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Performance Evaluation of Irrigation Canals Using Data Envelopment Analysis for Efficient and Sustainable Irrigation Management in Jharkhand State, India

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Abstract: Across the world, achieving sustainable water resource development and managing limited natural resources like water have proven to be significant issues, and India is no exception to the same. At present, irrigation consumes about 80 percent of the total available water in India and is predicted to remain the dominant water user. India is already a country with water stress and is on its way to becoming a country with water scarcity. Rising agricultural productivity, expanding urbanisation, growing industrialisation, and accelerating industry create competing demands for water. Most irrigation system issues in India are attributable to poor management of the built infrastructure. The present study aims to rank the irrigation canals based on their efficiencies and inefficiencies to improve the overall performance of WUAs in Jharkhand. The ranking is done for nine irrigation canals based on financial inputs like investments in training and development of WUAs, maintenance and repairs of canals, and outputs like users' charges collection and yield in crop production. The Comprehensive Efficiency score analysis suggests that while there is room for improvement in the performance, the Water Users' Associations have generally been successful in improving the technical efficiency of the irrigation system. The findings can be used for further investigation to identify best practises and areas for improvement.

Keywords: water users' association; participatory irrigation management; data envelopment analysis; irrigation canals; comprehensive efficiency score

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1. Introduction

At present, irrigation consumes about 84 percent of the total available water in India and is predicted to remain the dominant water user. India is already a country with water stress and is on its way to becoming one with water scarcity. Even though the nation's finite water supplies are under increasing pressure, water use does not reflect the shortage. India uses 2–4 times as much water to grow one unit of crucial food crops as other major agricultural nations like China, Brazil, and the United States [1]. Whether farming is efficient or inefficient depends on the availability of water through irrigation or rainfall. Such difficulties would necessitate effective water management of the available surface and groundwater resources and their maximum exploitation [2]. In India, achieving sustainable development and effectively managing this limited resource have proven difficult. Rising agricultural productivity, expanding urbanisation, growing industrialisation, and accelerating industry create competing demands for water. Most irrigation system issues in India are attributable to poor management of the built infrastructure, including ineffective monitoring of the water flow in the irrigation system, timeliness of the water flow in the irrigation system, inefficiencies, poor coordination with the irrigation department in preparing water demands and collecting water charges, poor repair of the irrigation system, and the inability to resolve conflicts between members and WUAs.

In addition to managing, allocating, and distributing water, the government entities, which may go by the names of irrigation departments, municipal bodies, water boards, etc., also set and collect fees, have a role in crop patterns, and carry out operations and maintenance tasks. Under the restructured "Command Area Development & Water Management" (CADWM) Programme, more emphasis is given to the participatory approach. A further requirement for accepting the completion of the CADWM is the transfer of management and control of the irrigation system to the WUA. Numerous researchers in India have tried to assess various aspects of the effectiveness of WUAs. Based on such studies, it is challenging to draw broad conclusions regarding the effects of WUAs because of various variables, including their location and the degree of user interaction. Large-scale public irrigation systems require complex processes that are highly context-specific for cooperative action to be successful. In addition to managing, allocating, and distributing water, the government entities, which may go by the names of irrigation departments, municipal bodies, water boards, etc., also set and collect fees, have a role in crop patterns, and carry out operations and maintenance tasks. Under the restructured "Command Area Development & Water Management" (CADWM) Programme, more emphasis is given to the participatory approach. A further requirement for accepting the completion of the CADWM is the transfer of management and control of the irrigation system to the WUA [3]. Numerous researchers in India have tried to assess various aspects of the effectiveness of WUAs. Based on such studies, it is challenging to draw broad conclusions regarding the effects of WUAs because of various variables, including their location and the degree of user interaction. Large-scale public irrigation systems require complex processes that are highly context-specific for cooperative action to be successful.

The objective of the present study is to provide a methodology to effortlessly rank the WUAs, treating them as DMUs (Decision-Making Units), for further investigation into their efficiencies and inefficiencies to improve their overall performance. The current study was carried out in two stages. In the first stage, the performance of a selected nine canals is analysed using Data Envelopment Analysis (DEA) methods such as VRS input and output-oriented and a non-oriented slack-based method (SBM). The second stage is focused on ranking canals using Shannon's Entropy method blended with adopted DEA methods. The canals are grouped as efficient and inefficient by segregating and ranking the DMUs by obtaining Comprehensive Efficiency Scores (CES) for all the canals for all years. It recommends a precise procedure to decide which of the blended methods to use to rank canals. The ranks obtained by CES values using VRSIP can be considered for further investigation of canals.

