A non-parametric approach in assessment of operational efficiency of irrigation systems in Southern Mindanao, Philippines

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ABSTRACT

This study sought to estimate the technical efficiency of irrigation systems in Southern Mindanao Region, Philippines. In order to do so, the study assessed the relative efficiency of 108 communal irrigation systems of the five provinces in Southern Mindanao based on the combination inputs and outputs. The input-oriented data envelopment analysis via DEAP 2.1 revealed 28 irrigation systems that are fully-technically efficient as they exhibited 1.00 technical efficiency scores in both CRS and VRS assumptions. Among the fully efficient irrigation systems, Cebuza SIS, Cateel Integrated IS, Badagoy CIS, and Pantang CIS lead the irrigation systems that lie in the efficiency frontier. Implications were discussed.

Keywords: *econometrics, non-parametric efficiency, irrigation systems, data envelopment analysis, Southern Mindanao.*

INTRODUCTION

The crucial role of irrigation systems towards productivity in agriculture cannot be discounted. Furthermore, it is considered a key contributory factor in the increase of agricultural products among developing countries in Asia, including the Philippines (Yao, 2005). As a proof, farmers benefit chiefly by having access to irrigation system, thereby increasing their productivity. Succinctly put, irrigation systems are operating units with inputs and outputs to manage, and efficiently managing them ensures their sustainability.

Irrigation system is generally a lowland agricultural trend which primary objective is to transport the quality and amount of water needed by plants to improve growth and production (Wichelns, 2000). In several situations where agricultural development occurs near upland communities, farmers benefit chiefly by employing irrigation system, which increases yields indirectly by improving productivity of modern rice varieties and fertilizer use. Further, the system was considered as key contributing factor in the increase of agricultural products among developing countries in Asia, including the Philippines (Yao, 2005). Traditional irrigation system is beneficial in reducing farmers' susceptibility to weather conditions, hence making yield and revenue more stable. This process includes applying water evenly to all areas of the field without putting into consideration the spatial variability in soil and crop water requirements; this results in over irrigation in certain areas of the field, while other areas are under irrigated (Daccache, Knox, Weatherhead, Daneshkhah & Hess, 2015). However, traditional irrigation has also increased the pressure on water reservoirs and created pollution problems (Salazar & Rand, 2016).

Irrigation efficiency, which is a predictor of effective water resource management, varies from one region to another. In this context, a major concern is the scarcity of water in irrigation system command areas especially during dry season and dry spells in rainy season (Bareng, Balderama & Alejo, 2015; Sinuany-Stern, Mehrezz & Hadad, 2000). To address irrigation efficiency in the country, thorough research on water-saving irrigation techniques have been conducted, including the utilization of land leveling, dry or wet seeding and controlled irrigation (Palis, et al., 2005). Among these techniques, controlled irrigation system was studied rigorously and was observed to minimize water requirements while maintaining high production (Bouman & Tuong 2001, Belder et al. 2004).

The efficiency of irrigation systems is determined not only by the standard of the sector's own management, but also by variables beyond its control. In a 2019 report on Irrigation Performance Index, for instance, reported that only 23% of the total Irrigator's Associations (IAs) obtained high level of irrigation while 45% of the 151 IAs had low irrigation performance (Clemente, et al., 2020). Similarly, several irrigation projects do not submit baseline information in regards with the amount of service to water irrigation users and the factors which affect those services (Bareng, et al., 2015). The non-compliance of baseline information leads to incompetent project proposal, hence, negatively influence irrigation projects.

Irrigation efficiency, however, remains a besetting problem for most operational irrigation systems. Management of irrigations, whilst never for the sake of profit, is marred not only by problems relative to scarcity of water during dry spells (Bareng, Balderama & Alejo, 2015; Sinuany-Stern, Mehrezz & Hadad, 2000), but also in terms of IAs organization-related issues (e.g., Bouman & Tuong 2001, Belder et al. 2004). A 2019 report on Irrigation Performance Index, for instance, reported that only 23% of the total Irrigator's Associations (IAs) obtained high level of irrigation while 45% of the 151 IAs had low irrigation performance (Clemente et al., 2020). Similarly, several irrigation projects do not submit baseline information in regards with the amount of service to water irrigation users and the factors which affect those services (Bareng et al., 2015). At the farm level, irrigation concerns involve underestimation of the field water requirements and water losses, canal lining, water flow level and water use efficiency (Dejaresco III, 2019; David & Inocencio, 2014). The efficiency of irrigation service as well as the quality of water delivered was further affected by illegal settlers, illegal pumping and mismanagement of garbage disposal.

