JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2022, 23(5), 207–215
https://doi.org/10.12911/22998993/147321
ISSN 2299–8993, License CC-BY 4.0

Received: 2022.02.23
Accepted: 2022.03.18
Published: 2022.04.01

Input Use Efficiency in Operational and Maintenance Management of Small-Pumping Scale Irrigation Systems in Red River Delta, Vietnam

Dao Van Dinh[1*], Phong Tung Nguyen[2], Dat Van Tran[1,2], Mukheibir Pierre[3], Au Nu Hai Ton[4]

[1] Institute for Water Resources Economics and Management, 131 Chua Boc, Dong Da, Ha Noi, Vietnam
[2] Vietnam Academy of Water Resources, 171 Tay Son, Dong Da, Ha Noi, Vietnam
[3] Institute for Sustainable Futures, 15 Broadway, Ultimo, NSW, Australia
[4] University of Economics, Hue University, 99 Ho Dac Di, Hue City, Vietnam
* Corresponding author's e-mail: dvdao.thuyloi@gmail.com

ABSTRACT
In the Red River Delta (RRD) of Vietnam, small-pumping systems are one of main systems for paddy irrigation. It is imperative to analyze the operation and maintenance performance of irrigation systems by using the input factors when applying pricing mechanisms in the irrigation sector in Vietnam. In this study, based on the data of 48 irrigation systems managed by teams under irrigation companies, the non-parametric program, Data Envelopment Analysis, was used to measure the technical efficiency and scale efficiency for small-pumping scale irrigation systems in the Red River Delta. The seven input factors were the annual direct and indirect labor, materials, electricity, recurrent maintenance, overhead, and depreciation cost, and an output factor was the paddy areas irrigated by the systems. The results demonstrated that the average technical efficiency scores under constant returns to scale and variable returns to scale were 0.924 and 0.946, respectively. Thus, the wasted inputs were suggested to be 7.6% and 5.4% of the current input level, respectively. The average scale efficiency score was 0.977 and therefore, some 72.9% of the Decision-Making Units should adjust their input scales to achieve the efficiency in input factors.

Keywords: technical efficiency, scale efficiency, irrigation systems, DEA.

INTRODUCTION

In the Red River Delta of Vietnam, the water resources used for agricultural production ar mainly from river systems, reusing water sources or drainage canal systems. They have been exploited by pumping systems for irrigation targets. According to the specific irrigation needs and infrastructure conditions, the pumping irrigation systems were established by different scales. In the small irrigation areas, which were located in separated areas and with low water levels, the small-pumping scale irrigation systems (capacity under 3600 m^3/h) were more effective. Their functions provided irrigation water for rice cultivation by beneficiaries in their demand areas (Jean-Paul Luc et al., 2006). There were about 3,281 small-pumping scale irrigation systems (irrigation systems) with the designed capacity from 300 to 1000 m^3/h and providing irrigation water for about 30% in total of 806 thousand hectares of agricultural areas in the RRD (MARD, 2019).

In practice, the operation and maintenance management (O&M) models of the small irrigation systems are very diverse. One the major models is called decision making units (DMU), where O&M teams are established under branches of provincial irrigation companies (IMC), and which worked independently and excercised self-control. These DMUs were set up according to small-scale and independent systems and implemented the tasks of O&M under internal agreement mechanisms, such as irrigation management transfers to share roles and responsibilities in O&M management of irrigation systems from IMCs to DMUs.

For the model of DMUs, the distribution and use of resources during O&M process to provide irrigation service were different and depended on actual irrigation infrastructures and capacity of DMUs' managers. Therefore, there were quite a number of challenges to determine the irrigation efficiency using technical and economic indicators. In the fact, the inputs in O&M were divided into two groups. The first group included variable inputs which were dependent on actual needs during the operational process of the systems such as direct labor, materials, electricity, current routine reparations. The second group included a group of fixed inputs which were based on norms annually assigned for DMUs by IMCs such as indirect labor, overhead cost according to the O&M technical cost norms, and depreciation cost according to investment unit cost regulated and production life of the pumps and concrete canals. Moreover, due to irrigation management types changing from fixed fee to market mechanisms or service-oriented management, utilization of input resources how to achieve the best efficiency has been a major concern and consideration by both practical and scientific sides (Nguyen Tung Phong, 2019; Hector Manalo, 2004).