Description of the Study Area

The study has been carried out in Jharkhand State, which has made a policy decision to transfer the whole irrigation system management to the users (farmers) group since 2014. The state has also enacted rules under the Jharkhand Participatory Irrigation Management Rules to provide legal recognition to the Water Users' Association (2014). Since the performance of WUAs functioning at different locations using different water sources is expected to be different because of heterogeneity in physical and other characteristics, a major canal irrigation project in Jharkhand State was selected based on the available data and consultation with the irrigation bureaucrats. The Kanchi Irrigation Scheme is a very important project of Jharkhand state that provides irrigation to 23 villages in the Sonahatu and Ichagarh blocks of Seraikela district, 44 villages in the Tamar block of Ranchi district, and 14 villages in the Arki blocks of Khunti district. In this project, the intended irrigation potential is 17,800 hectares, the CCA is 21,235 hectares, and the GCA is 34,210 hectares. The Government of India's Second Five-Year Plan (1956–1961) included the design for the Kanchi Irrigation Scheme. The building project began in 1958 and was finished in 1966. The Kanchi irrigation scheme's main construction site is in the village of Churki in the Khunti district, which is located at a latitude of 25°07′30″ S and a longitude of 85°09′30″ E. The main canal of the Kanchi Irrigation Scheme is 18.29 kilometres long. Tamar branch canal, with a total length of 13.27 km and a discharge capacity of slightly under 150 cusecs, exits from its right bank at 18.23 km. Under the auspices of CADWM, this branch canal has undergone rehabilitation work, including pavement. The Adradih Branch Canal's bank has been damaged, and the structures are in poor condition. There is only partial irrigation because the water output from this canal is substantially lower than the canal's overall capacity.

Methodological studies on the topic and case studies conducted in various nations were used to construct the theoretical foundation for evaluating the performance of the WUAs under the Kanchi Canal irrigation project. In addition, records from the Water Resources Department, Ranchi Division, and WUAs were consulted for information about the Kanchi Irrigation Scheme, and field surveys were conducted with WUA members about the functioning of WUAs. Altogether, a sample of 09 WUAs concerning 09 canals as DMUs were selected, and four years of field-level data were collected on various costs and outputs covered in the field study as Table 1:

Table 1. Inputs and outputs for the study.

Input 1	The amount invested in WUA by the Water Resources Department, Government of Jharkhand, for meetings and other training
Output 1	The amount collected by WUA.
Input 2	The amount invested by the Water Resources Department, Government of Jharkhand, and WUA in the operation and maintenance of the canals
Output 2	yield in crop production

The names of the DMUs are Amlesha, Babaikund, Kokadih, Hesadih, Konkadih, Jargodih, Hartaldih, Chitri, and Tiruldih (Appendix A). Section 2 details the literature review, followed by Section 3, which describes the methodology and models used. Section 4 brings forth the analysis, and Section 5 details the research conclusions.

2. Literature Review

A large and growing body of literature has investigated irrigation, agricultural projects, and the Water Users' Associations' efficiency using various DEA and other combination methods. Therefore, this section brings forth some of these studies. The DEA and MCDM combination methods were deployed to test various irrigation projects in Sri Ramsagar, Andhra Pradesh, India [4]. The results from DEA analysis were compared with results obtained from various MCDM methods like PROMETHEE and EXPROM. Interestingly, all the results obtained were found to be similar. The same authors, Raju and Kumar, deployed a fuzzy DEA model to evaluate the performance of the sixteen irrigation systems of the Mahi Bajaj Sagar project [5]. A substantial difference between ranking patterns and efficiency values was noticed before and after the cross-efficiency matrix analysis. The impact of irrigation type and other related variables on the efficiency of irrigation water in western Kansas was investigated [6]. A weak relationship was found between the level of excess irrigation water and the type of irrigation system. A similar investigation was done on small irrigation projects in the North Province of South Africa [7]. The results prove that crop choice, landownership, land size, irrigation type, and irrigation method deployed demonstrated a significant impact on water efficiency. Thereby, the DEA, in combination with other methods, has found its use in various studies [8–14].

The efficiency of WUAs was explored in Tunisia using DEA models in [15]. The study measured WUA efficiency and engineering and management sub-vector efficiencies using modified DEA models. An efficiency of more than 18% was achieved through WUA operations. However, based on scale efficiency, WUAs were not found to be efficient. Likewise, a study in Tunisia was done using inverse DEA models, and results show that farmers who were found to be more technically efficient had higher irrigation water demand functions [16]. Such farmers were found to be able to afford water prices but adjust to a limited extent for changes in demand. DEA was also deployed to measure the irrigation efficiencies of WUAs in the Samrat Ashok Sagar project in India [17]. From the findings of the research, the WUAs were found to be below 70% efficiency and to be affected by independent variables. The WUAs were also evaluated in Calabria, Italy, by deploying DEA models [18]. From the analysis, the cost recovery of WUAs was found to be low, excess water was delivered, and the water service was underutilised.

