.T. Frontier production functions and technical efficiency measures. *J. Econ. Surv.* **1999**, *13*, 149–172. [CrossRef]
37. Coelli, T.J.; Rao, D.S.P.; O'Donnell, C.J.; Battese, G.E. *An Introduction to Efficiency and Productivity Analysis*; Springer Science & Business Media: Berlin, Germany, 2005. [CrossRef]
38. Raimondo, M.; Caracciolo, F.; Nazzaro, C.; Marotta, G. Organic farming increases the technical efficiency of olive farms in Italy. *Agriculture* **2021**, *11*, 209. [CrossRef]
39. Huy, H.T.; Nguyen, T.T. Cropland rental market and farm technical efficiency in rural Vietnam. *Land Use Policy* **2019**, *81*, 408–423. [CrossRef]
40. Muzdalifah; Masyhuri, M.; Ani, S. Pendapatan dab Risiko Pendapatan Usahatani Padi Daerah Irigasi dan Non-Irigasi di Kabupaten Banjar Kalimantan Selatan. *J. Sos. Ekon. Pertan. Dan Agribisnis* **2012**, *1*, 65–74.
41. Abubakar, D.; Anggraeni, L.; Fariyanti, A. Analisis Pengaruh Kredit terhadap Efisiensi Usahatani Padi di Pulau Jawa. *J. Ekon. Dan Kebijak. Pembang.* **2019**, *8*, 120–144. [CrossRef]
42. Athukorala, W. Identifying the role of agricultural extension services in improving technical efficiency in the paddy farming sector in Sri Lanka. *Sri Lanka J. Econ. Res.* **2017**, *5*, 63–77. [CrossRef]
43. Shaheen, S.; Fatima, H.; Khan, M.A. Technical Efficiency Analysis of Rice Production in Pakistan under Dry and Puddle Conditions: A Case Study of Selected Districts of Punjab province, Pakistan. *Sarhad J. Agric.* **2017**, *33*, 447–458. [CrossRef]
44. Thayaparan, A.; Jayathilaka, D.M.P.I.L. Technical efficiency of paddy farmers and its determinants: Application of translog frontier analysis. *Int. Conf. Bus. Res.* **2020**, 199–218.
45. Nguyen, T.T.; Do, T.L.; Parvathi, P.; Wossink, A.; Grote, U. Farm production efficiency and natural forest extraction: Evidence from Cambodia. *Land Use Policy* **2018**, *71*, 480–493. [CrossRef]

46. Konja, D.T.; Mabe, F.N.; Alhassan, H. Technical and resource-use-efficiency among smallholder rice farmers in Northern Ghana. *Cogent Food Agric.* **2019**, *5*, 1651473. [CrossRef]
47. Hendrani, Y.; Nugraheni, S.; Karliya, N. Technical efficiency of paddy farming in West Java: A combination of synthetic and organic fertilisers versus conventional farming. *J. Agric. Rural Dev. Trop. Subtrop.* **2022**, *123*, 51–62. [CrossRef]
48. Obianefo, C.A.; Ng'ombe, J.N.; Mzyece, A.; Masasi, B.; Obiekwe, N.J.; Anumudu, O.O. Technical efficiency and technological gaps of rice production in Anambra state, Nigeria. *Agriculture* **2021**, *11*, 1240. [CrossRef]
49. PBhoi, B.; Wali, V.S.; Swain, D.K.; Sharma, K.; Bhoi, A.K.; Bacco, M.; Barsocchi, P. Input use efficiency management for paddy production systems in india: A machine learning approach. *Agriculture* **2021**, *11*, 837. [CrossRef]
50. Cañete, D.C.; Temanel, B.E. Factors Influencing Productivity and Technical Efficiency of Rice Farmers in Isabela, Philippines. *J. Adv. Agric. Technol.* **2017**, *4*, 111–122. [CrossRef]
51. Meenasulochani, R.; Rajendran, T.; Pushpa, J.; Senthilnathan, S. Technical Efficiency of Paddy Production and Factors Affecting the Efficiency in Nagapattinam District, Tamil Nadu. *Int. J. Agric. Innov. Res.* **2018**, *6*, 355–358.
52. Nguyen, T.H.; Sahin, O.; Howes, M. Climate change adaptation influences and barriers impacting the asian agricultural industry. *Sustainability* **2021**, *13*, 7346. [CrossRef]
53. Winata, V.V.; Rondhi, M.; Mori, Y.; Kondo, T. Jurnal Sosial Ekonomi Pertanian ISSN 2580-0566. *J. Sos. Ekon. Pertan.* **2020**, *13*, 286–295.
