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THE IMPACT OF POLICY INTERVENTIONS ON WUA EFFICIENCY IN BUNDELKHAND: A DEA EVALUATION

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SUMMARY

Water efficiency in agriculture is a crucial measure of how effectively farmers use their most vital resource. In practical terms, it reveals how much applied water actually nourishes crops versus being lost to evaporation or runoff. In the Bundelkhand region of Uttar Pradesh, India, where water is incredibly scarce, making every drop count is crucial. Farmers here struggle to grow enough crops with the little water they have. To tackle this problem, researchers used a method called Data Envelopment Analysis (DEA) to evaluate how well Water User Associations along the Rohini Canal System were managing irrigation, looking at different parts of the smaller canals. DEA, a mathematical tool that doesn't rely on pre-set assumptions, compares the efficiency of different groups by looking at what they put in (like money spent) and what they get out (like the number of people helped, the area of land irrigated, and the number of crops produced). By comparing each group's actual performance to what's theoretically possible, DEA pinpoints where they can improve and sets standards for the best way to operate. The findings of the study done in this area revealed considerable. These results really highlight how important it is that we focus on improving how we manage our water resources and boost farm output overall. We need to do this to tackle these inequalities head-on. Plus, pinpointing which Water User Associations (WUAs) are doing a great job at using water efficiently gives us incredibly useful information. These successful WUAs can serve as role models, showing others how to adopt better irrigation methods. This way, we can all work together towards more sustainable farming in the area.

Key words: *benchmarking, data envelopment analysis, efficiency, operations management, participatory approach, water users associations.*

INTRODUCTION

Irrigation management has undergone a major change, moving away from top-down control to a system where users are in charge. This change is meant to help increase incomes in rural areas, ensure more balanced development, and lower poverty rates. Participatory Irrigation Management, or PIM, popped up because the old ways of doing things, run by the government, just weren't cutting it. These old systems were particularly bad at keeping things in good shape and sharing water fairly [8], [30], [37]. Big international players like the World Bank and USAID started pushing for new policies that gave the people who actually use the water more of a voice [24], [39]. They did this mostly by creating Water Users' Associations, or WUAs [4], [27].

Research on how well these WUAs is actually working has been kind of all over the place [2]. Some studies show that they're pretty great at making water distribution more efficient, boosting farm yields, and making economic sense [11], [22], [18]. But other research points out the troubles WUAs have in getting organized and working well together [12], [29].

The whole idea of using WUAs in policy comes from ideas about collective action [7]. Back in proposed the idea that the effectiveness of these systems hinges on the extent to which people are engaged in their design and upkeep [36]. Real-world cases in China, Nepal, and India demonstrate that successful Water User Associations (WUAs) are about more than just their structure; they're also shaped by the local power dynamics and the particular setting they function within, as highlighted [10], [22], [26]. To ensure WUAs operate effectively in the long run, they need transparency, capable leadership, and ongoing community engagement [9], [15], [19]. The research takes a comprehensive look at Effectiveness challenges in the Rohini Irrigation Scheme employing a broad benchmarking approach [31], [35], [38]. it combines benchmarking with information enclosure psychoanalysis (DEA) to raise the practical Productivity of WUAs [25], [13], [41]. DEA, a non-parametric linear programming method, allows for the simultaneous evaluation of various inputs and outputs without requiring pre-established production functions or benchmarks [6], [20], [34]. Despite DEA's potential, it's not widely used in irrigation management [22], [28]. However, research in Andalusia, Spain, and Mauritania demonstrates its effectiveness in highlighting performance variations among irrigation districts [5], [23], [16].

This research aims to delve into how well WUAs are doing within the Rohini Irrigation Scheme, figure out what factors affect their performance, see if there's a difference in efficiency between the start and end of the irrigation system, and set some performance standards for the region [21], [40], [32]. By taking a close look at key performance measures, the study hopes to help create sustainable local irrigation policies and boost how efficiently the Rohini Irrigation Scheme runs [3], [26], [33].

METHODOLOGY

We took a deep dive into Uttar Pradesh's Water Resources and Irrigation Department, pulling together information from all sorts of places in a very organized way. We talked to a bunch of people who work there, including the higher-ups, using a set list of questions to get a really clear picture of what we were trying to figure out. We also chatted with the folks who actually use the water, which gave us some super valuable insights from the field.

To make sense of all this data, we used something called Data Envelopment Analysis, or DEA for short. We looked at things using two different lenses: one that assumes you get the same output no matter how much you put in (Constant Returns to Scale) and another that understands output can change based on input (Variable Returns to Scale). We focused on the input side of things because our main goal was to see if we could find ways to save money by using fewer resources. This methodology enabled assessment of both individual sub-outcomes and aggregate effects, focusing on optimizing outcomes while minimizing resource usage.

DEA was chosen over alternative analytical techniques such as Stochastic Frontier Analysis (SFA) and Total Factor Productivity (TFP) for several compelling reasons:

- The ability to handle multiple inputs (operational expenditure) and outputs (beneficiaries, irrigated area, crop yield) simultaneously without requiring price information or functional form specification
- Capacity to provide specific efficiency targets for improvement, unlike traditional regression analysis
- No requirement for assumptions about inefficiency distribution, in contrast to SFA

- Proven track record in irrigation studies, as demonstrated by previous research [5], [25].
- The DEA models that focus on inputs really zero in on how things are run and managed. They're all about finding ways to use fewer resources (inputs) but keep the same level of output. This makes a lot of sense because it helps improve efficiency without affecting the quality of services provided.