Studies related to water and agricultural efficiencies found more in China. DEA techniques based on input–output technical efficiency and sub-vector efficiencies for irrigation were analysed for water use [19]. By using inputs more efficiently, the wheat farmers could increase their production by approximately 38%. The determinants of water efficiency were explored for China in the Guanzhong Plan using stochastic frontier analysis [20]. Management reforms, water prices, farm level, and disclosure were found to be important factors affecting water use efficiency. A case study on the Heihe river basin in China was studied to understand the impact of water-use efficiency on the water consumption of agricultural production [21]. The results also indicate that economic growth, agricultural investment, and agricultural plants' structural adjustment significantly influence agricultural water use efficiency. Based on the stochastic frontier analysis model, by taking data from 31 provinces in China, agricultural water use efficiency was examined [22]. The efficiency of water use was found to be influenced by the proportion of high school education and rural household income. Apart from the two, the storage capacity of reservoirs, the number of water-saving machines, the sown area of crops, and the number of motors also influenced the efficiency. DEA analysis was also deployed to find the relative water use efficiency of the 31 provinces of China in green-blue water and blue-only conditions [23]. The pure technical efficiency and the technical efficiency of green-blue conditions were found to be relatively high. However, the potential for blue-water efficiency was found to be high. In a similar region, the projection pursuit model is deployed, and thereby overall efficiency is determined for all 31 provinces in China [24]. Provinces with high, medium, and low efficiency were identified, but in some provinces, the environmental quality of the water was reduced due to various factors.

Research Gap

There is a need to understand economic, social, and environmental perspectives towards sustainable water management in irrigation [25]. Thereby, there is a need to understand various issues in irrigation management systems and the contributions of WUAs. The water investments by the government need to understand the objectives of land area irrigated and irrigation modernisation [13]. The study attempts to evaluate the investments and user charges collected by WUAs in Jharkhand state.

3. Methodology

The term "technical efficiency" first appeared in economic literature in the early 1950s when ref. [26] described it as an input–output vector that is technically efficient if and only if increasing any output or decreasing any input is possible only by increasing any other input or decreasing any other output. This definition is regarded as a Pareto–Koopmans condition of technical efficiency in economics. By creating a linear programming (LP) model utilising real input–output data from a sample of businesses, ref. [27] expanded on Koopmans' work and made a ground-breaking contribution. The application of [27]'s linear programming methods eventually influenced [28] to develop DEA.

Because DEA makes fewer assumptions about the nature of technology and mathematical programming techniques that can be used to obtain pointwise estimates of the production function, it is preferable to its archrival SFA (Suitability, Feasibility, and Acceptability) in the current context. DEA's inherent advantages include its ability to easily handle multiple inputs and outputs. This is a significant benefit given the typical lack of such information. Third, unlike SFA, which attempts to correlate a DMU's performance with statistical averages, DEA determines the inefficiency of a specific DMU by comparing it with comparable DMUs that are considered to be efficient. Additionally, this method aids in evaluating the causes of inefficiency, such as inefficiency brought on by scale or size (scale inefficiency) and/or management methods (pure technical inefficiency).

3.1. Selection of the Model

Efficiency is determined by either modifying inputs or outputs in the fundamental CCR [28] model based on constant returns to scale (CRS) and the BCC (Banker, Charnes, and Cooper 1984) model based on Variable Returns to Scale (VRS) models, i.e., either the input-oriented model (IP) or output-oriented model (OP). An input-orientation model creates the intended result with the fewest possible inputs. On the other hand, the output orientation paradigm maximises outputs while maintaining a constant quantity of input. The BCC model [29] and the radial CCR model also have this flaw: they fail to account for efficiencies' slacks. Therefore, to compensate for this flaw, efficiency scores might occasionally be calculated using the "slack-based model" (SBM) proposed by [30]. A non-oriented SBM model is used when inputs and outputs can be altered simultaneously, meaning the DMU can decrease inputs while increasing outputs. To maximise efficiency, managers can use this approach to work on both inputs and outcomes. The SBM model was used [31] to examine the effectiveness of public hospitals in Uttarakhand, India. The output-oriented paradigm and other input-oriented models have been used in several investigations. In most cases, choosing the orientation (input or output) for evaluating efficiency is challenging, so reducing input levels or raising output levels is not admirable. Therefore, in the literature, ref. [32] employed the orientation-independent CCR model, the orientation-dependent BCC model, as well as the non-oriented and non-radial SBM-DEA model. Moreover, the authors studied the efficiency scores of the hotels and restaurants in India using combined Data Envelopment Analysis and Shannon's Entropy.

