MINISTRY OF EDUCATION AND TRAINING
MINISTRY OF AGRICULTURE AND RURAL DEVELOPMENT
VIETNAM ACADEMY FOR WATER RESOURCES

ĐINH VĂN ĐẠO

Research on impacts of the operational and maintenance cost allocation on management efficiency of small-pumping scale irrigation systems

Major: Water Resources Engineering
Code: 09 58 02 12

Summary of Doctoral Thesis

HA NOI - 2023

The thesis was implemented at:

VIETNAM ACADEMY FOR WATER RESOURSES

Supervisors:

1. Prof. Dr Nguyen Tung Phong
2. Dr. Tran Van Dat

Reviewer #1:

Reviewer #2:

Reviewer #3:

The thesis will be defended in front of the national thesis committee at the Vietnam Academy for Water Resources, at ....time ....day ...... month ....year 2023

The thesis can be read at the libraries:

- National Library of Vietnam
- Library of Vietnam Academy for Water Resources.

INTRODUCTION

1. Neccessary

In Red River Delta (RRD), there were about 3.421 small-pumping scale irrigation systems with capacities under $1000m^3/h$ (irrigation system). They provided irrigation water for all of the agricultural areas and were mainly managed by operational and maintenance (O&M) teams belonging to state-owned irrigation agencies. Their O&M costs were covered by only subsidies from the governmental budget. In fact, this source could not cover all O&M costs, meanwhile resources governance capacities O&M agencies very limited caused lower O&M efficiency than expectation and subjected to works' degradation. To enhance O&M efficiency, O&M agencies need to be provided the solutions and guidance of cost allocation and utilization and state needs to issue the supportive and subsidy distribution policies in more efficient manner. On the other hand, in context of movement of O&M management towards to market mechanism, it requests that the O&M agencies must improve their financial autonomy and water users also have to pay fee. The efficient input cost structures (ICS) were considered as the significant basis to solve the above issues in the better way.

Currently, O&M efficiency assessment has just been based on current methods by using the technical performance indicators without showing reasons and quantity solutions. This research will use input quantity and cost, irrigated areas as data sources and Data Envelopment Analysis (DEA) methods to identify scores of both technical and economic efficiencies, optimal ICSs and to analyze impacts of cost distribution by the ICSs in both technical and economic aspects. These provide the basis for giving out the solutions improving O&M efficiency and system sustainability. Therefore, "**Research on impacts of the operational and maintenance cost allocation on management efficiency of small-pumping scale irrigation system"** implemented will provide many scientific and practical significances for suggesting policy options of subsidy distribution, allocation and use in O&M management of the irrigation systems.

2. Objectives

- To provide the scientific base of Data Envelopment Analysis (DEA) application on assessment of O&M management efficiency of the irrigation systems.

- To determine scores of technical and economic efficiencies, input cost structure (ICS) and impacts of cost allocation according to efficient ICS to enhance O&M management efficiency of the irrigation systems.

3. Object and scope

- The objects are small-pumping scale irrigation systems with the headworks capacity under $1000m^3/h$, managed by O&M teams belonging to provincial irrigation companies in lowland areas of RRD.

- Research scopes that are assessment of technical and economic efficiency in O&M management of the irrigation systems by using O&M input quantity and cost as input factors and irrigated rice areas as output factors (public irrigation service).

- The approaches applied were the concepts of "international cooperation development researchers" and hypothesis of the replicative algorism for multi-purpose optimal mathematics due to being non-homonymous and insufficient data sources.

- The main methods were DEA, a non-parametric frontier efficient program and its input-oriented model according to assumptions of constant returns to scale (CRS) and variable returns to scale (VRS) were applied.

5. The scientific and practical significance

- *Scientific significances*: (1) Calculating technical efficiency scores by input quantity and economic efficiency scores by input costs. Then, determining efficient ICS and using it as a basis for suggesting cost allocation mechanism at the technical and economic aspects in context of irrigation management towards to market orientation; (2) Establishing the scientific evidence for assessing O&M management efficiency of small-pumping scale irrigation systems by using input quantity and cost in DEA. Thus, the research indicated causes and quantitative solutions for adjusting the scale of inputs by both quantity and cost to enhance O&M management efficiency.

- *Practical significance*: Providing practical solutions which O&M management agencies could use for optimal input resources governance and allocation; the state agencies could use for creating suitable policy options and plans of financial subsidy; and water users are possible to receive the irrigation services equality with their payment levels.

6. New contributions

- Found out scores of the technical efficiency, scale efficiency of input quantity at the technical efficiency classes, and allocative efficiency, cost efficiency at the economic efficiency classes. Similarly, findings of the efficient cost units and ICS at technical, optimal technical and economic efficiency classes. The impacts of application of optimal ICS to allocate cost by input factors on improvement of O&M efficiency through criteria of area increased per cost unit and O&M cost decreased per ha.

- The research has successfully applied DEA into O&M management efficiency assessment for small-pumping scale irrigation systems by data sources of O&M input quantity and cost in frame of current management structure and policies.

7. Contents and structures of the thesis

Excluding the introduction and conclusion, the thesis includes three chapters, 31 tables, 20 figures and charts, 4 papers published (one on the international journal in ISI systems), 131 references and annexes.

- Chapter I: Review on Irrigation Management Efficiency,
- Chapter II: Rationale and Methodologies,
- Chapter III: Results and Discussion.

CHAPTER I. REVIEW ON IRRIGATION MANAGEMENT EFFICIENCY

1.1 Status of the pumping irrigation systems in RRD

There are about 9,043 pumping irrigation systems in RRD, in which the small-pumping scale irrigation systems with capacities from 300 to 1000m^3/h were 3.187 systems. They provide irrigation water for all irrigated areas of the region. In total canal length of 82,510km, 23.5% were concreted. The primary canal was concreted 40.6%, secondary canal being 27.2% and on-farm canals being 18.6%. But the systems were subjected to degradation and weren't high O&M efficiency.