Many studies have just used the technical indicators to assess of the O&M management efficiency of irrigation systems, such as water saving per an irrigated area unit or changes of cropping yields after adaptation of a new construction and equipment of pumping, changes of construction types or irrigation techniques (Goodstein et al., 1993; Hector Malano et al., 1999; Nguyen Tung Phong et al., 2019; Doan The Loi et al., 2019. There were several research papers on irrigation efficient assessment in Vietnam using technical and social indicators (Ha Luong Thuan, 1995; Nguyen The Quang et al., 2001; Dinh Vu Thanh et al., 2007, Le Van Chinh 2012, Hong Minh Hoang et al., 2020). Some others were based on cost efficiency such as the studies by Doan The Loi et al., 2019; Nguyen Trung Dung, 2017; Nguyen Duc Viet et al., 2018 and Hector Manalo et al., 2004. However, these studies were mainly based on key performance indicators which followed a simple rule such as inputs per outputs without showing information or reasons and suggestions to improve the current efficient values. By reviewing the literature on irrigation performance assessment methods, Hector Manalo et al., 2004 suggested the application of an optimal frontier program, non-parametric data envelopment analysis (DEA) on the irrigation sector. Up to now, there have been some research conducted outside of Vietnam which applied input-oriented models of DEA to analyze the technical efficiency in O&M management of irrigation systems or O&M agencies. However, these studies only assessed irrigation water use efficiency in agricultural, dairy, and aquaculture production models at a household or household group scales (Fraser I. and Cordina D., 1999; Tim Coelli et al., 2005; Stijn Speelman et al., 2008; Fraj Chemaka el al., 2009; WANG Xue-yua, 2010; Aymen Frija et al., 2011; Ismet Boz et al., 2018).

There is an absence of published research on the O&M management efficiency of irrigation sector towards service-oriented management in Vietnam, especially with small-pumping scale irrigation systems based on O&M inputs and resource use, as well as application of DEA methods in this issue. Therefore, this study used DEA methods to assess the technical efficiency in O&M management of irrigation systems in RRD. The objectives of the study were to identify the inefficiency and levels of waste of input resources according to two assumptions of (1) constant returns to scale (CRS) and (2) variable returns to scale (VRS), as well as scale efficiency as a basis on the input scale adjustment in O&M process of irrigation systems in RRD.

METHODOLOGY

Data envelopment analysis

The DEA method, a non-parametric method, in which the efficient frontier was set by inputs and outputs of the best management agencies based on the observed practical data that was prepared by Farrel (1957). This method is used to assess the productive or management efficiency of agencies, units, even sectors. The efficient assessment in DEA could be considered in two orientations including a) minimizing inputs used without changing outputs (Input-Orientation) or b) maximizing outputs without changing input amount (Output-Orientation) (Ton Nu Hai Au et al., 2019; T. Coelli et al., 2005). This study selected the Input-Orientation model to consider technical efficiency (TE) under the two assumptions of constant returns to scale and variable returns to scale (VRS) of the small-pumping scale irrigation systems in the RRD. The general CRS-DEA and VRS-DEA models were described as below:

CRS-DEA $$\min_{\theta,\lambda j} \theta \quad (1)$$

Subject to: $$Y\lambda \geq y$$

$$\theta x_j \geq X\lambda$$

$$\lambda \geq 0$$

VRS-DEA Adding condition of: $$\sum_{i=1}^{N} \lambda j = 1 \quad (2)$$

In addition, in order to identify the specific suggestions on constant, increasing or decreasing scales of DMUs which were inefficient, this article continued measuring scale efficiency (SE) using the equation:

$$\text{SE} = \frac{TE\_CRS}{TE\_VRS} \quad (3)$$

In which, θ is the technical efficiency indicator and λ is the weight vectors of input and output variables. The linear mathematic program in the equation 1 is calculated in n times for n DMUs. Value of θ ranges from 0 to 1. When θ of a DMU equals to 1, the DMU is efficient and lies on the frontier. If θ indicator is less than 1, it means that DMU is inefficient. In order to be efficient, DMU needs to reduce the current level of input by $(1 - \theta)\cdot 100\%$. Vector λ is defined as the linear combination between the peer of the i-th DMU. n is the number of DMUs. Yi is the vector of irrigated output areas of the i-th DMU. Xi is the actual level of inputs of the i-th DMU.

The value of SE also ranges from 0 to 1. The DMU is operating at an efficient scale if the value of SE equals to 1 and the DMU is scale inefficient if the value of SE is less than 1.

Data and variables

The data was collected and gathered according to operation and maintenance criteria of the systems listed in forms at each DMU. A DMU was a team under the irrigation companies which were assigned the O&M tasks of the separated small pumping systems. Their input data was classified into two groups of direct and indirect inputs. The indirect labor and overhead cost were from the total cost of all companies averaged by the number designated areas of the systems. The depreciation cost was determined by the average of total of pumping and canal construction cost for 10 years. The input data of direct labor, materials, electricity and maintenance cost were collected on basis of real expenses which DMUs used during the process of operating and maintaining the systems to provide irrigation service for users. Output data was the annual irrigation areas of the systems over the assessment period. All data were observed and averaged for three years from 2018 to 2020 at each DMU and their irrigation systems.