In the present study, we followed similar lines of [32] procedure to evaluate the efficiencies and performance of the selected nine canals.

3.2. DEA with Shannon's Entropy

The number of DMUs may be divided into two disjoint groups, efficient and inefficient, using DEA methods such as CCR, BCC, SBM, etc. However, it is time-consuming to rank all of the DMUs or determine which is the most effective among the effective DMUs. There are several approaches available in the literature to rate the DMUs, including super efficiency [33], cross-efficiency [34], minimum and maximum efficiency scores [35], maximal balance index [36], etc.

When ranking the DMUs with the techniques, a specific model is considered along with the provided dataset. The process of choosing the study's variables can be difficult at times. In these circumstances, it was advised to test every DEA model available [37–40]. Then, using Shannon's Entropy, a total score is produced based on the combined data. Shannon's Entropy combined with DEA is also used in engineering fields such as the composition of drug gel [41] and choosing experimental parameters [42]. In this work, we used the [30] methodology to rank the DMUs using comprehensive efficiency scores (CES). The chosen strategy is demonstrated below.

Steps for Combined Shannon's Entropy and DEA:

Step 1: Select datasets.

Step 2: Create every feasible pairing of the initial dataset's input and output subgroups is $\boldsymbol{L} = (\boldsymbol{2^m} - \boldsymbol{1})(\boldsymbol{2^s} - \boldsymbol{1})$.

Step 3: Determine the relative efficiency scores of each DMU by evaluating the efficiency scores using DEA models (VRS-IP, VRS-OP, and SBM non-oriented). As $\boldsymbol{E_{jl}}$ Variable Returns to Scale (VRS) models, i.e., either the input-oriented model (IP) or output-oriented model (OP) slack-based method (SBM).

Step 4: Using the matrix $\left(\boldsymbol{E_{jl}}\right)_{\boldsymbol{nXL}}$, determine the set $\boldsymbol{e_{jl}} = \frac{E_{jl}}{\sum_{j=1}^{n} E_{jl}}$.

Step 5: Determine the level of diversification set $\boldsymbol{d_l} = \boldsymbol{1} - \boldsymbol{f_l}$ *where* $\boldsymbol{f_l} = \frac{-1}{\ln(n)} \sum_{j=1}^{n} \boldsymbol{e_{jl}} \ln\left(\boldsymbol{e_{jl}}\right)$.

Step 6: Determine the CES as $\theta_j = \sum_{l=1}^{L} w_l \, E_{jl}$, where $w_l = \frac{d_l}{\sum_{l=1}^{L} d_l}$, such that $\sum_{l=1}^{L} w_l = 1$.

Utilising the mathematical software (Version 22) MATLAB, the findings of the DEA with Shannon's Entropy model are provided.

4. Results and Discussion

The current study was carried out in two stages. Commissioned in the 1960s, the Kanchi River Canal Project, which gets its waters from the Kanchi River, is spread over 150 kilometres and is a source of irrigation for 17,800 hectares of land cultivated by over 50,000 farmers in five blocks in Khunti, Ranchi, and Seraikela-Kharsawan districts of the state. The canal starts in Ranchi district, flows through Khunti, and ends in Seraikela Kharsawan. But neglect and the fact that large tracts of the canal continue to be kuccha (non-lined and uncemented) have led to the water drying up in large tracts, complain the farmers. The farmers said that they have agitated several times to draw attention to the disuse of the Kanchi canal. The Irrigation Department of the Government of Jharkhand acknowledged that farmers were suffering due to a lack of repairs. The work at a cost of INR 12 lakhs had been taken up, and the irrigation department had sent a detailed project report to the state government about the repairs needed at an expected cost of INR 65 lakhs. In view of the importance of the project and the ongoing and proposed repair and rehabilitation work, the study was undertaken for the reference period of 2018 to 2021. In the first stage, the performance of a selected nine canals in India is analysed using DEA methods such as VRS input and output-oriented and a non-oriented slack-based method (SBM). The second stage is focused on ranking canals using Shannon's Entropy method blended with adopted DEA methods. Results are shown in Tables 2–4 and Figure 1 of the selected nine canal datasets for the years 2018–2021. Table 2 shows the efficiencies of all canals from 2018 to 2021 using VRSIP, VRSOP, and SBM. It is evident from Table 2 that the number of efficient canals and the DMUs are the same under the adopted methods in the respective years. Canal 7 is not efficient in all years, and Canal 5 is efficient in 3 years. There is no canal efficiency in all four years. Five canals have shown efficiency in 2018, four in 2021, three in 2019, and only two in 2020. Neglected during the COVID pandemic as a result of group activities and meetings of WUAs and also the adverse functioning of the government offices due to restrictions and lockdown led to the water drying up in large tracts. This, in turn, has affected the trend in efficiency of DMUs during the period with the worst performance in the year 2020. It is undecidable to group canals as efficient or inefficient, as the number of efficient canals is not the same in all years. A new methodology is needed to segregate and rank canals. The adopted methods are blended with Shannon's Entropy to obtain comprehensive efficiency scores, or CES. Table 3 shows the captivating CES of all canals for all the years. Primarily, Canal 7 has obtained the lowest CES among all canals in all years under the respective adopted methods. It is noticeable that every canal has a non-repeated CES in its respective years. It enables us to rank canals effortlessly, as shown in Table 4. From Table 4, it is observed that canals are ranked in sporadic order from year to year. The adopted blended method is merely beneficial for ranking canals effortlessly.