Table 1.1 Pumping irrigation systems classed by water flow Q (m^3/h)

Pumping Systems	Total	1.000 to 3.600	Lower 1.000
Total in RRD	9,043	4,582	3,421
Irrigation	6,790	3343	3187
Drainage	6,50	302	36
Irrigation and drainage	1,603	937	198

The O&M management models are state-owned O&M agencies and O&M cost were covered by governmental subsidies with estimation of 2.023 bill. VND/ a year and no change since 2013. O&M human resources were up to 13.562 people, of which 50% of them have just qualified career at primary, short or without training levels. They worked as direct laborers in O&M teams to operate the systems. These are the big challenges when implementing the targets enhancing O&M efficiency of the irrigation systems towards to market orientation.

1.2. Definitions on irrigation and O&M management efficiency

Small-pumping scale irrigation systems: According to the technical dictionary, irrigation and drainage systems is "a system that include deferent structures which are directly connected together on aspects of water exploitation and maintenance in an area" or is a system that is constructed by headwords and water flow and delivery structures. In this research, irrigation systems are defined as a system that includes headworks being small-scale pumps with functions of transferring irrigation water from low to high altitude by canal systems to the farmers' fields.

O&M management efficiency: Irrigation efficiency is a large concept including O&M management efficiency. In fact, depending on specific aspects and utilization scopes, researchers set up different definitions on irrigation efficiencies such as water allocations, O&M performance, cost efficiency… In this research, irrigation performance is considered under concepts of O&M management efficiency, being assessing the process of management, use and distribution of input factors of O&M management units through existing resources distribution and use efficiencies and general indicators being input quantity and cost per irrigated area.

Definition of waste and cost: The waste was indicated by input quantity and cost is the waste which is converted into moneyed value by combining market price and quantity of input factors used for O&M management of irrigation systems. The input quantity and cost were instituted during O&M process such as water resources creation, regulation, and delivery. Results of input quantity and cost use were shown on basis of a water irrigated unit or irrigated area provided …. Comparisons among irrigated areas and input quantity and cost will exhibit the goods' value of irrigation service.

Irrigation water cost structure: The most specific classification which could be used for performing O&M cost of the systems is basis on general principle on identification of water supply management cost, fig. 1.3.

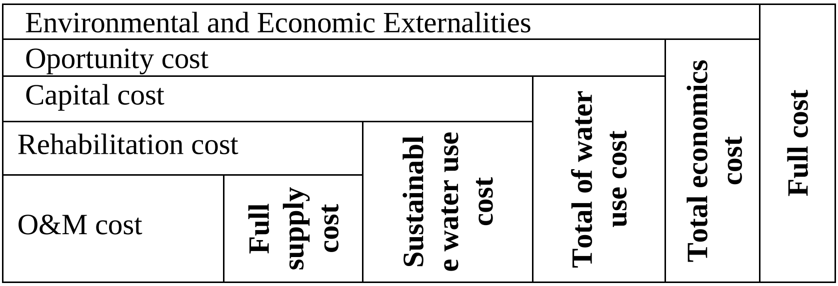


Figure 1.3 Water service supply cost structure

1.3. Overviews of research on irrigation efficiencies

Technical aspects: Research of Ha Luong Thuan (1995) assessed irrigation performance based on water influence on crop yields. Nguyen The Quang et al. (2001), Hong Minh Hoang et al. (2016) reviewed and recommended that irrigation performance assessment should include the economic and social indicators.

Socio-economic aspects: Truong Duc Toan (2015) and Do Van Quang (2016) considered impacts of irrigation fee subsidy policies and feedback of water use in agricultural production. Research of Nguyen Thi My Linh et al. (2017) was also about O&M efficiency of irrigation systems for agricultural production…

Financial aspect: The research of Doan The Loi et al. (2019) indicated average input cost unit (ICU) being 2.3 Mill. VND/ha and classed into 9 groups (wage 738.05 thousand VND/ha; electricity 206.75; materials 21.92; training, scientific research 54.04; depreciation 48.2; recurrent reparation 248.6; major reparation 211.52; overhead cost 80.96); In 2017, Nguyen Trung Dung show that wage rate was the highest, ranged from 36.15 to 52.56%. Nguyen Duc Viet et al. (2018) determined O&M cost efficiency of 33 systems being 1.14 Mill/ha in average, in which labor rate was 41.45%, other O&M and reparation cost were 21.89%.

Before Law on Irrigation approved, Hector et al. (2004) researched financial changes of irrigation companies in Vietnam and shown that labor cost occupied at the highest rate in ICS being 54.09%. Tran Chi Trung (2005) also showed that estimation of labor cost was the highest in ICS being 32%, maintenance 22%, 19% for overhead cost. Truong Duc Toan (2015) indicated that water users willing to pay the ICS including O&M cost (50.0%); capital charge 39.1%, opportunity cost 1.7%, economic and environmental externality cost 1.8% and 7.2% respectively. The electricity factor was also in the highest input cost groups.

The research of Palanisami (1997) in Tanzania about cost efficiency and structure in O&M management of small pumping irrigation station (2ha), in which total cost of labor, petrol, energy and others was 635,98 USD/ha/season, their rates were 33.36, 3.3, 38.75 and 24.59%, respectively for petrol pumps; was 504 USD/ha/season, their rate were 30.19, 2.97, 48.45 and 18.39% respectively for electric pumps. Thus, labor cost was estimated at the highest cost groups. Besides, there were some other research in Greece by Briscoe (1997) and ICS was 38.79; 45.71 and 15.49% for financial, resources and environmental cost groups, respectively.