The input variables (X) used in the DEA model are seven inputs used in operating and maintaining the irrigation systems. They are the numbers of indirect labor (man-day), direct labor (man-day), general materials (kg), electric energy for irrigation (kw), maintenance costs ($US), overhead cost ($US) depreciation cost ($US). Output (Y) used in the DEA model is the irrigation areas of paddy (ha).

The value of the variables was collected at each DMU by recording O&M data of the 48 small-pumping irrigation systems in the RRD. The number of DMUs were considered by sampling formulas introduced by Banker et al. (1989) and Cidália Leal Paço et al., (2013) with a general approach that the number of DMUs were equal to or higher than three times the total input and output variables used in the model. With the total of 7 inputs and 1 output variables, the number of sample irrigation systems equal to DMUs selected were 24 DMUs in the province by similar criteria such as pumping capacity under 1000 m^3/h, low water pressure head (lower 2.4 m), an independent system with supplements of other water sources, irrigated area of rice, irrigation transfer management application according to labor and other costs, managed by an irrigation team. This research selected 48 DMUs managing 48 systems and divided into 3 IMC groups in RRD which were the different management models and mechanisms of arranging indirect inputs and labor resources for their own irrigation teams among the IMCs. The analysis was undertaken using DEA Solver.

RESULTS AND DISCUSSION

Characteristics of the small-pumping scale irrigation systems

Total of number of systems was 27, 12 and 9 for the three IMCs in lowland areas of RRD coded by DN-VB, QT-TN and DK-DD,, respectively (Table 1). In practice, each IMC manages the different large irrigation systems in the region with the headworks being the large pumping or sluices which take water from the natural rivers to the large canal systems. Those provided sufficient water resources for the small systems to pump water to irrigate their controlled areas. Thus, pressure was the similar with an average of 2.4 m and the average of water flows and capacities of the systems were 896.7 m^3/h and 20.3 kw/h, respectively. For the systems managed by DK-DD IMC, the highest flow and capacity of systems were 1113.3 m^3/h and 24.9 kw/h, respectively. The total designed areas of the systems were 45.9ha, which largely ranged from 15.7 to 115.5 ha/system. The largest one was managed by DK-DD company, which pumped water from the same large irrigation system. The DN-VB and QT-TN companies pumped water from other sources such as natural river systems or canal systems in which the water levels were controlled by large sluices. The on-field survey of those systems showed that the operational productivity of the pumps in all three IMCs always achieved a high efficiency compared with their designed capacity and estimated at between 90% and 95% designed capacities. Although they all irrigated rice, there were differences from O&M process among DMUs and groups of DMUs because each IMC applied their own internal agreement mechanism in distributing inputs especially indirect labor, overhead cost and technical supports on reparation of the pumps and canals (Table 2).

Average of input unit per irrigated rice areas

The average of the input amount by annual irrigated rice areas which were used for operating and maintaining the irrigation systems by DMUs is shown in Table 2. Specifically, the mean of the direct labor spent was about 2.6 man-day/ha annually, the highest level was in DMU group of DN-VB and the lowest one was in the DMU group of DK-DD at 2.98 and 2.22 man-day/ha, respectively. This level was higher than levels of 2,4 man-day/ha in the whole RRD region which was estimated by Nguyen Vu Viet (2018). The mean of electricity used was 83.4 kw/ha, where the highest level was in the group of DN-VB and the lowest one was in the group of DK-DD at levels of 108.6 and 61.5 kw/ha, respectively. The variable of depreciation cost input was also found to range between the highest level of 46.69 $US/ha for the irrigated system of QT-TN and the lowest level of 43.37 $US/ha for the irrigated system of DK-DD. Thus, the result showed that correlation between the irrigated area and those three components was negative.