Table 2. Efficiencies of canals from 2018 to 2021 using VRSIP, VRSOP, and SBM.

	Efficiencies Using VRSIP				Efficiencies Using VRSOP				Efficiencies Using SBM			
DMU	**2018**	**2019**	**2020**	**2021**	**2018**	**2019**	**2020**	**2021**	**2018**	**2019**	**2020**	**2021**
Canal 1	0.9487	0.8392	1	0.8778	0.9678	0.969	1	0.9472	0.9364	0.6679	1	0.8243
Canal 2	1	0.7177	0.8403	1	1	0.9002	0.9495	1	1	0.7142	0.6148	0.8746
Canal 3	1	0.9365	0.9955	0.9512	1	0.9589	0.9989	0.9653	1	0.8635	0.8925	0.7964
Canal 4	0.9217	1	1	0.9384	0.9367	1	1	0.9554	0.8603	1	1	0.6941
Canal 5	1	1	0.9024	1	1	1	0.9094	1	1	1	0.7539	1
Canal 6	0.9901	1	0.9795	1	0.9901	1	0.9795	1	0.986	1	0.7841	1

Table 2. *Cont.*

	Efficiencies Using VRSIP				Efficiencies Using VRSOP				Efficiencies Using SBM			
DMU	**2018**	**2019**	**2020**	**2021**	**2018**	**2019**	**2020**	**2021**	**2018**	**2019**	**2020**	**2021**
Canal 7	0.7863	0.7346	0.8187	0.879	0.7863	0.7836	0.8238	0.8939	0.7665	0.5833	0.6112	0.6984
Canal 8	1	0.9188	0.9998	0.6626	1	0.9188	0.9998	0.6626	1	0.6749	0.9079	0.6074
Canal 9	1	0.8545	0.99	1	1	0.8545	0.99	1	1	0.6003	0.876	1

Table 3. Comprehensive efficiency scores of all canals from 2018 to 2021.

	CES Using VRSIP				CES Using VRSOP				CES Using SBM			
DMU	**2018**	**2019**	**2020**	**2021**	**2018**	**2019**	**2020**	**2021**	**2018**	**2019**	**2020**	**2021**
Canal 1	0.8051	0.6381	0.7877	0.7608	0.8918	0.8029	0.9855	0.8331	0.7897	0.6265	0.7026	0.7066
Canal 2	0.8398	0.6828	0.6343	0.892	0.9244	0.8798	0.8026	0.9702	0.8061	0.6838	0.5854	0.8218
Canal 3	0.8662	0.8043	0.8996	0.7315	0.9038	0.8826	0.9008	0.8103	0.8684	0.8183	0.8874	0.6754
Canal 4	0.7464	0.7772	0.9988	0.6305	0.8661	0.8202	0.9984	0.7343	0.7358	0.7535	0.9991	0.5858
Canal 5	0.9667	0.9604	0.7245	0.9325	0.9875	0.9936	0.8804	0.948	0.8493	0.9702	0.7062	0.8668
Canal 6	0.8414	0.8482	0.6761	0.964	0.9126	0.797	0.8351	0.9895	0.835	0.6667	0.6524	0.8823
Canal 7	0.6508	0.5281	0.5946	0.6573	0.6858	0.556	0.6469	0.6701	0.6499	0.546	0.5726	0.6033
Canal 8	0.8429	0.6167	0.7395	0.5249	0.8919	0.5314	0.7563	0.5516	0.8621	0.6088	0.733	0.5216
Canal 9	0.8145	0.5368	0.9156	0.9299	0.8212	0.5359	0.8959	0.9116	0.8137	0.5485	0.8955	0.9235

Table 4. Ranks of all canals using VRSIP, VRSOP, and SBM CES.