DEA application: Rodríguez-Díaz et al. (2004) assessed O&M management efficiency of irrigation systems of 34/156 districts in Andalusia; Sanjay et al. (2012) also did same research for WUAs in India. Giannoccaro et al. (2010) did it based on theories of water price assumptions in Puglia, Italia. Besides, there were other research using DEA to assess irrgation water use efficiency in agricultural production models such as Noelina et al. (2010) in Andalusia, Spain; Stijn et al. (2008) in southern-west areas of South-Africa ….

Irrigation efficiency according to DEA: Practically, methods of production efficiency assessment almost set up on basis of calculating rate among inputs and outputs or contrary, such as principles using indicators in KPIs; frontier and on frontier efficiencies. In 1957, Farrel was the first one to develop this approach, divided into non-parametric and parametric methods. DEA was a typical one (non-parametric mathematics, management, and directive science…) and Stochastic frontier analysis-SFA was parametric method, econometric).

DEA was considered as one of mathematic tools used to O&M management of irrigation and drainage systems basing on production frontier technique and target efficient measures which were more particular than COLS and SFA by Hector et al. (1999 and 2004). *DEA advantages* in irrigation efficiency assessment are that (1) it could analyze concurrently multi-input and output factors and indicate efficient levels self among factors analyzed, (2) it doesn't request to set standards comparing with efficiency measured; (3) it doesn't request in advance productive functions relating to input and output factors.

1.8 Conclusion of Chapter I

Through reviewing existing researches, the thesis indicated practical and scientific gaps and hypothesis which will be solved as following: (1) Lack of researches on O&M management efficiency of irrigation systems basing on input quantity and cost of input factors to show concurrently scores of technical and economic efficiency, and then being foundation to calculate input quantity and finding out the IUC and ICS; (2) There have been not yet research which applied DEA for O&M performance assessment of the irrigation systems in Vietnam. Specially, used the input orientation model according to CRS and VRS assumptions to consider technical and economic efficiencies; and (3) There have been not yet research which identifies the basis for suggesting solutions regulating cost amount of each input factors. These are used for setting up plans of cost resource distribution for O&M agencies and subsidy policy of government.

To solve the above issues, the thesis used DEA to consider O&M performance of irrigation systems based on input costs and expenses through technical scores (expensive amount) and economic scores (if added input price and technical set: skill, knowledge, organizational modes). And then found out and applied optimal efficient cost structures to assess impacts of cost distribution by input factors on O&M performance of small-pumping scale irrigation systems.

CHAPTER II. RATIONAL AND METHODOLOGIES

2.1 Study objects

Selective criteria: To ensure the representative and significant research findings and number of objects satisfied with sampling conditions in DEA, the study objects will be small-pumping scale irrigation systems managed by O&M teams according to 8 following criteria: (1) Following sampling principle of DEA; (2) Pumping headword capacity being under 1000m^3/h; (3) Canal system and service areas being mainly for rice cultivation; (4) Pressure head of pump, head works being around 2,4m; (5) There are not additional water sources irrigated; (6) Applying contracting and transferring O&M responsibility mechanism by input factors of IMC; (7) O&M team is independence, relative self-control in decision makings about organization and directly implement O&M activities, distribution, utilization of input factors by cost and quantity; (8) O&M teams is under branches of the IMCs.

Research objects: The irrigation systems are in low-land areas of RRD, use water creative sources of 03 large irrigation systems being Đa Độ; Ba Đồng; and Hòn Ngọc – Giá river reservoirs representatively, managed by 3 IMCs being Dương Kinh, Đa Độ; Đồng Ngừ, Vĩnh Bảo; and Quang Thanh, Thủy Nguyên in Hải Phòng city. The water inlet and outlet of these systems are controlled to ensure the similar of technical factors such as water sources, height of pressure head, canal, on field water management and sustainability of inlet water of the irrigation systems.

DEA sampling principles: The authors of DEA such as Banker et al. (1989) defined number of objects being *"minimization or triple of total input and output variables in the model*": **K>= 3 x (N + M)**; K: number of O&M teams; N: input variables; M: output variables.

Data: Primary data that is amount of O&M cost and expenses of irrigation systems in O&M teams is collected by semi-interview through the assessment forms in three years (2018 to 2020). Secondary data is about the status of O&M management of all irrigation systems in region, provinces, and IMCs.

2.2. DEA methodologies

The applied model of DEA was input orientation model with two assumptions of Constant Returns to Scale (CRS) and Variable Returns to Scale about the volume of inputs and their cost value.

Technical efficiency:

a) Model of technical Efficiency (TE):

CRS $TE_j = \min_{\theta,\lambda j} \theta$, subject to:

$\theta X_j \geq \sum_{i=1}^{m} \lambda j\, X_{ij}$ (i = 1,2,3, …, m; (2.1)

$\sum_{j=1}^{k} \lambda r\, Y_{rj} \geq Y_r$ (r = 1, 2, 3, …, n; (2.2)

$\lambda_j \geq 0$ với j = 1, 2, 3, …, k; (2.3)

VRS Additional constraints: $\sum_{i=1}^{K} \lambda j = 1$; (2.4)

In which: $TE_j = \theta$ is the technical efficiency indicator of j^{th} O&M team, matching with the constraint of efficiency indicator θ, ranging from 0 to 1 ($0 < TE \leq 1$), not higher than 1 and being optimal when θ is equal to 1 (θ<=1). Measurement of TE indicators is all volume of input which could be reduced a volume equal to (1- θ)*100 but output amount are still maintained, being rice area irrigated. O&M teams that lie on the frontier were considered as achieving technical efficiency θ=1. The linear programming was processed in k times, each time for an O&M team in the observed samples. Therefore, the value of θ calculated is for each O&M team. λ is constant vector. k is the number of O&M teams.

b) Scale efficiency (SE): Being ratio between TE according to Constant Returns to Scale (TE_{CRS}) and TE according to Variable Returns to Scale (TE_{VRS}). $SE = TE_{CRS} / TE_{VRS}$ (2.5).