Technical efficiency in O&M management of irrigation systems

The full range of tasks for O&M management of an irrigation system included the operation and maintenance of the pumping headworks, water delivery on canals, irrigation service quality monitoring and consumer management on the paddy field. These were transferred to a DMU under an agreement document, thus

Table 1. Technical characteristics of the small-pumping scale irrigation systems

No	DMU groups	Number of systems	Flow (m^3/h)	Capacity of systems (Kw/h)	Height of pressure head (m)	Designed areas (ha)		
						Mean	Max	Min
1	DN-VB	27	879.3	19.9	2.5	32.2	87.8	12.0
2	QT-TN	12	763.6	17.8	2.3	50.2	89.1	20.6
3	DK-DD	9	1113.3	24.9	2.4	83.2	233.9	21.1
Total		48						
Average			89.7	20.3	2.4	45.9	115.5	15.7

Table 2. Annual average of input resources per hectare by given DMUs' groups

No	DMUs groups	Paddy areas (ha/DMUs)	Indirect Labor (man-day/ha)	Direct labor (man-day/ha)	Materials (1000/ha)	Electricity (Kw/ha)	Maintenance cost ($US/ha)	Overhead cost ($US/ha)	Depreciation ($US/ha)
1	DN-VB	61.89	0.45	2.98	0.29	108.6	22.36	3.00	45.10
2	QT-TN	88.40	0.27	2.52	0.58	74.2	21.51	3.64	46.69
3	DK-DD	163.67	0.53	2.22	0.14	61.5	23.44	4.33	43.37
4	Mean	87.60	0.43	2.60	0.31	83.4	22.53	3.63	44.90

DMU themselves managed and made decision in distributing the necessary expenses during the process of O&M management with the targets of achieving the highest efficiency use of the input resources and to ensure enough water and a good quality of service for users. In practice, to improve irrigation efficiency, IMCs transferred a part of the irrigation responsibilities and related input costs to specific DMUs to stick their roles, responsibilities and to encourage the operators in utilization and adaptation of advanced knowledge, experiences and technologies in O&M activities of the systems. These lead to improved economic and technical efficiency in using input expenses and cost to operate sustainable irrigation systems and to provide irrigation water with the highest criteria of service quality and quantity as requested. With these modes, besides the indirect support from their own IMC, as well as following the national and IMCs' standards and regulations, the DMUs actively made decisions in O&M activities especially in using efficiently inputs assigned and to ensure the irrigation tasks. For these purposes, DMUs became an independent agency in making decision for irrigation management for the specific irrigation system that fell under their responsibility.

The TE score of DMUs as estimated by DEA based on the levels of irrigation tasks by assigned areas and the efficient use of input resources utilized in each year to comply with the O&M regulations and technical standards and technologies. It was a comparison among observed inefficient DMUs and the best DMUs in the given DMUs. Some recommendations were made for the elimination of current inputs elimination were made but that still ensured the full provision of irrigation service for the current irrigation area of the irrigation systems.

The estimation of TE scores according to TE-CRS assumption

Mean of TE-CRS scores of given DMUs was 0.92 and ranged from 0.783 to 1, standard deviation being 0.062 at significant level e=95% (Table 3). This meant that being compared with the best DMUs, there were some DMUs that exceed the more efficient input amounts for O&M activities. It was necessary to consider the reduction of wasted input resources, estimated about 7.6% in total of current input amount. The highest input waste reduction potential according to the CRS models was about 21,3%. This level appeared in the DMU's group of the DK-DD branch.

Table 3. Technical efficiency scores according to TE-CRS model of given DMUs

No	DMU groups	Mean	Min	Max	Standard Deviation
1	DN-VB	0.918	0.797	1.00	0.059
2	QT-TN	0.937	0.854	1.00	0.058
3	DK-DD	0.927	0.783	1.00	0.079
4	All	0.924	0.783	1.00	0.062