The study's results gave us some really useful information about how well the Uttar Pradesh water resources and irrigation department is operating. It pinpointed some areas where they could use resources more wisely while still keeping up the good quality of their services. These findings give the department some solid advice on how to improve its performance and manage its resources better.

Charnes, Cooper, and Rhodes Model (CCR Model)

The CCR efficiency model assumes Constant Returns to Scale (CRS). Here's how it figures out efficiency when you have multiple inputs and outputs:

$$Efficiency = \frac{weighted\ sum\ of\ outputs}{weighted\ sum\ of\ inputs}$$

Banker Charnes and Cooper Model (BCC Model)

To get a more complete picture of efficiency, the study used two different models: one assuming Constant Returns to Scale (CRS) and another assuming Variable Returns to Scale (VRS). The VRS analysis, which is based on the model (also known as BCC), was especially important for assessing Decision-Making Units (DMUs) that weren't operating at their ideal size. By using both models, the study was able to gain a deeper understanding of efficiency by comparing technical efficiency under both CRS and VRS conditions [1].

Technological efficiency was measured using the input-oriented CCR efficiency model developed [6]. This method checks if an inefficient DMU could become efficient by scaling back its inputs in proportion while keeping its output the same. Data Envelopment Analysis (DEA) was the main tool used for analysis, offering clear benefits over more traditional methods like regression analysis. DEA was chosen because it's been successfully used in a bunch of different areas, especially when it comes to water supply and irrigation.

Area of Study

The Rohini canal system, located in Lalitpur in southwestern Uttar Pradesh, was finished between 1983 and 1984 as a part of the larger Rohini dam project. This region is known for growing a few key crops:

- Wheat
- Gram (chickpeas)
- Peas
- Masoor (red lentils)

These crops are commonly found in the agricultural areas of Bundelkhand, showing the local farming methods and the impact of the environment. Covering an area of 44.03 square kilometers, the canal system has a main canal that's 8.460 kilometers long and can release water at a rate of 40 cubic meters per second. Four smaller canals, named Chhaprauni, Tisgana, Gadhauli, and Chauka, branch off from this main canal. You can see this setup in Figure 1, which shows both a map and a diagram of the area studied by the Water User Association (WUA).

This area is pretty special because it's one of the rare places in Uttar Pradesh where the Participatory Irrigation Management (PIM) Act has actually been put into action. That makes it a really useful case study for figuring out how PIM is working in other parts of the state. The research here is all about comparing the water situation at the start and end of the irrigation system to spot differences in how water is handed out and managed by the different Water User Associations (WUAs).

Using a technique called Data Envelopment Analysis (DEA), the study comes up with efficiency scores that do two important things: they show where current WUAs could be doing a better job, and they offer some pointers on how to make new WUAs run more efficiently.

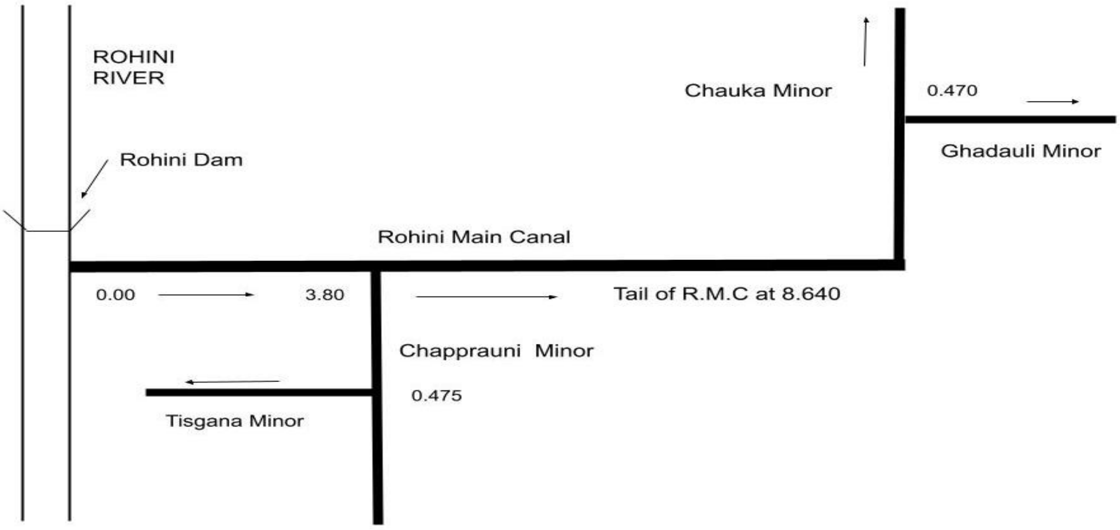

Figure 1. Rohini canal system

RESULTS AND DISCUSSION

The study has revealed significant challenges in Water Users' Association (WUA) management, primarily stemming from limited operational scale and suboptimal management practices within certain associations [17]. These findings underscore the need for substantial organizational restructuring.