Irrigation systems in Southern Mindanao Region are not exempted from these problems. The contention suggests that increased efficiency may therefore increase equity in water distribution and reduce the discrepancy between possible need for crop water and actual usage of water. In an operational context, the preparation, design and construction of irrigation systems receive significant interest and are usually accomplished with utmost care, nonetheless, little attention is given to maintenance and operational matters. Locally, there is no research conducted in assessing the technical efficiency of irrigation systems in Southern Mindanao Region. With this, this study wants to determine the technical efficiency of irrigation systems in the Region using a non-parametric approach that consider multiple inputs and outputs. This information can be used by policymakers and concerned IAs to enhance their operation. In addition, the policymakers could use this information to look for and target public interventions to enhance farm productivity and operational viability.

METHOD

The study utilized an econometric approach, particularly data envelopment analysis (DEA). DEA measures the comparative efficiency manifested by single input-output and multiple inputs and outputs factors of firms or decision-making units (DMUs). When the weights are restricted, efficiency of DMUs could be defined as the ratio of the weighted sum of outputs over the weighted sum of inputs (Talluri, 2000). Two general approaches are considered in measuring efficiency – mathematical programming approach and econometric approach. The DEA, which was utilized in this study, signifies the former group and is a common approach. This study employed DEA to improve relative measures in terms of technical (in)efficiency of irrigation systems in Southern Mindanao. In addition, the study focused on including irrigation systems that have been operational for at least 12 months or more. Only the communal irrigation systems were included, such that they capture specific data, with national irrigation systems having aggregated or lumped data.

Both input- and output-oriented DEA models will be estimated in both CRS and VRS assumptions. The model specification in DEA must have its positivity and isotonicity property. The first term refers to the positive values of inputs and outputs or values greater than zero, while the latter term refers to the mathematical property, which means that an increase of inputs should, in some ways, result to increasing outputs (Bowlin, 1998).To this effect, the DEA model in this study considered the following inputs and outputs for the two models studied:

Table 1. *Input-output specification*

Inputs	Outputs
• volume of water extracted	• size of farm hectarage served
• length of irrigation canals	• number of farmer beneficiaries
• number of active farmer members doing labor and maintenance	• fees/income earned from irrigations
• operational costs (MOOE)	

The mathematical foundations of DEA held the study of Farrell (1957) and DeBreau (1951), the proponents of the idea that linear programming could be employed to empirically apprehend economic components of the production circumstance. This technique of measuring efficiency was based on the recognized body of input-output trajectories of the production potentials. The measure employs the information provided by the members of a group of enterprises and hence, is a relative measure of efficiency (Coelli, 1996). DEA specifies a non-parametric mathematical program that estimates the best frontier (Charnes, Cooper, & Rhodes, 1978). It is a linear programming approach grounded on measuring the relative accomplishments of decision-making units (DMUs). Efficiency, in this manner, can be measured by identifying the ratio of the total value of output along with the sum of input and should be administered for every DMU (Asmild, Paradi, Reese & Tam, 2007; Tone, 2001). The ratio ranges from zero to one, with one represents to the best practice while less than one to zero signifies inefficiency in the practice. This approach is more flexible in managing several output and input since this measure has no parametric requirement (Grosskopf & Valdmanis, 1987; Tongzon, 2001). Estimations were done in DEAP 2.1 software by Coelli (1996).

RESULTS

Irrigation systems were examined by analyzing the descriptive profile of inputs (which includes volume of water extracted, length of irrigation canals, number of active farmer members doing labor and maintenance, and operational costs) and outputs (size of farm hectarage served, number of farmer beneficiaries, and fees/income earned from irrigations). As shown in Table 1, the analysis focused on the average and standard deviation which data were taken from 108 irrigation systems in Region XI.

Table 1. *Production variables of irrigation systems (n=108)*

Variables	Mean	SD
Outputs		
Size of farm hectarage served	233.66	294.33
Number of farmer beneficiaries	127.37	189.47
Fees/income earned from irrigations	349,523.37	578,177.13
Inputs		
Volume of water extracted	5,218,551.20	6,869,756.03
Length of irrigation canals	7.74	6.91
Number of active members	93.63	141.99
Operating costs (MOOE)	301,230.81	527,164.01

It is noted that average volume of water extracted is 5.2 million cum. Irrigation systems have an average of 7.74 km of irrigation canals. They are maintained by an average of 94 personnel and annual MOOE is Php 301,230.81. As to outputs, average size of firmed-up service area is 233.66 ha, benefitting an average of 127 farmers, and earning Php 349,523.37 in terms of irrigation fees earned.