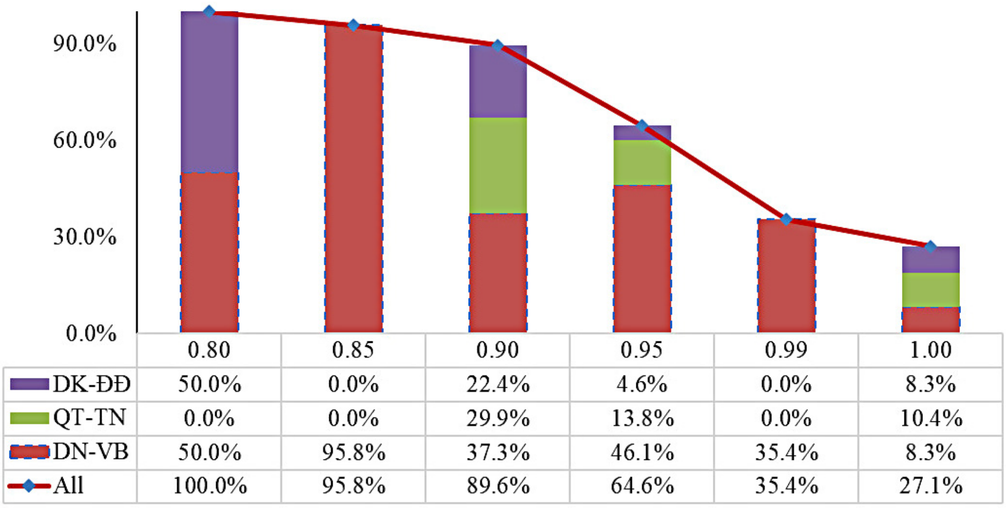


Figure 1. Percentage of TE-CRS scores exceeding given DMUs

For specific DMU groups in three branches of 3 IMCs, there also were the best DMUs which achieved the optimal TE-CRS score at 1. However, there were many inefficient DMUs such as the DMU group in QT-TN branch whose waste input average was at the lowest levels being at 6,3% and the maximum reduction of waste was 14,6% in estimation. Over 65% of DMUs with TE-CRS score were higher than the mean TE score of 0.924 (Figure 1).

100% of DMUs with the TE-CRS scores was higher than 0.8 and 27% (13/48) of DMUs were at TE-CRS score being equal to 1. Some of DMUs with TE-CRS scores equal to 1, the optimal efficient ones, were distributed in all DMU groups across the 3 branches. These were the DMUs that efficiently used the input resources in O&M management. It meant that these DMUs did a good job of combining the technical and human factors to efficiently use the inputs in O&M management when applying the internal irrigation management transfer mechanism. Moreover, there were 35.4% DMUs with TE scores higher than 0.99, approaching the optimal levels. In total, 90% of DMUs had TE score higher than 0.9, the highest score was found in the DMUs of DN-VB branch and the lowest ones were in the group of DK-DD.

The estimation of TE scores according to TE-VRS assumption

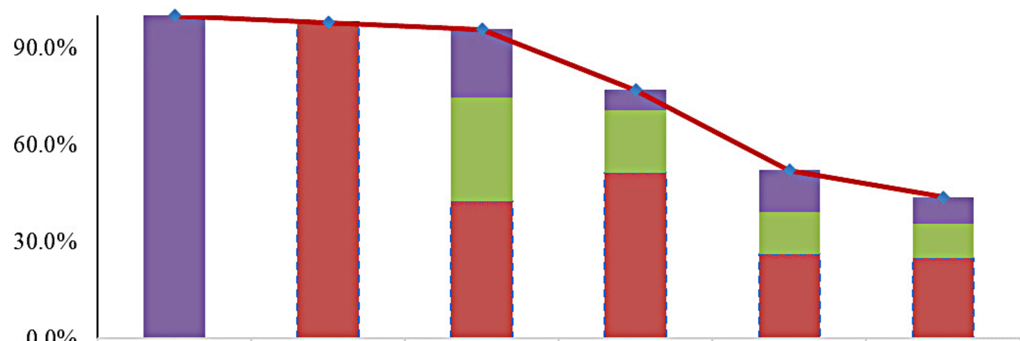
The mean of TE-VRS scores of DMUs was 0.946 (Table 4), which means that the observed DMUs wasted 5,4% of the total of current inputs which is lower than the waste levels recorded in the TE-CRS assumption. In general, the highest waste level was about 20,7% (Min of TE-VRS=0.793), and a similar value was found for DMUs' of group of DK-DD branch in this study.

The distribution of DMUs by TE-VRS score was sorted by efficient levels from 0 to 1 (Figure 2).

It was found that 44% of DMUs with optimal TE-VRS scores, in which 25% were in the DMUs of the DN-VB branch. About 77% of DMUs had TE-VRS scores being higher the mean level. It meant that TE scores of more than 50% of the observed DMUs were higher than 0.946 and had good efficiency levels with a low waste of input resources. About 96% of DMUs produced a TE-VRS score of greater than 0.90, it meant that there were a few DMUs wasting more than 10% of the total input amount. Further, it was found that the TE-VRS scores for all of the DMUs in QT-TN branch were over 0.90, followed by DN-VB and DK-DD with levels of 0.85 and 0.80, respectively, or in other words, demonstrating a waste rate of 15% and 20%, respectively.