The research methodology focused on efficiency assessment at two levels:

1. Individual WUA performance evaluation
2. Comparative analysis between head and tail minors of the system

Using Data Envelopment Analysis (DEA) with an input-oriented model, efficiency calculations were performed for the head and tail minors of the Rohini canal system across two periods: 2018-2019 and 2019-2020. The analysis incorporated specific inputs and outputs as detailed in Table 1 (see Appendix A, B & C), generating both Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS) values (presented in Tables 2 & 3).

Model used:

Table 1. Input and output used in DEA modelling are as follows

S. No.	INPUT	OUTPUT
1	Opex (operation and expenditure) (Rs.)	a). Number of beneficiaries (Numbers)
2		b). Area irrigated (hectare)
3		c). Crop yield (Rs.)

Table 2. Rohini main canal results of 2018-2019

DMU No.	**DMU Name**	**Input-Oriented VRS Efficiency**	**Input-Oriented CRS Efficiency**	**RTS**
1	RMC K(1-R)	0.67	0.65	Decreasing
2	RMC K(2-R)	0.56	0.56	Decreasing
3	RMC K(3-R)	0.42	0.37	Decreasing
4	RMC K(4-R)	0.33	0.33	Decreasing
5	RMC K(5-R)	0.36	0.35	Decreasing
6	RMC K(6-R)	0.38	0.33	Decreasing
7	RMC K(7-R)	1	1	Constant
8	RMC K(8-R)	0.74	0.71	Decreasing
9	RMC K(9-R)	1	1	Constant
10	RMC K(10-L)	0.67	0.67	Increasing
11	RMC K(11-R)	0.42	0.31	Decreasing
12	RMC K(12-R)	1	1	Constant
13	RMC K(13-R)	0.4	0.4	Decreasing
14	RMC K(14-R)	0.32	0.29	Decreasing
15	RMC K(15-R)	0.37	0.37	Increasing
16	RMC K(16-R)	0.42	0.42	Increasing
17	RMC K(17-R)	1	1	Constant
18	RMC K(18-L)	0.46	0.45	Decreasing
19	RMC (19TAIL)	0.61	0.6	Decreasing

The Rohini canal system's structure features the Rohini Main Canal (RMC) as the primary and head channel, while Chauka and Gadhauli serve as tail minors. The system operates through outlets (kulabas), each managed by a dedicated Water Users' Association (WUA). These WUAs are organized at the outlet level, with outlets designated as "R" and "L" indicating their position on the right and left sides of the canal respectively.

Efficiency analysis for 2018-2019 revealed:

- High-performing WUAs: RMC 9-R, RMC 12-R, and RMC 17-R achieved optimal efficiency
- Distribution of efficiency rates:
- Five outlets demonstrated efficiency rates above 50%
- Ten WUAs operated below 50% efficiency

The 2019-2020 period showed marked improvement:

- Top performers: RMC 2-R, RMC 12-R, and RMC 17-R emerged as the most efficient Decision-Making Units (DMUs)
- Significant efficiency gains:
- Thirteen DMUs achieved efficiency rates above 50%
- Only two WUAs remained below 50% efficiency

As illustrated in Figure 2, the year-over-year comparison demonstrates substantial performance enhancement across WUAs from 2018-2019 to 2019-2020. This improvement is further supported by the input and output data analysis detailed in Appendix A.

Table 3. Rohini main canal results of 2019-2020

DMU No.	**DMU Name**	**Input-oriented VRS Efficiency**	**Input-oriented CRS Efficiency**	**RTS**
1	RMC K(1-R)	0.35	0.35	Decreasing
2	RMC K(2-R)	1	1	Constant
3	RMC K(3-R)	0.87	0.65	Decreasing
4	RMC K(4-R)	0.56	0.46	Decreasing
5	RMC K(5-R)	0.81	0.85	Decreasing
6	RMC K(6-R)	0.78	0.62	Decreasing
7	RMC K(7-R)	0.76	0.53	Decreasing
8	RMC K(8-R)	0.76	0.52	Decreasing
9	RMC K(9-R)	0.67	0.67	Decreasing
10	RMC K(10-L)	0.66	0.65	Increasing
11	RMC K(11-R)	0.81	0.69	Decreasing
12	RMC K(12-R)	1	1	Constant
13	RMC K(13-R)	0.52	0.44	Decreasing
14	RMC K(14-R)	0.88	0.88	Increasing
15	RMC K(15-R)	0.47	0.44	Decreasing
16	RMC K(16-R)	0.52	0.44	Decreasing
17	RMC K(17-R)	1	1	Constant
18	RMC K(18-L)	0.99	0.98	Increasing
19	RMC K(19-TAIL)	1	1	Constant