	Ranks Using VRSIP-CES				Ranks Using VRSOP-CES				Ranks Using SBM-CES			
DMU	**2018**	**2019**	**2020**	**2021**	**2018**	**2019**	**2020**	**2021**	**2018**	**2019**	**2020**	**2021**
Canal 1	7	6	4	5	6	5	2	5	7	6	6	5
Canal 2	5	5	8	4	2	3	7	2	6	4	8	4
Canal 3	2	3	3	6	4	2	3	6	1	2	3	6
Canal 4	8	4	1	8	7	4	1	7	8	3	1	8
Canal 5	1	1	6	2	1	1	5	3	3	1	5	3
Canal 6	4	2	7	1	3	6	6	1	4	5	7	2
Canal 7	9	9	9	7	9	7	9	8	9	9	9	7
Canal 8	3	7	5	9	5	9	8	9	2	7	4	9
Canal 9	6	8	2	3	8	8	4	4	5	8	2	1

Nevertheless, it is difficult to make a decision on the ranks obtained by the blended methods. Therefore, it recommends a precise procedure to decide which of the blended methods to use to rank canals. A typical linear fit procedure and coefficient of determination value benefit in deciding on the ranks obtained by adopted methods.

The linear fit between ranks obtained by CES values evaluated using adopted methods and coefficient of determination values is illustrated in Figure 2a–d. Figure 2a,c shows that the coefficient of determination value is very low between the ranks obtained by the CES values of VRSOP and SBM. The coefficient of determination value between ranks obtained by CES values of VRSIP and VRSOP is medium in Figure 2a–c. It is evident from Figure 2a–d that there is a strong relationship between ranks obtained by CES values of VRSIP and SBM methods. From all the figures, it can be noted that medium and strong relationships can be considered one of the adopted methods to decide the ranks of canals. Ranks obtained by CES values using VRSIP are mostly in medium and strong relation to ranks obtained using CES values of VRSOP and SBM methods, respectively. It emphasises that ranks obtained by CES values using VRSIP can be considered for further investigation of canals.