Table 4. TE scores according to VRS assumption of given DMUs

No	DMU group	Mean	Min	Max	Standard Deviation
1	DN-VB	0.948	0.828	1.00	0.055
2	QT-TN	0.946	0.868	1.00	0.052
3	DK-DD	0.940	0.793	1.00	0.072
4	All	0.946	0.793	1.00	0.056



	0.80	0.85	0.90	0.95	1.00	1.00
DK-ĐĐ	100.0%	0.0%	21.3%	6.4%	13.0%	8.3%
QT-TN	0.0%	0.0%	31.9%	19.3%	13.0%	10.4%
DN-VB	0.0%	97.9%	42.6%	51.4%	26.0%	25.0%
All	100.0%	97.9%	95.8%	77.1%	52.1%	43.8%

Figure 2. Percentage of TE-VRS scores exceeding given DMUs

Scale efficiency assessment

Scores for scale efficiency (SE) in the model were considered when there was the difference between the score value of TE-CRS and TE-VRS for the inefficient DMUs. This indicated that there were some issues which negatively affected the O&M activities leading to the inefficiency of O&M input scales and suggested that it was necessary to have adjustment of increases or decreases of input scales for the inefficient irrigation systems. Comparing the general average scores of TE-CRS and TE-VRS that were presented in table 2 and 3, the different levels of their values being 0.924 and 0.946. Therefore, there was still inefficiency in the input use scale aspects of the observed DMUs or irrigation systems that was probably a reason leading to the technical inefficiency. The mean score of SE of all observed DMUs was 0.977, while for the irrigation systems in the QT-TN DK-DD and DN-VB branches, it was 0.990, 0.985 and 0.969, respectively (Table 5). Therefore, a small adjustment of the input scale resulted in an increase in the efficiency of the irrigated system. It meant that they only needed to adjust a little of their input scale to become an efficient one, estimated for all systems to be about 2.3%.

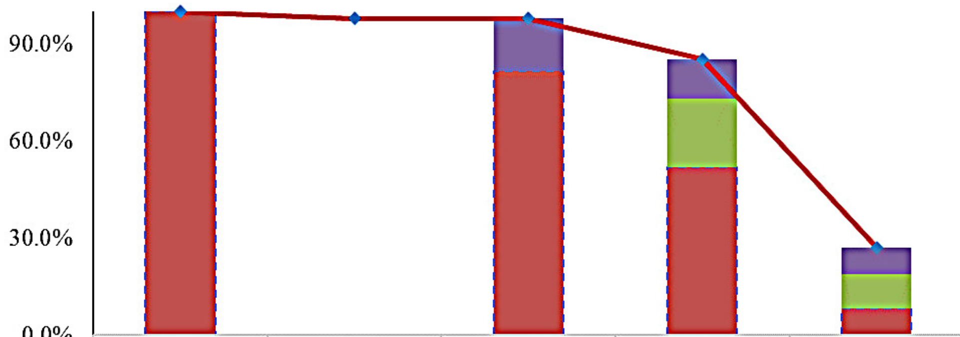
The distribution series of DMU's SE scores (Figure 3) indicated that about 27,1% (13/48) irrigation systems operated in the optimal scale, in which up to 23% of DMUs were in the DN-VB branch and the remaining parts were divided into 2 DMU's groups of the other branches. For 72.9% of DMUs, where the SE scores were lower than 1, it was suggested that they adjust their input scales with new technological applications or management regulations in order to use the input resources and to improve the O&M management activities inorder to achieve improved efficiency as the effected DMUs. The results also showed that 85.4% DMUs applied O&M tasks that reached the optimal levels, at a SE score of 0.99. The DMUs in the QT-TN branch demonstrated the lowest efficient level of 0.99, with DK-DD and DN-VB having 0.95 and 0.85, respectively.

Suggestions for changing O&M input scale

Based on the SE score estimation of the inefficient DMUs by the DEA, there were some similar suggestions of changing operational scales to increase or decrease O&M input scales. The percentage of increased and decreased DMUs on the O&M input scale were presented in Figure 4.

Table 5. Average score of scale efficiency in O&M management of given DMUs

No	DMU groups	Number of DMUs	Mean	Min	Max	Standard deviation
1	All	48	0.977	0.819	1.0	0.035
2	DN-VB	27	0.969	0.819	1.0	0.043
3	QT-TN	12	0.990	0.962	1.0	0.014
4	DK-DD	9	0.985	0.935	1.0	0.022



	0.85	0.90	0.95	0.99	1.00
DK-ĐD	0.0%	0.0%	16.3%	12.2%	8.3%
QT-TN	0.0%	0.0%	0.0%	21.4%	10.4%
DN-VB	100.0%	0.0%	81.6%	51.9%	8.3%
All	100.0%	97.9%	97.9%	85.4%	27.1%