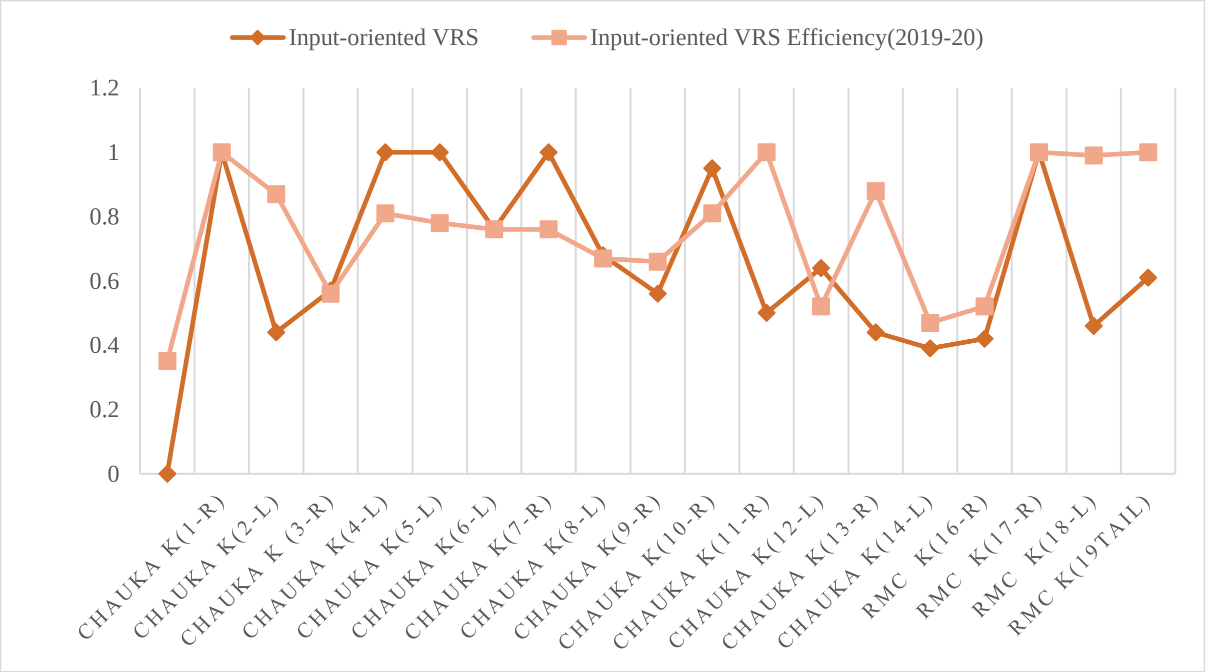

Figure 2. Rohini main canal 2018-2019 and 2019-2020 comparison of efficiencies of WUA’s performance result graph

In the 2018-2019 period, four of the seventeen WUAs in the Chauka minor were completely efficient, while ten were more than 50% efficient and three were less than 50% efficient (Table 4). Compared to the previous year, the 2019-2020 data show an increase in efficiency, with four WUAs achieving 100% efficiency, most of which are located at the tail of the minor (Figure 3). Appendix B shows the input and output data used for the analysis.

Table 4. Chauka minor results of 2018-2019

DMU No.	**DMU Name**	**Input-oriented VRS Efficiency**	**Input-oriented CRS Efficiency**	**RTS**
1	CHAUKA K(1-R)	1	1	Constant
2	CHAUKA K(2-L)	0.44	0.41	Increasing
3	CHAUKA K (3-R)	0.57	0.52	Increasing
4	CHAUKA K(4-L)	1	1	Constant
5	CHAUKA K(5-L)	1	1	Constant
6	CHAUKA K(6-L)	0.76	0.72	Decreasing
7	CHAUKA K(7-R)	1	1	Constant
8	CHAUKA K(8-L)	0.68	0.67	Increasing
9	CHAUKA K(9-R)	0.56	0.55	Increasing
10	CHAUKA K(10-R)	0.95	0.88	Decreasing
11	CHAUKA K(11-R)	0.5	0.5	Decreasing
12	CHAUKA K(12-L)	0.64	0.61	Decreasing
13	CHAUKA K(13-R)	0.44	0.44	Decreasing
14	CHAUKA K(14-L)	0.39	0.36	Increasing
15	CHAUKA K(15-R)	0.55	0.51	Decreasing
16	CHAUKA K(16-L)	0.49	0.48	Decreasing
17	CHAUKA K(17TAIL)	0.5	0.3	Increasing

Table 5. Chauka minor results of 2019-2020

DMU No.	**DMU Name**	**Input-oriented VRS Efficiency**	**Input-oriented CRS Efficiency**	**RTS**
1.	CHAUKA K(1-R)	0.78	0.81	Decreasing
2.	CHAUKA K(2-L)	0.95	0.63	Decreasing
3.	CHAUKA K (3-R)	0.79	0.72	Decreasing
4.	CHAUKA K(4-L)	0.93	0.42	Decreasing
5.	CHAUKA K(5-L)	0.46	0.46	Increasing
6.	CHAUKA K(6-L)	0.72	0.64	Increasing
7.	CHAUKA K(7-R)	0.62	0.61	Decreasing
8.	CHAUKA K(8-L)	0.41	0.41	Increasing
9.	CHAUKA K(9-R)	0.91	0.41	Decreasing
10.	CHAUKA K(10-R)	1.00	1.00	Constant
11.	CHAUKA K(11-R)	0.55	0.53	Increasing
12.	CHAUKA K(12-L)	0.43	0.39	Decreasing
13.	CHAUKA K(13-R)	0.63	0.62	Decreasing
14.	CHAUKA K(14-L)	1.00	1.00	Constant
15.	CHAUKA K(15-R)	0.99	0.90	Increasing
16.	CHAUKA K(16-L)	1.00	1.00	Constant
17.	CHAUKA K(17TAIL)	1.00	1.00	Constant