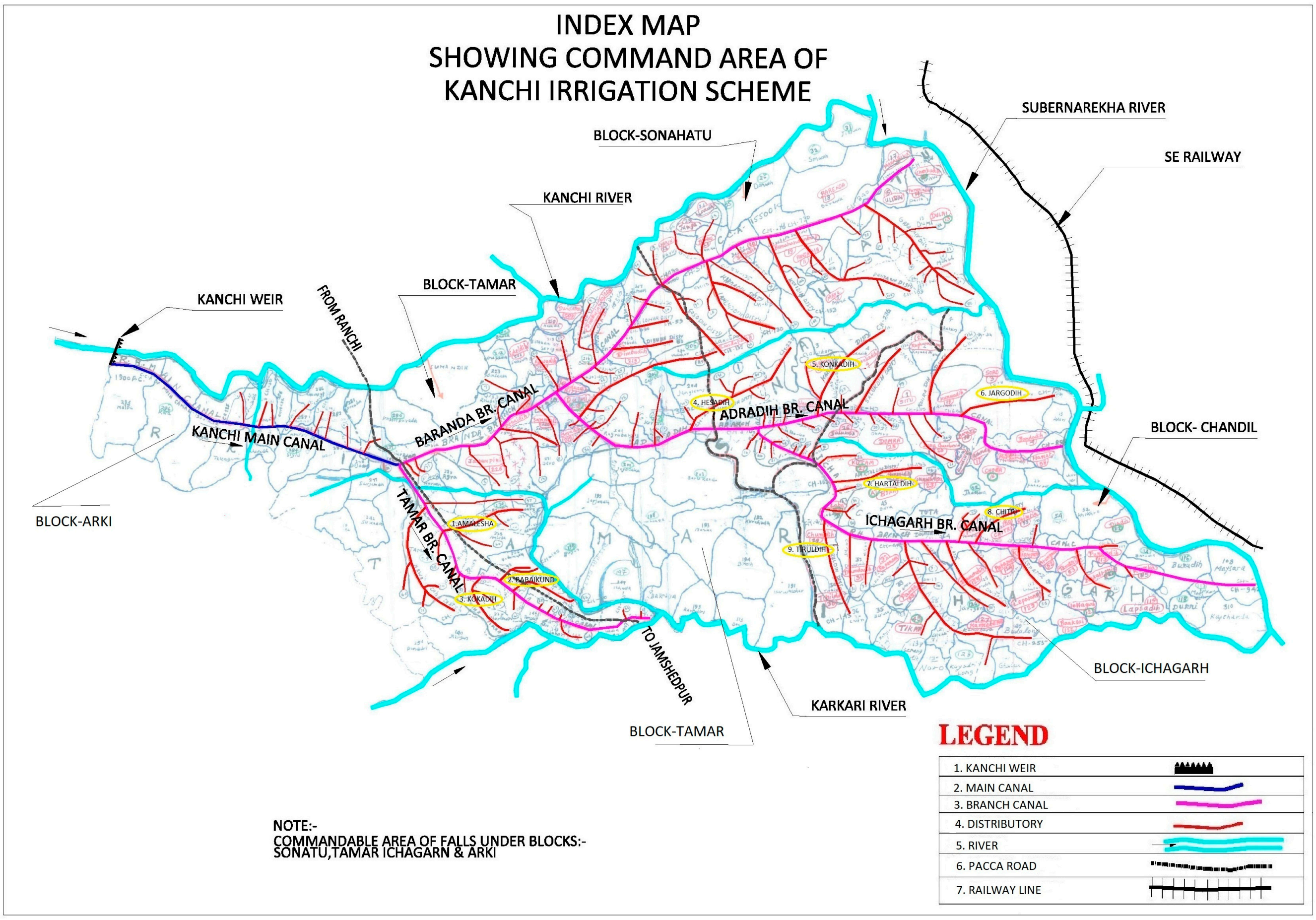
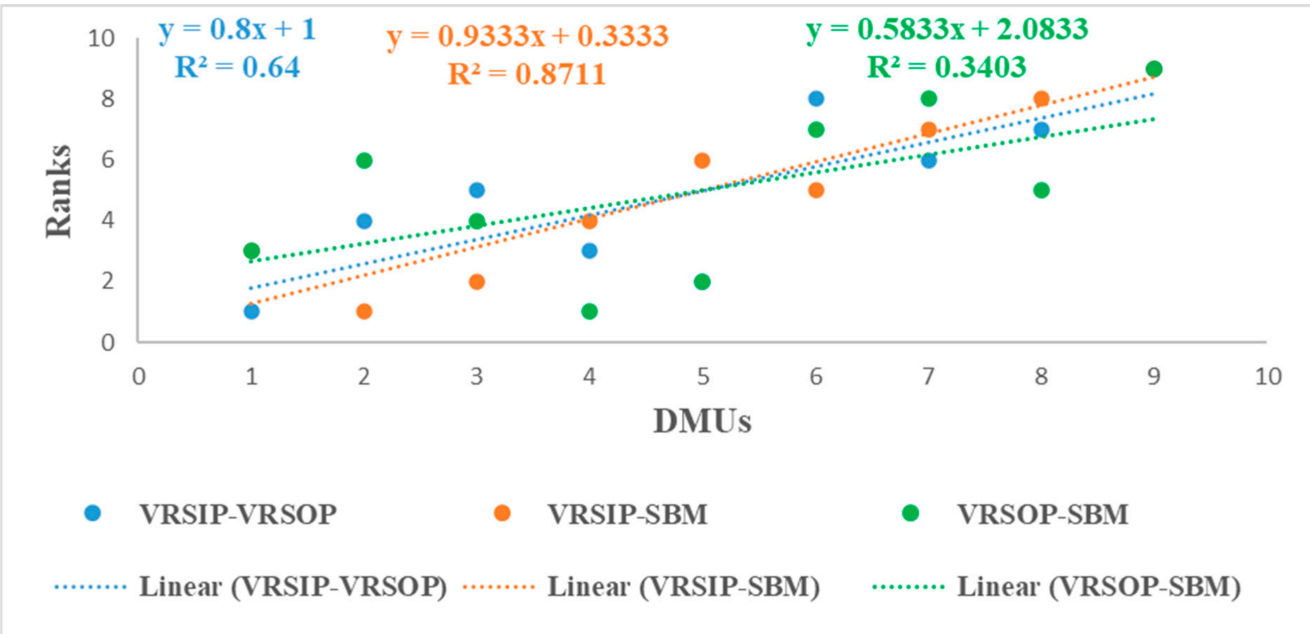
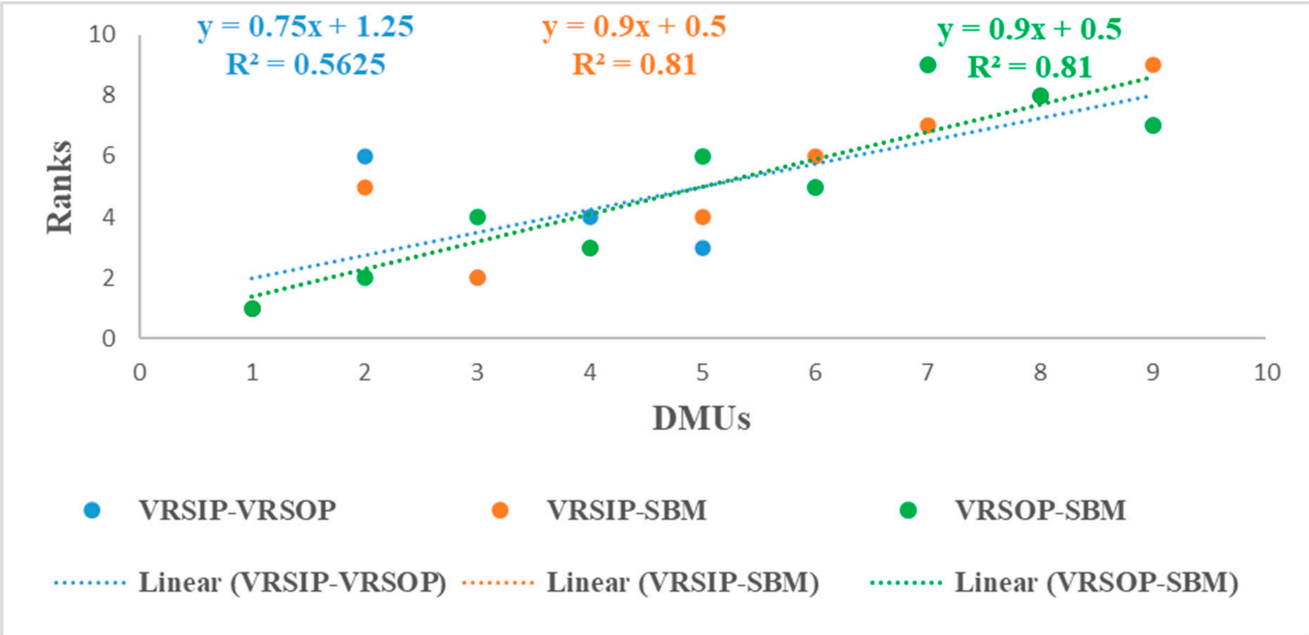