Figure 3. Percentage of SE-VRS scores exceeding given DMUs

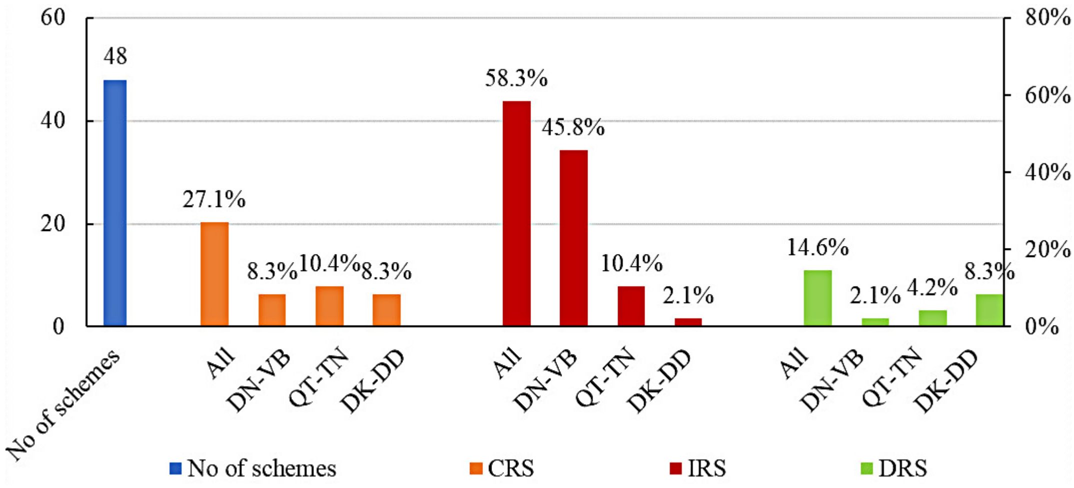


Figure 4. Directives of O&M input scale adjustment of given DMUs Notes: CRS: Constant returns to scale; IRS: Increasing Returns to scale; DRS: Decreasing returns to scale

The SE scores indicated that 27% of DMUs did not need to change their scale due to their SE score were 1. About 58% of DMUs (28 irrigation systems) should increase their current scales and 15% of DMUs should reduce their scales of inputs for irrigation service provision to improve their efficient scores. The optional implications of increasing and decreasing returns to scale included upgrading the pumping headwork, concreting canals, expanding the irrigated service areas or providing more other irrigation products. In practice, some DMUs could be assigned more tasks for supplementing O&M activities of other irrigation systems that were outside of their managed irrigation systems to increase the efficient use of available resources by reducing the direct labor input which occupied the highest proportion in the input cost structure.

CONCLUSIONS

The study used the non-parametric DEA method by the input orientation model to analyze the O&M performance of small-pumping scale irrigation systems in RRD. The two assumptions applied were constant returns to scale and variable returns to scale. The results showed average scores of TE-CRS and TE-VRS being 0.924 and 0.946, respectively. Conversely, this suggested that DMUs input wastage is 7.6% and 5.4%, respectively. The inefficient DMUs should reduce these wastages to make their systems more efficient. The DEA estimation also indicated that 27% (13/48) of DMUs had TE-CRS scores of 1 and 44% (22/48) with optimal TE-VRS scores of 1. These were the DMUs that managed their resources optimally and were used as the benchmark for the inefficient ones.

The model estimated scale efficiency (SE) scores and indicated the high average SE scores being at 0.977 level. Up to 43% (23/48) DMUs were found to reach the optimal level. The DEA models suggest that 72.9 DMUs should adjust their input scales, in which 58.3% of DMUs should increase their scales and 14.6% of DMUs should decrease their scale in O&M management to get the optimal efficient level. Some DMUs were operating at highly efficient levels and there were some inefficient DMUs that should reduce their current input and cost amounts. The inefficient DMUs should benchmark themselves against the best ones as a learning opportunity and work towards achieving the efficient targets.

REFERENCES

1. Aymen Frija, Ada Wossink, Jeroen Buysse, Stijn Speelman, Guido Van Huylenbroeck. 201. "Irrigation pricing policies and its impact on agricultural inputs demand in Tunisia: A DEA-based methodology", Journal of Environmental Management, 92, 2109–2118.
2. Banker R. Charnes A., Cooper W., Swarts J., Thomas D.A. 1989. An introduction to Data Envelopment analysis with some of their models and its uses", Research in Governmental and Nonprofit Accounting, 5, 125–163.
3. Cidália Leal Paço, Juan Manuel Cepeda Pérez. 2013. The use of DEA (Data Envelopment Analysis) methodology to evaluate the impact of ICT

on productivity in the hotel sector. *Via* [Online], 3.2013, online dal 01 janvier 2013, consultato il 10 novembre 2021. URL: http://journals.openedition.org/viatourism/1005; DOI: https://doi.org/10.4000/viatourism.1005