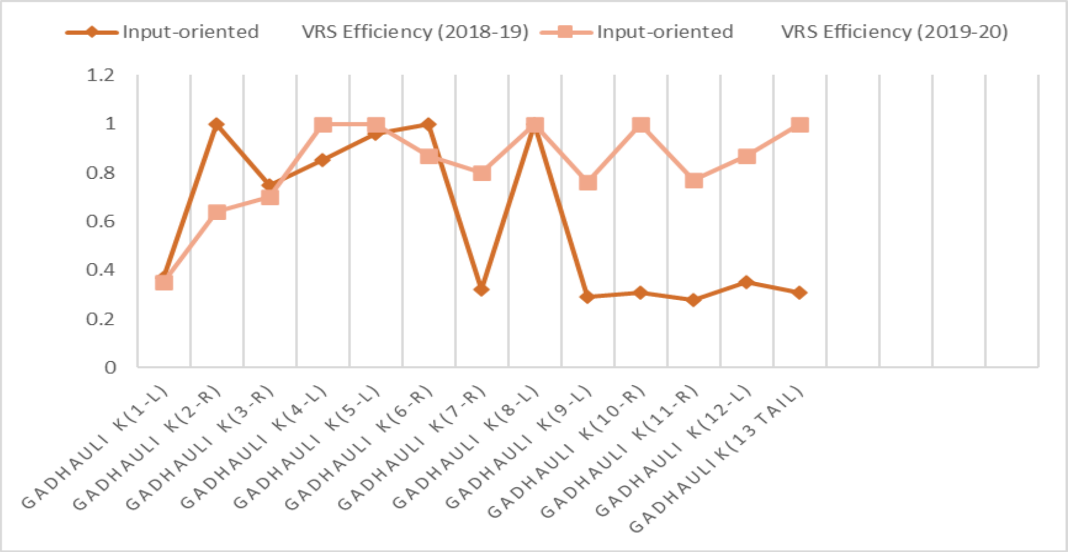

Figure 3. Chauka Minor 2018-2019 and 2019-2020 comparison of efficiencies of WUA's performance result graph

Table 6. Gadhauli minor results of 2018-2019

DMU No.	**DMU Name**	**Input-oriented VRS Efficiency**	**Input-oriented CRS Efficiency**	**RTS**
1	GADHAULI K(1-L)	0.37	0.35	Increasing
2	GADHAULI K(2-R)	1	1	Constant
3	GADHAULI K(3-R)	0.75	0.73	Increasing
4	GADHAULI K(4-L)	0.85	0.81	Decreasing
5	GADHAULI K(5-L)	0.96	0.68	Increasing
6	GADHAULI K(6-R)	1	1	Constant
7	GADHAULI K(7-R)	0.32	0.32	Decreasing
8	GADHAULI K(8-L)	1	1	Constant
9	GADHAULI K(9-L)	0.29	0.26	Decreasing
10	GADHAULI K(10-R)	0.31	0.31	Increasing
11	GADHAULI K(11-R)	0.28	0.27	Decreasing
12	GADHAULI K(12-L)	0.35	0.33	Decreasing
13	GADHAULI K(13 TAIL)	0.31	0.27	Decreasing

In the Gadhauli minor, on analysing the data (Appendix C), only three of the thirteen WUAs achieved complete efficiency, while three more were above 70% efficient and seven were below 40%. The number of efficient WUAs increased from three to five in 2019-2020 (Table 6 & Table 7), with seven WUAs scoring above 50% and one scoring below 40% (Figure 4).

Table 7. Gadhauli minor results of 2019-2020

DMU No.	**DMU Name**	**Input-oriented VRS Efficiency**	**Input-oriented CRS Efficiency**	**RTS**
1	GADHAULI K(1-L)	0.35	0.35	Increasing
2	GADHAULI K(2-R)	0.64	0.57	Decreasing
3	GADHAULI K(3-R)	0.7	0.7	Increasing
4	GADHAULI K(4-L)	1	1	Constant
5	GADHAULI K(5-L)	1	1	Constant
6	GADHAULI K(6-R)	0.87	0.82	Decreasing
7	GADHAULI K(7-R)	0.8	0.8	Decreasing
8	GADHAULI K(8-L)	1	1	Constant
9	GADHAULI K(9-L)	0.76	0.76	Increasing
10	GADHAULI K(10-R)	1	1	Constant
11	GADHAULI K(11-R)	0.77	0.72	Increasing
12	GADHAULI K(12-L)	0.87	0.79	Increasing
13	GADHAULI K(13 TAIL)	1	1	Constant