SE indicator also ranges from 0 to 1. An O&M team is efficient scale when its score by input volume is equal to 1.

Economic Efficiency: When input price and technology (T) are added to the model, O&M cost of j[th] O&M team will be $w^T{}_j x_j$ and cost efficiency (CE) of j[th] O&M team is ratio between minimum cost $w^T{}_j x^*{}_j$ and observed cost $w^T{}_j x_j$ of self O&M team as per equation:

$$CE = \frac{w^T{}_j x^*{}_j}{w^T{}_j x_j} \quad (2.6)$$

In which: $w^T{}_j x^*{}_j$ is minimum cost and $w^T{}_j x_j$ was observed cost of j[th] O&M team. T is a technological set including capacity and mechanism of input use, skill, knowledge, and distribution organization).

Allocative Efficiency: AE=CE/TE (2.7)

In which: CE is cost efficiency; TE is technical efficiency; AE scores range from 0 to 1. AE indicator is equal to 1 meaning that O&M team got efficiency.

Cost Efficiency model:

CRS $Min_{\lambda,xj*}\, w^T{}_j X^*{}_j$; subject to:

$Xj^* - \sum_{j=1}^{k} \lambda\, x_{ij} \geq 0$ (i = 1,2,3, …, m; (2.8)

$-\, Yj + \sum_{j=1}^{k} \lambda r\, Y_{rj} \geq 0$, r = 1, 2, 3, …, n; (2.9)

$\lambda_j \geq 0$, với j = 1, 2, 3, …, k; (2.10)

VRS Additional constraints: $\sum_{j=1}^{k} \lambda j = 1$; (2.11)

In which: w_i is price vector of input factors of j[th] O&M team and x_j^* was vector of input volume of j[th] O&M team at time of cost minimization. x_j^* was calculated by linear programming.

+ The study used DEA method to calculate efficiency scores for 48 O&M teams which manage 48 irrigation systems (k = 48); number of output factors (y) (n=1) is annual rice irrigation areas (ha) (n=1); and input factors (x) (m=7), in which: x_1 is indirect labor; x_2 is direct labor; x_3 is materials; x_4 is electric energy for irrigation; x_5 is maintenance cost; x_6 overhead cost; x_7 is capital cost (depreciation).

+ θ is efficient indicator of each O&M team and value of TEs,

+ λ is constant vector of each O&M team.

CHAPTER III. RESULTS AND DISCUSSION

3.1 Status of selected small-pumping scale irrigation systems.

48 irrigation systems are similar in terms of the height of water pressure and real capacity of the pumps. Average flow, the highest level is about 1,113.3m^3/h, the lowest is 763.6m^3/h and average of designed areas is highest being 83.2ha, the lowest being 32.2ha/station (Table 3.1). The length of canal is about 1,03km on average.

Table 3.1 Average of technical indicators of pumping station

No	O&M team groups	Amount	Flow (m^3/h)	Capacity (Kw/h)	Pressure head (m)	Designed areas (ha)
1	DK-ĐĐ	9	1,113.3	24.9	2.4	83.2
2	DN-VB	27	879.3	19.9	2.5	32.2
3	QT-TN	12	763.6	17.8	2.3	50.2
	Average	**48**	**896.7**	**20.3**	**2.4**	**45.9**

They were managed by O&M teams under IMCs' branches according to the internal agreement mechanism of practical input and outputs a year such as practical irrigated areas are 87.4ha/system, labor is about 1-2 labor/system. Fund is subsidized by the government. However, O&M management includes technical infrastructures and economic factors. To enhance O&M efficiency of the systems, it needs to have comprehensive solutions.

3.2 General assessment of efficiency and cost allocation according to real input cost structure

In ICS, the highest value of capital cost was 39.13% (1.03 mill. VND/ha), labor was 32.5% (0.89 mill. VND); maintenance 19.63% (0.586 VND). The value of other inputs was at a low level. Cost allocation by real ICS show that indirect labor volume was 0.42 day/ha, lower than general level of IMCs being 0.14 man-day/ha. Real IUC is 2.639 mill. VND/ha, higher than those of the region being 2.3 mill. VND (Doan The Loi et al. (2019)); higher than subsidy level of government 1.646 mill. VND/ha, equal to 62%. These results only indicate descriptive measures, very few information about reasons, directives to enhance O&M management efficiency (Table 3.5).

Table 3.5 Average of real input unit cost and input cost structure by area of irrigation systems

No	Criteria	Average	Rate (%)
I	**Input volume per area**		
1	Indirect labor (man day/ha)	0.42	
2	Direct labor (day/ha)	2.60	
3	Electric energy for irrigation (Kw/ha)	83.38	
II	**Cost (1000 VND/ha)**		
1	Indirect labor	161.73	6.13
2	Direct labor	683.91	25.92
3	Electric energy for irrigation	152.13	5.76
4	Materials	7.16	0.27
5	Recurrent maintenance	518.06	19.63
6	Overhead cost	83.44	3.16
7	Capital cost (depreciation)	1,032.61	39.13
	Real input unit cost (IUC)	**2,639.04**	**100.00**

3.3 TE assessment of O&M management of irrigation systems by DEA

DEA indicates TE indicators and efficient volume of input unit at TE class, and then suggests the general reductive rate on volume of input unit for each O&M team. And, at EIT class, DEA calculates the reductive rate of inefficient O&M team to consider optimal technical IUC.

3.3.1 TE in O&M management of irrigation systems according to CRS

Technical efficient class: Average TE_{CRS} scores was 0.924, ranges from 0.783 to 1. Compared to the best O&M team, the inefficient teams were wastefully input by volume, they needed to cut down the 7.6% total of general input volume in average, and the highest levels were 21.7%.