4. MARD. 2019. Decision no. 4076/QĐ-BNN-TCTL dated 28/10/2019 on approval of survey reports on O&M management and use of irrigation systems in Vietnam.
5. Dinh Vu Thanh, Ha Luong Thuan. 2007. Opportunity, challenges and solutions improving irrigation service in new period. Journal of Water Resources Science and Technology, Vietnam Academy for Water Resources. 18, 77–81. (in Vietnamese)
6. Do Van Quang. 2016. Research on options of O&M management improvement of irrigation in context of water fee exemption in Red River Delta, PhD. Dissertation. Water Resources University.
7. Doan The Loi, Le Thu Phuong. 2019. Literature review on irrigation product, service pricing. Journal of Water Resources Science and Technology, 52, 8–24.
8. Goodstein L.T. Nolan J.W. Pfeiffer. 1993. Applied Strategic Planning: A Comprehensive Guide. MC Graw Hill, Inc. New York, P379.
9. Ha Luong Thuan. 1995. Rice irrigation effectiveness in Red River Delta, PhD. Dissertation, Institute for Water Resources Science and Economics. (in Vietnamese) http://luanan.nlv.gov.vn/luanan?a=d&d=TTkGBCiyTnGK1995.1.7&e=-vi-20-1-img-txIN-h%c3%a0+l%c6%b0%c6%a1ng+thu%e1%ba%a7n-#
10. Hector Malano, Paul J.M. Van Hofwegen. 1999. Performance of Irrigation and Drainage Service, a Service Approach. Hardbound edition. Rotterdam, Netherlands, pp. 130.
11. Hector Malano, Martin Burton and Ian Makin. 2004. Benchmarking Performance in the irrigation and drainage Sector: A tool for change. Journal of Irrigation and Drainage, 53, 119–133.
12. Hong Minh Hoang, Le Anh Tuan, Le Van Dung, Truong Nhu Phuong and Dang Tram Anh. 2016. Evaluating the economic efficiency and water-saving of automatic irrigation model for Shallot crop in Vinh Chau district, Soc Trang province. Journal of Science, Can Tho University, 47a, 1–12. (in Vietnamese)
13. Fraser I., Cordina D. 1999. An application of data envelopment analysis to irrigated dairy farms in Northern Victoria, Australia. Agricultural Systems, 59, 267–282.
14. Ismet Boz, Shamsheer Ul Haq, Cagatay Yildirim, Hatice Turkten and Pomi Shahbaz. 2018. Technical and water use efficiency estimation of adopters and non-adopters of pressurized irrigation systems among hazelnut farmers. African Journal of Agricultural Research, 13(43), 2449–2459.
15. Le Van Chinh. 2012. Return flow and reuse of drainage water in a rice-based irrigation and drainage area in the Red River Basin, Vietnam, PhD. Dissertation.
16. Nguyen Duc Viet, Dao Trong Tu, Nguyen Tung Phong, Ha Hai Duong. 2018. Performance Assessment of irrigation Systems and Water Pollution Issues Raised in the Red River, Vietnam. International Journal of Environmental Protection and Policy, 6(1), 1–8. DOI: 10.11648/j.ijepp.20180601.11
17. Nguyen The Quang, Doan Doan Tuan. 2001. Strategies of hungry eraser and poverty reduction in irrigated agriculture of Vietnam. Cooperation project with IWMI, 2001.
18. Nguyen Trung Dung. 2017. Price of irrigation product, service on basis of cost recovery – comments to application of Irrigation Law. Journal of Water Resources and Environment Engineering, 59, 17–25. (in Vietnamese)
19. Nguyen Tung Phong, Vu Hai Nam. 2019. Modernizations in irrigation systems operation. Science and Technics Publishing House, Ha Noi. (in Vietnamese)
20. Stijn Speelman, Marijke D'Haese, Jeroen Buyse, Lc D'Haese. 2008. A measure for the efficiency of water use and its determinants, a case study of small-scale irrigation systems in North-West Province, South Africa. Agricultural Systems, 98, 31–39.
21. Timothy J. Coelli, D.S. Prasada Rao, Christopher J. O'Donnell and George E. Battese. 2005. An Introduction of Efficiency and Productive Analysis (Second Edition). Springer Science and Business Media, New York. 2005.
22. Ton Nu Hai Au, Nguyen Thi Dieu Linh. 2020. Analyzing agricultural production by Data Envelopment Analysis (DEA), Hue University Publishing House.
23. Wang Xue-yua. 2010. Irrigation Water Use Efficiency of Farmers and Its Determinants: Evidence from a Survey in Northwestern China", Agricultural Sciences in China, 9(9), 1326–1337.