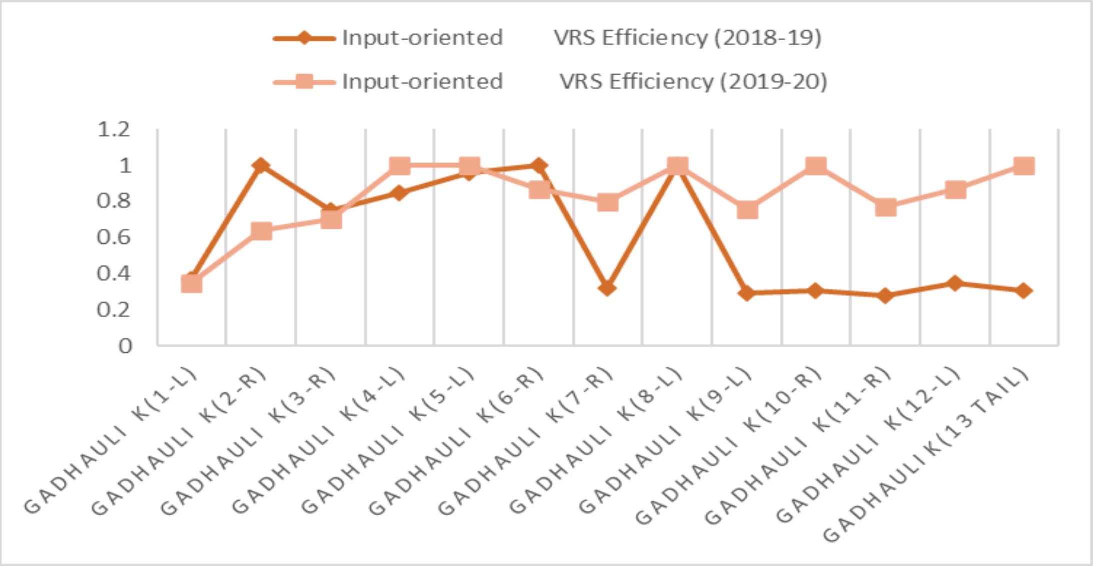

Figure 4. Gadhauli minor 2018-2019 and 2019-2020 comparison of efficiencies of WUA's performance result graph 2019-2020 results graph

Analysis of the 2019-2020 data reveals superior performance among Water Users' Associations (WUAs) at the tail minors of the system. This finding highlights the importance of outlet-level efficiency monitoring, particularly for resolving conflicts and addressing operational issues within individual WUAs in large-scale irrigation projects.

The identification of inefficiencies, even within projects that appear efficient overall, raises important questions about potential inequities in resource distribution and management. This underscores the critical role of WUA-level benchmarking in:

- Providing comprehensive performance assessment
- Detecting hidden inequities within the project
- Establishing baseline standards for operational efficiency

The improved performance of tail-end WUAs challenges common assumptions about water distribution advantages in canal systems, suggesting successful implementation of equitable water management practices in this case.

DISCUSSION

This study employed Data Envelopment Analysis (DEA) to evaluate the technical relative efficiency of Water User Associations (WUAs) in the Rohini Canal System. Key findings demonstrate significant performance improvements:

The Gadhauli minor exhibited remarkable progress with a 70% efficiency increase between 2018-19 and 2019-20, accompanied by a substantial reduction in operating expenses (OPEX) from 8238.06 to 994.56. Analysis indicates that OPEX serves as a critical determinant of overall efficiency, with management and maintenance inefficiencies surpassing general operational inefficiencies.

WUAs have shown considerable improvement since their establishment, overcoming initial operational challenges that stemmed from:

- Limited understanding of participatory management principles
- Insufficient training programs

- Low farmer awareness levels
- Gaps in technological comprehension

A notable positive factor in WUA performance has been the integration of technical personnel, suggesting that investment in qualified staff with relevant expertise can significantly enhance operation and maintenance activities. This finding indicates that allocating resources for technical expertise may be a crucial strategy for improving WUA effectiveness.

Social and economic findings of the study

The Rohini Canal system has demonstrated notable improvements through increased family participation in its management. Over two consecutive years, enhanced awareness and active engagement have led to more effective management practices.

The system's performance shows significant positive outcomes:

1. Water supply has markedly improved within the first two years of implementation
2. Farmers report high levels of satisfaction with irrigation services
3. Staff have received recognition from farmers for enhanced performance
4. Tail-end farmers, notably, express particularly high satisfaction levels

This last point is especially significant as tail-end users in irrigation systems typically experience more challenges with water access. Their high satisfaction levels suggest successful implementation of equitable water distribution practices throughout the canal system.

CONCLUSIONS

The empirical analysis reveals significant variations in Water Users' Association (WUA) efficiencies, with a positive trend emerging over time. The data shows an increasing number of WUAs achieving both 100% efficiency and exceeding the 50% efficiency threshold across consecutive years. The study demonstrates the effectiveness of Data Envelopment Analysis (DEA) in evaluating large-scale irrigation and drainage projects through:

- Performance benchmarking of Water Users' Associations (WUAs)
- Identifying efficiency variations across canal system sections
- Quantifying operational and technical inefficiencies
- Providing actionable insights for resource management
- Enabling comparative analysis of irrigation infrastructure performance

The efficiency improvements in 2018-2019 and 2019-2020 reflect enhanced farmer engagement and more sophisticated management approaches, highlighting the potential of participatory irrigation management strategies. Comparative performance assessment across projects and years

- Identification of operational shortcomings
- Setting targeted efficiency goals
- Development of strategic improvement plans

- Optimization of resource allocation

These capabilities make DEA particularly valuable for regulators in open market environments, supporting the implementation of incentive-based frameworks and promoting healthy competition among utilities. The efficiency measurement process serves as a fundamental step in ensuring long-term sector sustainability.