There were more than 65% of O&M teams achieving at TE_{CRS}= 0.924 and cutting down maximum inputs at 7.6%; the remaining 35% of O&M teams need to reduce from 7.6% to 21.7%. 27.1% (13/48) of O&M teams have score equal to 1 (TE_{CRS} = 1) therefore they were efficiently using input amount and did not need to cut down input volume. Average IUC according to CRS assumption being 2.438 mill. VND/ha, higher than average cost calculated by the previous research and subsidy level of the government (Table 3.7).

Table 3.7. Average TE scores according to CRS assumption

O&M team groups	Average	Min	Max	Variance	Upper bound	Under bound
All	0.924	0.783	1.0	0.062	0.942	0.907
ĐN-VB	0.918	0.797	1.0	0.059	0.940	0.896
QT-TN	0.937	0.854	1.0	0.058	0.970	0.905
DK-ĐĐ	0.927	0.783	1.0	0.079	0.956	0.898

Efficient Input Target class EIT_{CRS}: It showed reduction levels of each input factor for 48 irrigation systems: Capital cost being cut down was lowest at 7.96%; the highest one being electric energy for irrigation was 20.87%. The reduction suggested was caused by several reasons such as degradation of infrastructure, sustainability of voltage which influence to electric consumption…. With indirect and direct labors, the reduction rate were 9.05 and 17.11% respectively; and equal to average of labor norm being 2.54 man-day/ha and it was estimated by 80% comparing with geneal labor norm. Therefore, the O&M team that have high inefficient rates need to consider the process of input use such as improvement of maintenance procedure of the pumping station or making sure the sustainability of the electric voltage during the operation of pump… to save the electric energy.

Table 3.8 Average of percentage of input volume being cut down to get the EIT according to CRS assumption (%)

O&M team groups	Indirect labor	Direct labor	Materi als	Electric energy	Recurrent maintenanc e	Over head cost	Capital cost
All	9.05	17.11	15.87	20.87	14.00	16.56	7.96
ĐN-VB	10.78	23.41	20.14	26.58	12.44	22.25	8.25
QT-TN	6.43	9.30	12.68	16.36	10.83	9.91	7.25
DK-ĐĐ	7.33	8.59	7.33	9.75	22.91	8.38	8.02

3.3.2 TE in O&M management of irrigation systems according to VRS

TE class: Meaning of TE_{VRS} scores indicate efficient rate more flexible than that of TE_{CRS} when their input volume constraint could be changed. Table 3.10, TE_{VRS} score was 0.946, it means that the O&M team needs to cut down generally 5.4% of input volume, lower than reduction rate requested in TE_{CRS}. The IUC being 2.496 mill. VND/ha, it was higher than subsidy of the central government by about 51%. This IUC showed difficulties in practice when doing O&M of the irrigation systems if there are no other funds covering the shortage.

Table 3.10 TE scores according to VRS assumption

O&M team groups	Mean	Min	Max	Variance	Upper bound	Under bound
All	0.946	0.793	1.0	0.056	0.962	0.930
ĐN-VB	0.948	0.828	1.0	0.055	0.969	0.927
QT-TN	0.946	0.868	1.0	0.052	0.976	0.917
DK-ĐĐ	0.940	0.793	1.0	0.072	0.966	0.914

43.75% of the systems got TE_{VRS} score by 1, the optimal rate without request of reduction. At average TE_{VRS} score, there were 77.1% of O&M team achieving this score, max reduction rate was 5.4%. Thus, the flexibility in input allocation could enhance O&M efficiency by referring to the good lessons on organizational modes from the efficient teams as the benchmarking ones.

At efficient input target EIT_{VRS}: The highest and lowest rate of input reduction suggested were electric energy and capital cost (14.30% and 5.85%). Direct labor needs to be cut down being 9.52% in general. This could be applied because it only adjusted input volume according to the mode and practical lessons of efficient O&M team as benchmarking ones.

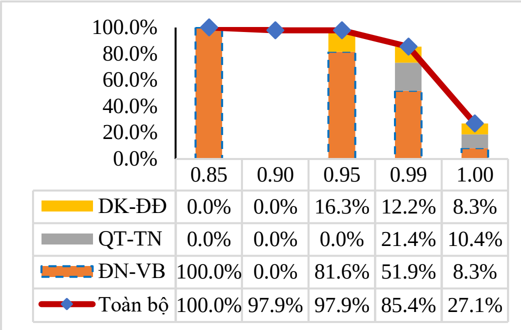
Considering more detailed constitution of the input factors, suitable labor arrangement with high skill and knowledge (3 of 4/7 level) and together with tight cooperation with indirect labor also contribute to productively enhancing input use in efficient irrigation systems.

Table 3.11 Average of percentage of input volume being cut down to get the EIT according to CRS assumption VRS (%)

O&M team groups	Indirect labor	Direct labor	Mate-rials	Electric energy	Recurrent maintenance	Over head cost	Capital cost
All	6.06	9.52	9.45	14.30	11.40	9.40	5.85
ĐN-VB	6.32	11.16	9.97	13.41	6.00	10.74	5.20
QT-TN	5.52	6.71	10.63	13.64	12.43	7.45	6.45
DK-ĐĐ	5.99	8.37	6.33	17.85	26.22	7.97	6.98

3.3.3. Assessment of scale efficiency of input volume

The difference between scores of TE_{CRS} and TE_{VRS}, is 0.924 and 0.946, shows that there was still SE inefficiency of input volume. Average scores of SE=0.977. Fig. 3.5, 27.1% (13/48) of the systems in optimal areas of input scale. 35/48 systems lie in areas which need to consider changing the scale of input volume, technology to improve efficiency level. In which 58.3% of the systems (28 HTT) are areas of increasing returns to scale if changing scale of input volume (IRS); 14.6% of the system were in areas where the rate of efficiency change will be not same as rate of input volume being changed. These system groups should consider allocation and use of input instead of changing input amount to get efficiency.