54. Nguyen, H.D.; Ngo, T.; Le, T.D.Q.; Ho, H.; Nguyen, H.T.H. The role of knowledge in sustainable agriculture: Evidence from rice farms' technical efficiency in Hanoi, Vietnam. *Sustainability* **2019**, *11*, 2472. [CrossRef]
55. Mishra, A.K.; Shaik, S.; Khanal, A.R.; Bairagi, S. Contract farming and technical efficiency: Evidence from low-value and high-value crops in Nepal. *Agribusiness* **2018**, *34*, 426–440. [CrossRef]
56. Ramezani, M.; Dourandish, A.; Jaghdani, T.J.; Aminizadeh, M. The Influence of Dense Planting System on the Technical Efficiency of Saffron Production and Land Use Sustainability: Empirical Evidence from Gonabad County, Iran. *Agriculture* **2022**, *12*, 92. [CrossRef]
57. Li, T.; Sun, M.; Fu, Q.; Cui, S.; Liu, D. Analysis of irrigation canal system characteristics in Heilongjiang Province and the influence on irrigation water use efficiency. *Water* **2018**, *10*, 1101. [CrossRef]
58. Obi, A.; Ayodeji, B.T. Determinants of economic farm-size–efficiency relationship in smallholder maize farms in the eastern cape province of South Africa. *Agriculture* **2020**, *10*, 98. [CrossRef]
59. RSalvador; Carlos, C.B.-C.; Playán, E. Irrigation performance in private urban landscapes: A study case in Zaragoza (Spain). *Landsc. Urban Plan.* **2011**, *100*, 302–311. [CrossRef]
60. Zhai, H.; Lv, C.; Liu, W.; Yang, C.; Fan, D.; Wang, Z.; Guan, Q. Understanding Spatio-Temporal Patterns of Land Use/Land cover change under urbanization in Wuhan, China, 2000–2019. *Remote Sens.* **2021**, *13*, 3331. [CrossRef]
61. VHandini; Pratiwi, P.; Sunartomo, A.; Rondhi, M.; Budiman, S. Agricultural Land Conversion, Land Economic Value, and Sustainable Agriculture: A Case Study in East Java, Indonesia. *Land* **2018**, *7*, 148. [CrossRef]
62. Li, W.; Wang, D.; Liu, S.; Zhu, Y. Measuring urbanization-occupation and internal conversion of peri-urban cultivated land to determine changes in the peri-urban agriculture of the black soil region. *Ecol. Indic.* **2019**, *102*, 328–337. [CrossRef]
63. Dadashpoor, H.; Azizi, P.; Moghadasi, M. Land use change, urbanization, and change in landscape pattern in a metropolitan area. *Sci. Total Environ.* **2019**, *655*, 707–719. [CrossRef]
64. Asabere, S.B.; Acheampong, R.A.; Ashiagbor, G.; Beckers, S.C.; Keck, M.; Erasmi, S.; Schanze, J.; Sauer, D. Urbanization, land use transformation and spatio-environmental impacts: Analyses of trends and implications in major metropolitan regions of Ghana. *Land Use Policy* **2020**, *96*, 104707. [CrossRef]
65. Rustiadi, E.; Pravitasari, A.E.; Setiawan, Y.; Mulya, S.P.; Pribadi, D.O.; Tsutsumida, N. Impact of continuous Jakarta megacity urban expansion on the formation of the Jakarta-Bandung conurbation over the rice farm regions. *Cities* **2021**, *111*, 103000. [CrossRef]
66. Fakkhong, S.; Suwanmaneepong, S.; Mankeb, P. Determinants of sustainable efficiency of rice farming in peri-urban area, evidence from Ladkrabang district, Bangkok, Thailand. *World Rev. Entrep. Manag. Sustain. Dev.* **2018**, *14*, 389–405. [CrossRef]
67. Liu, Y.; Zhou, Y. Reflections on China's food security and land use policy under rapid urbanization. *Land Use Policy* **2021**, *109*, 105699. [CrossRef]
68. Kulmatov, R.; Groll, M.; Rasulov, A.; Soliev, I.; Romic, M. Status quo and present challenges of the sustainable use and management of water and land resources in Central Asian irrigation zones—The example of the Navoi region (Uzbekistan). *Quat. Int.* **2018**, *464*, 396–410. [CrossRef]
69. Nguyen, T.T.; Ngo, H.H.; Guo, W.; Wang, X.C.; Ren, N.; Li, G.; Ding, J.; Liang, H. Implementation of a specific urban water management-Sponge City. *Sci. Total Environ.* **2019**, *652*, 147–162. [CrossRef] [PubMed]
70. He, C.; Liu, Z.; Wu, J.; Pan, X.; Fang, Z.; Li, J.; Bryan, B.A. Future global urban water scarcity and potential solutions. *Nat. Commun.* **2021**, *12*, 4667. [CrossRef] [PubMed]
71. Zhou, F.; Bo, Y.; Ciais, P.; Dumas, P.; Tang, Q.; Wang, X.; Liu, J.; Zheng, C.; Polcher, J.; Yin, Z.; et al. Deceleration of China's human water use and its key drivers. *Proc. Natl. Acad. Sci. USA* **2020**, *117*, 7702–7711. [CrossRef] [PubMed]
72. Carrard, N.; Foster, T.; Willetts, J. Groundwater as a source of drinking water in southeast asia and the pacific: A multi-country review of current reliance and resource concerns. *Water* **2019**, *11*, 1605. Erratum in *Water* **2020**, *12*, 298. [CrossRef]

73. Yang, Z.; Song, J.; Cheng, D.; Xia, J.; Li, Q.; Ahamad, M.I. Comprehensive evaluation and scenario simulation for the water resources carrying capacity in Xi'an city, China. *J. Environ. Manag.* **2019**, *230*, 221–233. [CrossRef]
74. Thebo, A.L.; Drechsel, P.; Lambin, E.F.; Nelson, K.L. A global, spatially-explicit assessment of irrigated croplands influenced by urban wastewater flows. *Environ. Res. Lett.* **2017**, *12*, 074008. [CrossRef]
75. Natasha; Shahid, M.; Khalid, S.; Niazi, N.K.; Murtaza, B.; Ahmad, N.; Farooq, A.; Zakir, A.; Imran, M.; Abbas, G. Health risks of arsenic buildup in soil and food crops after wastewater irrigation. *Sci. Total Environ.* **2021**, *772*, 145266. [CrossRef]
76. Fahad, S.; Hasanuzzaman, M.; Alam, M.; Ullah, H.; Saeed, M.; Khan, I.A.; Adnan, M. *Environment, Climate, Plant and Vegetation Growth*; Springer International Publishing: Berlin/Heidelberg, Germany, 2020. [CrossRef]