However, while DEA proves to be a powerful analytical tool, its application requires careful consideration:

- The methodology excels at diagnostic assessment but may not fully capture organization-specific objectives
- Its effectiveness in calculating WUA efficiencies has facilitated identification of minor issues and informed policy adjustments
- For comprehensive evaluation, particularly in systems with fewer WUAs, DEA should be supplemented with complementary performance measurement techniques
- To further enhance WUA efficiencies, the study recommends:
- Implementation of targeted policy interventions
- Adoption of successful management models from high-performing utilities
- Integration of multiple performance evaluation methodologies

REFERENCES

[1] Banker RD, Charnes A, Cooper WW. Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management science. 1984 Sep;30(9):1078-92. https://doi.org/10.1287/mnsc.30.9.1078

[2] Panchal BY, Shah A, Shah P, Bhatt P, Tiwari M, Yadav A. Exploring Synergies, Differences, and Impacts of Agile and DevOps on Software Development Efficiency. Indian Journal of Information Sources and Services. 2024;14(3):175-85. https://doi.org/10.51983/ijiss-2024.14.3.23.

[3] Bassi N, Rishi P, Choudhury N. Institutional organizers and collective action: the case of water users' associations in Gujarat, India. Water International. 2010 Feb 3;35(1):18-33. https://doi.org/10.1080/02508060903515275

[4] Nandy M, Dubey A. Effective Surveillance of Water Quality in Recirculating Aquaculture Systems through the Application of Intelligent Biosensors. Natural and Engineering Sciences. 2024 Sep 1;9(2):234-43. https://doi.org/10.28978/nesciences.1575456

[5] Borgia C, García-Bolaños M, Li T, Gómez-Macpherson H, Comas J, Connor D, Mateos L. Benchmarking for performance assessment of small and large irrigation schemes along the Senegal Valley in Mauritania. Agricultural Water Management. 2013 Apr 1;121:19-26. https://doi.org/10.1016/j.agwat.2013.01.002

[6] Viticchié A, Basile C, Valenza F, Lioy A. On the impossibility of effectively using likely-invariants for software attestation purposes. J. Wirel. Mob. Networks Ubiquitous Comput. Dependable Appl. 2018;9(2):1-25.

[7] Chun N. The challenge of collective action for irrigation management in India. Asian Economic Papers. 2014 Jun 1;13(2):88-111. https://doi.org/10.1162/ASEP_a_00271

[8] Vasquez E, Mendoza R. Membrane-Based Separation Methods for Effective Contaminant Removal in Wastewater and Water Systems. Engineering Perspectives in Filtration and Separation. 2024 Dec 27:21-7.

[9] Gulati A, Meinzen-Dick R, Raju KV. From Top down to bottoms Up: institutional reforms in Indian canal irrigation. Delhi: Institute of Economic Growth. 1999.

[10] Lei C, Ibrahim M. Efficient Revenue Management: Classification Model for Hotel Booking Cancellation Prediction. Global Perspectives in Management. 2024 Mar 29;2(1):12-21.

[11] Huang Q, Wang J, Easter KW, Rozelle S. Empirical assessment of water management institutions in northern China. Agricultural water management. 2010 Dec 15;98(2):361-9. https://doi.org/10.1016/j.agwat.2010.09.004

[12] Al-Jizani HN, Kayabaş A. Students Real Data Features Analyzing with Supervised Learning Algorithms to Predict Efficiency. International Journal of Advances in Engineering and Emerging Technology. 2023 Apr 30;14(1):34-45.

[13] Malano H, Hungspreug S, Plantey J, Bos MG, Vlotman WF, Molden D, Burton M. Benchmarking of irrigation and drainage projects. Report of the ICID Task Force. 2004(4).

[14] Meinzen-Dick R, Raju KV, Gulati A. What affects organization and collective action for managing resources? Evidence from canal irrigation systems in India. World development. 2002 Apr 1;30(4):649-66. https://doi.org/10.1016/S0305-750X(01)00130-9

[15] Saidova K, Madraimov A, Kodirova M, Madraimov A, Kodirova K, Babarakhimov T, Urinova S, Zokirov K. Assessing the impact of invasive species on native aquatic ecosystems and developing management strategies. International Journal of Aquatic Research and Environmental Studies. 2024;4:45-51. https://doi.org/10.70102/IJARES/V4S1/8

[16] Mukherji A, Blanka F, Tushaar S, Suhardiman D, Giordano M, Weligamage P. Irrigation reform in Asia: A review of 108 cases of irrigation management transfer. 1-131.

[17] Nedim S, Omer K. Analysis of Time Oscillations of Water on Lake Modric as a Multi-Purpose Reservoir. Archives for Technical Sciences/Arhiv za Tehnicke Nauke. 2018 Jan 1(18). 31-40. https://doi.org/10.7251/afts.2018.1018.031S

[18] Narain V. Brackets and black boxes: research on water users' associations. Water Policy. 2004 Jun 1;6(3):185-96. https://doi.org/10.2166/wp.2004.0012

[19] TalatianAzad, S., & Malekzadeh, M. (2015). Evaluation of performance in Cloud Computing with Queue Theory. *International Academic Journal of Science and Engineering, 2*(2), 109–120.