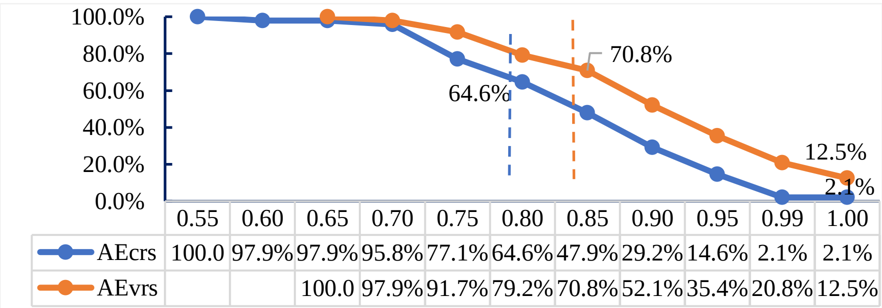
	0.85	0.90	0.95	0.99	1.00
DK-ĐĐ	0.0%	0.0%	16.3%	12.2%	8.3%
QT-TN	0.0%	0.0%	0.0%	21.4%	10.4%
ĐN-VB	100.0%	0.0%	81.6%	51.9%	8.3%
Toàn bộ	100.0%	97.9%	97.9%	85.4%	27.1%

Fig. 3.5 Exceeded percentage of O&M team according to SE scores.

3.4 Economic assessment in O&M of irrigation systems by DEA

3.4.1 Allocative efficiency according to CRS and VRS assumption

There were 64% of systems getting average scores of AE_{CRS} by 0.789 and 70,8% of systems by AE_{VRS}=0.856. It means that organization of input distribution of the O&M team needs more improvement to achieve optimal efficiency. Max reduction rate of cost was 25.4 and 14.4% respectively. O&M team manages Quảng Cư irrigation system got optimal AE due to being provided 2 labors with high skill, rich experience, and high attention in the irrigation sector, therefore the inputs such as labor time, materials were all taken advantages and operated the pump in time of energy and water irrigation saved.



	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	0.99	1.00
AEcrs	100.0	97.9%	97.9%	95.8%	77.1%	64.6%	47.9%	29.2%	14.6%	2.1%	2.1%
AEvrs			100.0	97.9%	91.7%	79.2%	70.8%	52.1%	35.4%	20.8%	12.5%

Fig. 3.7 Exceed percentage of O&M teams according to increasing scores of AE indicators by CRS and VRS assumptions.

3.4.2 Cost efficiency

To achieve CE, the O&M team must get both optimal efficient scores of TE and AE.

3.4.2.1 Cost efficiency according to CRS and VRS assumptions: Average scores of CE_{CRS} was 0.731, compared with O&M team managing Quảng Cư systems getting CE_{CRS} by 1, the inefficient team must cut down average cost of 26.9%. The average score of CE_{VRS} was higher, achieved at 0.812, inefficient teams should cut down 19% in general of current input cost (Table 3.15).

3.4.2.1 Distribution of the irrigation system according to exceed CE scores: 77% of the O&M teams achieved higher average scores CE_{CRS}=0.731 and the highest reduction rate being 26.9%. Up to 97.9% of O&M team need cut down general input cost and there was an O&M team achieving optimal efficiency and without input reduction. With CE_{VRS}, there was 14.3% of O&M team achieving optimal CE (7 systems).

Table 3.15 Average scores of optimal CE

Assumptions	**Mean**	**Min**	**Max**	**Variance**	**Upper bound**	**Under bound**
CRS	0.731	0.531	1.00	0.115	0.764	0.699
VRS	0.812	0.592	1.00	0.123	0.847	0.777

3.5 Impacts of cost allocation on O&M management of irrigation systems

Comparison among results calculated by DEA and by normal method indicated the impact of cost allocation and suggestion of solutions to enhance irrigation efficiency according to technical and economic aspects.

3.5.1 Input norm by area unit

According to CRS, direct labor should reduce from 2.6 to 2.41 day/ha (7.30%) to achieve TE, 15% to achieve EIT; and 34.23% to achieve CE. With VRS, electric energy needs to reduce 5,88% to achieve TE, 19.62% to achieve EIT…. Reduction rate of inputs such as direct labor at their efficient class was 5.5%, 10.12% and 22.32% respectively. With reduction rate according to TE, the O&M teams only change active solutions such as training and capacity building on pumping irrigation and application of new technologies… or enhancing the supports of indirect labor teams.

Table 3.16 Input norms per an irrigated area

Efficiency class	CRS			VRS		
	Indirect labor (day/ha)	**Direct labor** (day/ha)	**Electric Energy** (Kw/ha)	**Indirect labor** (day/ha)	**Direct labor** (day/ha)	**Electric Energy** (Kw/ha)
Reality	0.43	2.60	83.38	0.43	2.60	83.38
TE	0.41	2.41	77.21	0.41	2.46	78.47
EIT	0.40	2.21	63.85	0.41	2.34	67.02
CE	0.27	1.71	20.32	0.35	2.02	35.01

3.5.2 Input unit cost by input factors according to CRS

Almost of the IUCs in TE classes were lower than that of real IUCs. IUCs in EIT class were higher than that of TE and lower than that of CE. Labor cost in TE class was 637.46 thousand VND/ha and in EIT class being 601.05 thousand VND/ha and in CE class being 471.00 thousand VND/ha.