In estimating efficiency of irrigation systems, variety of DEA models was developed to measure the efficiency and capability in several approaches. These can generally be categorized into either input-oriented or output-oriented models. In this study, the input orientation was utilized. Based on the estimations done, the average score for constant returns-to-scale (CRTS) technical efficiency was 65.4% and for variable returns-to-scale (VRTS) technical efficiency, mean efficiency score is 79.8%.

Table 2 presents the distribution of irrigation systems according to their technical efficiency scores in both constant returns-to-scale (CRS) and the variable returns-to-scale (VRS) assumptions. Under the CRS assumption, 28 irrigation systems (or 25.93%) are technically efficient while under VRS assumption, 40 irrigation systems (or 37.04%). Note that in terms of the irrigation systems' capability to be marked as fully technically efficient in CRS and VRS assumptions, it must have 1.00 as TE score. This implies that they could gain a specified level of productivity at the minimum inputs' requirement of the production (Chavas & Aliber, 2013).

Based on conservative estimation, we consider only 28 irrigation systems that exhibit full efficiency. In this regard, studying possible slacks could help the inefficient irrigation systems to obtain or target given levels of inputs and outputs (Hafeez et al., 2007; Gajewski et al., 2009; Tang, Folmer & Xue, 2015).

Table 2. *Input-Oriented CRS and VRS Technical Efficiency DEA*

TE Score	CRS Assumption		VRS Assumption	
	f	%	*f*	%
less than 25%	10	9.26	-	-
25 to 50%	29	26.85	14	12.96
51 to 75%	23	21.30	26	24.07
76 to 99%	18	16.67	28	25.93
100%	28	25.93	40	37.04
Mean TE	65.4%		79.8%	

In the subsequent analysis, slacks were presented to determine the variable discrepancy among outputs and inputs of irrigation systems. As to input slacks, the inefficient irrigation systems need to increase their inputs by an average of 21.7 m^3 of water, add an average of 21 active members in its irrigation association, and Php 36,342.00 increase of their maintenance cost (MOOE). Accounting all irrigation systems, 11.11% have issues regarding the necessity to increase volume of extracted water to cope up with the optimal output, 16.67% have issues that concerns increasing the number of active members, and 12.96% have issues with regards to increasing maintenance cost or MOOE, while no irrigation systems have irrigation canals extension concerns.

As to output slacks, the inefficient irrigation systems need to increase their outputs by an average of 13.471 hectares more for firmed-up service area, 36.149 more beneficiary farmers, and raise an average of Php 46,463.00 for fees in irrigation systems. Accounting all DMUS, 16.67% have issues regarding the necessity to increase firmed-up service area to cope up with the optimal output, 45.37% have issues that concerns increasing the number of farmer beneficiaries, while 32.41% have fees/incomes earned from irrigation concerns.

In addition, additional analysis presented is the peer count summary of fully efficient irrigation systems that can be benchmarked or can serve as reference to the inefficient irrigation systems to improve their operations. Irrigation systems that can be benchmarked by inefficient irrigation systems include Cebuza SIS with 64 peers who can likely benchmark, Cateel Integrated IS with 58 peers who can likely benchmark, Badagoy CIS with 21 peers who can likely benchmark, and Pantang CIS with 21 peers who can likely benchmark. The peer suggests several firms that are inefficient in their practice, hence, inefficient to follow (Coelli & Walding, 2006). These four irrigation systems, with their presented full technical efficiency scores as well as the number of peer irrigation systems that can benchmark are their approaches and utilization of inputs and outputs are evident that these are the irrigation systems that best lie in the efficiency frontier.

DISCUSSION

The main objective of DEA is to quantify the competence of DMU (i.e., irrigation system) by means of a scalar measure that range from zero; being the worst, and one, signifying the best efficiency scale. This scalar measured through linear programming model. In addition, DMU with efficiency score of 1.0 or 100% or with no slacks, suggests that there is excess in inputs or deficiency in the outputs (Tone, 2001). Moreover, in discussing the total efficiency it is important to observe the ratio and the slacks. Measuring the slack can give advice aspects that need attention so that the farmers can be efficient.