[20] Ostrom E. Crafting institutions for self-governing irrigation systems. 1992. 1-111.

[21] Ostsrom E. Incentives, rules of the game and development. Washington, DC: World Bank; 1995 May 1. 207-316.

[22] Sitaram Phadnis S, Kulshrestha M. Evaluation of irrigation efficiencies for water users' associations in a major irrigation project in India by DEA. Benchmarking: An International Journal. 2012 Apr 6;19(2):193-218. https://doi.org/10.1108/14635771211224536

[23] Phadnis SS, Kulshrestha M. Benchmarking for water users associations to enhance performance of the samrat ashok sagar major irrigation scheme. Irrigation and Drainage. 2012 Oct;61(4):449-63. https://doi.org/10.1002/ird.662

[24] Rodríguez-Díaz JA, Camacho-Poyato E, Lopez-Luque R, Pérez-Urrestarazu L. Benchmarking and multivariate data analysis techniques for improving the efficiency of irrigation districts: an application in Spain. Agricultural systems. 2008 Mar 1;96(1-3):250-9. https://doi.org/10.1016/j.agsy.2007.07.010

[25] Reddy VR, Reddy PP. How participatory is participatory irrigation management? Water users' associations in Andhra Pradesh. Economic and political Weekly. 2005 Dec 31:5587-95.

[26] Sugden F, Agarwal B, Leder S, Saikia P, Raut M, Kumar A, Ray D. Experiments in farmers' collectives in Eastern India and Nepal: Process, benefits, and challenges. Journal of Agrarian Change. 2021 Jan;21(1):90-121. https://doi.org/10.1111/joac.12369

[27] Takayama T, Matsuda H, Nakatani T. The determinants of collective action in irrigation management systems: Evidence from rural communities in Japan. Agricultural Water Management. 2018 Jul 30;206:113-23. https://doi.org/10.1016/j.agwat.2018.04.031

[28] Wang Y, Wu J. An empirical examination on the role of water user associations for irrigation management in rural China. Water Resources Research. 2018 Dec;54(12):9791-811. https://doi.org/10.1029/2017WR021837

[29] Zema DA, Nicotra A, Mateos L, Zimbone SM. Improvement of the irrigation performance in Water Users Associations integrating data envelopment analysis and multi-regression models. Agricultural Water Management. 2018 Jun 30;205:38-49. https://doi.org/10.1016/j.agwat.2018.04.032

[30] Zhang L, Heerink N, Dries L, Shi X. Water users associations and irrigation water productivity in northern China. Ecological Economics. 2013 Nov 1;95:128-36. https://doi.org/10.1016/j.ecolecon.2013.08.014

[31] Bardhan P. Irrigation and cooperation: An empirical analysis of 48 irrigation communities in South India. Economic Development and cultural change. 2000 Jul;48(4):847-65. https://doi.org/10.1086/452480.

[32] Bastakoti RC, Shivakoti GP. Rules and collective action: An institutional analysis of the performance of irrigation systems in Nepal. Journal of Institutional Economics. 2012 Jun;8(2):225-46. https://doi.org/10.1017/S1744137411000452

[33] Charnes A, Cooper WW, Rhodes E. Measuring the efficiency of decision making units. European journal of operational research. 1978 Nov 1;2(6):429-44. https://doi.org/10.1016/0377-2217(78)90138-8

[34] Frija A, Wossink A, Buysse J, Speelman S, Van Huylenbroeck G. Irrigation pricing policies and its impact on agricultural inputs demand in Tunisia: A DEA-based methodology. Journal of environmental management. 2011 Sep 1;92(9):2109-18. https://doi.org/10.1016/j.jenvman.2011.03.013

[35] Hu XJ, Xiong YC, Li YJ, Wang JX, Li FM, Wang HY, Li LL. Integrated water resources management and water users' associations in the arid region of northwest China: A case study of farmers' perceptions. Journal of environmental management. 2014 Dec 1;145:162-9. https://doi.org/10.1016/j.jenvman.2014.06.018

[36] Kulshrestha M, Vishwakarma A. Efficiency evaluation of urban water supply services in an Indian state. Water policy. 2013 Feb 1;15(1):134-52. https://doi.org/10.2166/wp.2012.072

[37] McCarthy N, Essam T. Impact of water user associations on agricultural productivity in Chile. Washington, DC, USA: International Food Policy Research Institute (IFPRI); 2009 Aug. 1-31

[38] Muchara B, Ortmann G, Wale E, Mudhara M. Collective action and participation in irrigation water management: A case study of Mooi River Irrigation Scheme in KwaZulu-Natal Province, South Africa. Water SA. 2014 Nov 18;40(4):699-708.

[39] Narain V. Institutions, technology and water control: Water users associations and irrigation management reform in two large-scale systems in India. Wageningen University and Research; 2003. 1-2.

[40] Nyathikala SA, Kulshrestha M. Performance measurement of water supply services: a cross-Country comparison between India and the UK. Environmental Management. 2020 Oct;66(4):517-34. https://doi.org/10.1007/s00267-020-01333-1