Table 3.17 IUC in efficient classes according to CRS (1,000 VND/ha)

Inputs	Reality	TE	EIT	CE
Indirect labor	161.73	151.78	149.51	107.30
Direct labor	683.91	637.46	601.05	471.56
Material	7.16	6.66	5.87	15.11
Electric Energy	152.13	140.90	116.64	37.17
Recurrent maintenance	518.06	480.92	434.83	300.39
Overhead cost	83.44	77.90	73.86	57.01
Capital cost	1032.61	966.21	959.70	993.05
IUC	**2639.04**	**2461.82**	**2341.45**	**1981.59**

3.5.3 Input unit cost according to VRS

Direct labor unit cost in TE class was 647.82 thousand VND/ha, in EIT was 625.16 thousand VND/ha and in CE was 530.34 thousand VND/ha (Table 3.18). To ensure sustainable structures and equal irrigation services provision, the government could choose the supportive solutions by prior inputs and irrigation water users must pay the shortage ones, at least equal to the difference compared to optimal IUC. Concurrently, they could consider subsidizing by inputs which belonged to roles and responsibilities of owners when provided public goods such as maintenance cost for irrigation infrastructure…. This solution could encourage O&M team to improve the O&M activities toward to optimization when they had to self-collect fee such as labor cost and overhead cost…

Table 3.18 IUC in efficient classes according to VRS (1000 VND/ha)

Inputs	Reality	TE	EIT	CE
Indirect labor	161.73	154.04	152.75	131.92
Direct labor	683.91	647.82	625.16	530.34
Material	7.16	6.76	6.18	10.48
Electric Energy	152.13	143.19	122.29	64.04
Recurrent maintenance	518.06	489.24	438.12	354.76
Overhead cost	83.44	79.16	76.42	65.33
Capital cost	1032.61	980.61	972.95	1009.76
IUC	**2639.04**	**2500.80**	**2393.87**	**2166.63**

3.5.4 General IUC per area

3.5.4.1 General IUC according to CRS and VRS: By CRS, average efficient IUCs were quite different from the real IUCs. The real IUC was 2.639 mill VND/ha, next being IUC in TE class 2.462 mill VND/ha, in EIT class being 2.341 mill VND/ha and the lowest in CE being 1.982 mill.

VND/ha. Similarly, by *VRS assumption:* efficient IUCs were 2.501; 2.394 and 2.167 mill VND/ha.

3.5.4.1 General cost allocation according to CRS and VRS: By CRS, there were 13 O&M teams achieving TE_{CRS}=1 and IUCs at TE classes were the same. The scores of TE_{CRS} were lower and lower, the differentiation with real IUC was larger and larger, the largest differences were 36.9%, 17.3% and 6.86% according to TE, EIT and CE class respectively. By VRS, there were 21 irrigation systems achieving TE_{VRS}=1, but there were only 7 O&M teams that achieved both CE_{VRS} and TE_{VRS}, and their all IUCs were the same and same as real IUCs. These O&M teams achieved both TE and CE in context of current input amount, price, technology, and management mode application.

3.5.5 Optimal input cost structure calculated by DEA results.

Those of ICS in efficient classes, rate of capital cost always was the highest occupy, next being labor, recurrent maintenance cost. The lowest one was the rate of materials. The value of efficient ICSs was different from those of previous research results which were calculated by normal methods. The government could select these ICS to conduct supportive mechanism in O&M management by fixed input factors which will enhance proactiveness of O&M management agencies and irrigation water users must participate in payment of irrigation fee to enhance their water saving use attitude.

Table 3.20; 3.21 and 3.23: ICSs in efficient classes (%)

Efficient classes	Indirect labor	Direct labor	Mate-rials	Electric energy	Recurrent maintenance	Over head cost	Capital cost
Reality	6.13	25.92	0.27	5.76	19.63	3.16	39.13
TE class							
TE-CRS	6.17	25.89	0.27	5.72	19.53	3.16	39.25
TE-VRS	6.16	25.90	0.27	5.73	19.56	3.17	39.21
EIT class							
EIT-CRS	6.39	25.67	0.25	4.98	18.57	3.15	40.99
EIT-VRS	6.38	26.11	0.26	5.11	18.30	3.19	40.64
CE class							
CE-CRS	5.41	23.80	0.76	1.88	15.16	2.88	50.11
CE-VRS	6.09	24.48	0.48	2.96	16.37	3.02	46.61

3.5.6 Impacts of cost allocation according to optimal ICSs

3.5.6.1 Impacts on O&M IUC reduction of irrigation systems

According to CRS, Table 3.25 indicated impact rates on O&M management when O&M team applied optimal ICSs by CE classes to allocate input cost. IUC per ha reduced 24.91% in average; applying ICSs by EIT class, IUC reduced about 11.28%; and by TE class being 6.72%. Similarly, the maximum reduction rates were 46.86%, 37.46% and 21.65% for efficient classes respectively. According to VRS, by applying optimal ICSs, reduction rate could be lower, especially applying ICSs by CE classes, IUCs reduced generally 17.90% in average. By applying optimal ICSs by IET classes, reduction rate was 9.29% and at TE classes, IUC reduced 5.24%. The reduction rates were compared with real IUCs which are applied by O&M teams. Similarly, maximum reduction rates that O&M team could achieve by efficient levels calculated at efficient classes being 40,75; 30,42% và 20,69% respectively.

Table 3.25 Impacts of IUC reduction when allocating cost by ICSs at efficient classes (%)

Reduction rate	CRS			VRS		
	CE	EIT	TE	CE	EIT	TE
Mean	24.91	11.28	6.72	17.90	9.29	5.24
Max	46.86	37.46	21.65	40.75	30.42	20.69
Min	-	-	-	-	-	-

3.5.6.2 Impacts of irrigation area increased in O&M management.

VRS assumption: The real irrigation efficiency of irrigation systems was 0.38 ha/a mill. VND. Assessment of results of cost allocation when applying optimal ICSs at CE classes and used them to compare with results of real ICSs, the results was 0,50 ha/mill. VND, increasing 31.57%. At EIT classes, irrigation area rate was 0.43 ha/mill VND, increased 13.15%, at CE classes, it was 0.41 ha/mill VND, average increasing 7.89%, ranging from 1.4 to 20.28%.