Measuring technical efficiency, identifying imperative factors associated with it serves as a potential evaluation for expanding sustainable aquaculture. Most of the studies of technical efficiency in the agricultural sector have used DEA, in addition to stochastic frontier analysis (SFA) and free disposal hull (FDH) methods. Studies like Rodriguez-Diaz, Camacho-Poyato and López-Luque (2004), Lilienfeld and Asmild (2007), and Díaz, Poyato and Luque (2004) arrived with a consensus that evaluation of efficiency of individual decision-making units (DMUs) relative to the production frontier with DEA as main approach produces relative efficiency as a primary limitation, despite being able to identify which are efficient and inefficient irrigation systems to begin with.

There are many sources of variation in DEA formulation; hence, it is imperative to characterize the model that fits in accordance with the data being analyzed (Kalirajan & Shand, 1999). This study used the only the input orientated DEA approach which focuses on minimizing the utilization of resources/input given with certain level of output. Secondly, we also need to determine the source of variation based on returns to scale, the constant returns (CRS) and the variable returns (VRS) (Battese, Rao & O'Donnell, 2004). Whereas, the constant returns which output/input ratio is constant over time, irrespective of the amount of inputs, while variable returns the contribution of the inputs to outputs changes over time its either increasing or decreasing over the time (Burda & Wyplosz, 2013).

The efficiency score for irrigation systems emerges to be dissimilar for both CRS and VRS models. In CRS model, there are only 28 irrigation systems that are considered technically efficient having 1.0 TE score, while in the VRS model, there are 40 irrigation systems having 1.0 as TE score. On average, irrigation systems' efficiency scores are 65.4% for constant returns-to-scale (CRTS), which indicates irrigation systems could reduce their inputs by 34.6% to obtain the same level of production. On the other hand, variable returns to scale (VRS) technical efficiency is 79.8%, which means that a fully efficient irrigation system is capable of reducing input consumption by 20.2%.

The summary of slacks refers to a value that demonstrates the inconsistency in the constant or relative change among the input and the output variable (Coelli & Walding, 2006). The measure ought to display the result that would either increase or decrease (Cooper, Seiford, & Zhu, 2011). The findings from the summary of slacks based on variable scale assumptions, input and output orientation has different results. In this study, there are 80 irrigation systems were inefficient. Furthermore, number of active members of the irrigation association has the highest rated input slacks while for the output slack, irrigation systems have most pressing concern on increasing the number of farmer beneficiaries. This implies that efficiency for irrigation systems in the context of Southern Mindanao is more of expecting more people to actively engage to benefit more farmers. Such is corollary with the findings of Dhungana, Nuthall and Nartea (2004) in the context of Nepalese rice farms, and Tang, Folmer and Xue (2015) in the context of Chinese agricultural water use efficiency, noting that the human capital component as input or output have drastic effects on efficiency.

CONCLUSION

Input-output relationship in irrigation systems and the variations within the output was conjointly accounted for by the variable of inputs of production such as volume of water extracted, length of irrigation canals, number of active farmer members doing labor and maintenance, and operational costs. It anchors on the production theory of Cobb and Douglas (1928) which explains an input and output relationship. In this production process, the manager is concerned with efficiency in the use of the inputs.

The average technical efficiency scores based on CRS is only 0.654, this indicates that on average they could increase their inputs by about 0.346 to maximize their outputs. As such, by the help of slack analysis, managers or farmers of irrigation systems have a basis what input they need to increase/decrease to achieve an efficiency score of 1.00. Moreover, the range of measures is an important tool to determine the efficiency of the firms in yielding maximum output (Perelman & Serebrisky, 2012).

In this study, 28 irrigation systems in the CRS assumption and 40 irrigation systems in the VRS assumption are technically efficient. These mean that they can gain the optimal outputs depending on the provided set of inputs. All discerned points lie on or below the production frontier (Coelli, 1996). Hence, points that lie on both CRS and VRS efficient while the points that lie on both CRS and VRS are fully technical efficient. However, those that are below the line are inefficient. However, among the fully efficient irrigation systems, Cebuza SIS, Cateel Integrated IS, Badagoy CIS, and Pantang CIS lead the irrigation systems that lie in the efficiency frontier; hence, they may become capable of being benchmarked for their best practices in the utilization of inputs for optimal production.

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