VRS assumption: The increasing impact rate was lower than that of at CRS assumption. At CE classes, irrigation area rate achieved 0.42 ha/mill. VND, increasing impact 21.80% compared to real efficiency. At EIT classes, achievement was 0.40 ha/mill VND, increasing 10.24%, at TE classes being 0.43 ha/mill VND, average increasing 5.53% and maximum increasing 8.99%.

O&M teams easily catch-up objective plans in TE classes due to increasing rate was lower than other classes and fewer depending on constraints. Increasing objectives at EIT and CE classes were theory, unreality and only to being applied to make the long-term plans and to assess strategic efficiency. These showed selection of fixed or variable input rates in optimal ICSs to use for setting up supportive and contracting policies in O&M management through economic agreement with O&M state and non-state agencies.

Table 3.26 and 3.27 Impacts of irrigation area increasing when allocating cost by ICSs at efficient classes (%)

Criteria	**Real efficiency** (ha/mill VND)	**CE class**		**EIT class**		**TE class**	
		Area (ha/mill VND)	**Inc.sing rate** (%)	**Area** (ha/mill VND)	**Inc.sing rate** (%)	**Area** (ha/mill VND)	**Inc.sing rate** (%)
According to CRS							
Mean	0.38	0.50	31.57	0.43	13.15	0.41	7.89
Min	0.26	0.41	-	0.31	-	0.31	20.28
Max	0.50	0.60	88.17	0.51	59.90	0.50	1.40
According to VRS							
Mean	0.38	0.46	21.80	0.42	10.24	0.40	5.53
Min	0.26	0.28	-	0.28	-	0.28	8.99
Max	0.50	0.57	68.79	0.50	43.72	0.50	-

3.5.5. Solutions applying ICSs to enhance O&M efficiency.

For state management agencies: Selecting optimal ICSs to prior support by cost rate of inputs according to roles and responsibilities of state owner with the infrastructures in context of existing funding resources. For example, to support priorly capital cost (depreciation), maintenance, materials, electric energy for irrigation…. respectively.

For O&M management agencies: Based on optimal ICSs to set up solutions, governance mechanism, contracting by input volume and cost during O&M activities to improve organizational plans, approaching input cost minimization. Especially, by applying cost use contract mechanism by input factors for O&M teams, the O&M teams proactively regulate, control, and arrange time and contracting resources as well as take advantage of their experience and skill; apply modern technologies to be the most effective.

CONCLUSION

1. Conclusion:

The thesis's achievements:

(1) Having synthesized, analyzed, and identified the necessaries and new approaches in assessing O&M management efficiency of irrigation according to service management and market orientation.

(2) Having analyzed and developed scientific base for applying DEA in O&M efficiency assessment of irrigation systems.

(3) Having indicated average efficient indicators such as TE_{CRS} =0.924; TE_{VRS} =0.946; SE = 0.977; AE_{CRS} = 0.79 and AE_{VRS} = 0.856; CE_{CRS} =0.731 and CE_{VRS} = 0.812.

(4) Having indicated general IUCs of each system and their IUCs of each input factor, and then optimal ICSs at CE, EIT and TE classes.

(5) Having identified impacting consequence of areas increased per cost unit and cost decreased per ha when applying optimal ICSs to allocate and use cost resources to improve O&M efficiency of irrigation systems.

(6) Having indicated efficient rate when applying optimal ICSs to allocate and use cost resources.

2 Limitation and directives for further research

Expanding research scopes such as increase number of samples, applying in other irrigation structures by both scale and types; doing research by concepts of "development researchers"; DEA could not indicate the regression between IUC change and efficient rate.

LIST OF PAPERS PUBLISHED

No	Name of papers	Types
1	**Dao. Dinh Van,** Phong. Nguyen Tung, Dat. Tran Van, Pierre Mukheibir, Au. Ton Nu Hai, 2022, "Input use efficiency in operational and maintenance management of small-pumping scale irrigation systems in Red River Delta, Vietnam", *Journal of Ecological Engineering*, ISSN 2299-8993, Vol. 23: 208-2016. http://www.jeeng.net/Input-Use-Efficiency-in-Operational-and-Maintenance-Management-of-Small-Pumping-Scale,147321,0,2.html.	ISI, Q3
2	**Đinh Văn Đạo,** Nguyễn Tùng Phong, Trần Văn Đạt, Tôn Nữ Hai Âu, 2022, "Optimal cost efficiency in operational and maintenance of small - pumping irrigation systems in red river delta", *Science and Technology Journal of Agriculture and Rural Development*, ISSN: 1859-4581, No. 3+4/2022, Pp. 126-134.	Journals to qualify Professor of irrigation and drainage 2022.
3	**Đinh Văn Đạo**, Nguyễn Tùng Phong, Trần Văn Đạt, Nguyễn Quang Phi, 2022, "Assessment of operational and maintenance cost efficiency and structure for small-pumping scale irrigation systems in Red River Delta", *Journal of water resources and Environmental Engineering*, Thuyloi University, ISBN: 1859-3941, No 78, March - 2022, Pp. 62-72.	Journals to qualify Professor of irrigation and drainage 2022.
4	**Đinh Văn Đạo**, Nguyễn Tùng Phong, Trần Văn Đạt, 2022, "Scientific review for DEA application in O&M management efficiency assessment of Small-pumping scale irrigation systems", *Journal of Water Resources Science and Technology*, Vietnam Academy for Water Resources, ISBN: 1859-4255, no 71, April – 2022, Pp. 2-12.	Journals to qualify Professor of irrigation and drainage 2022.