Figure 1. Location of Kanchi Irrigation Project.

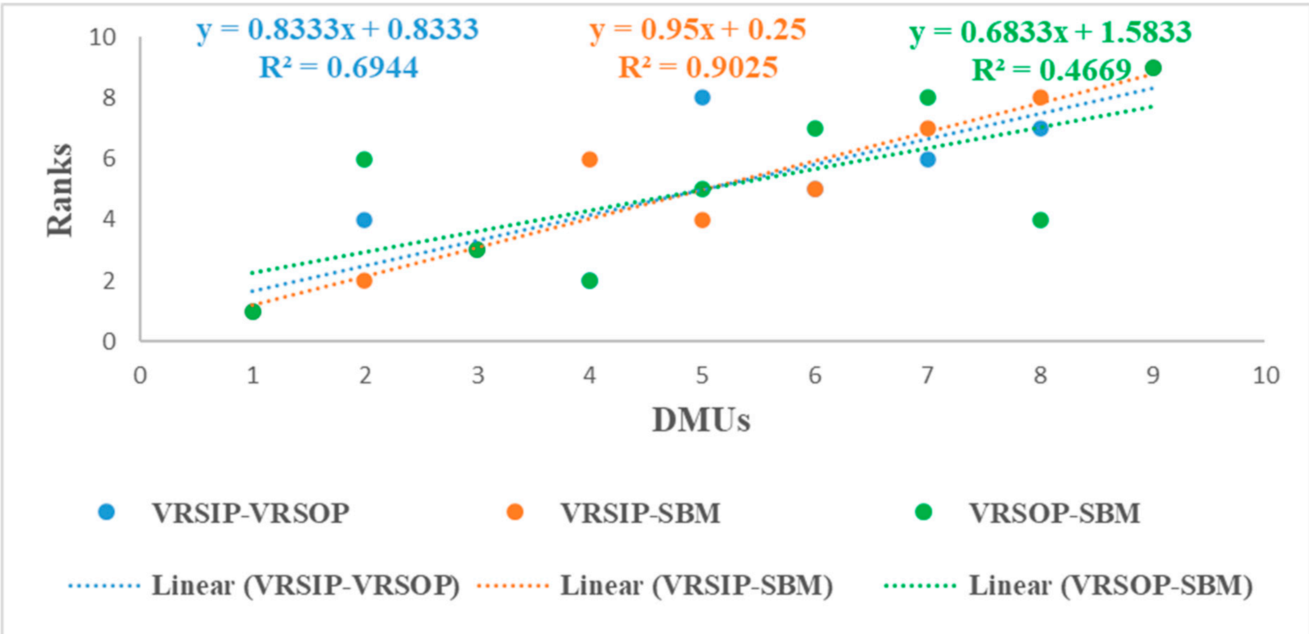


(**a**)

Figure 2. *Cont.*

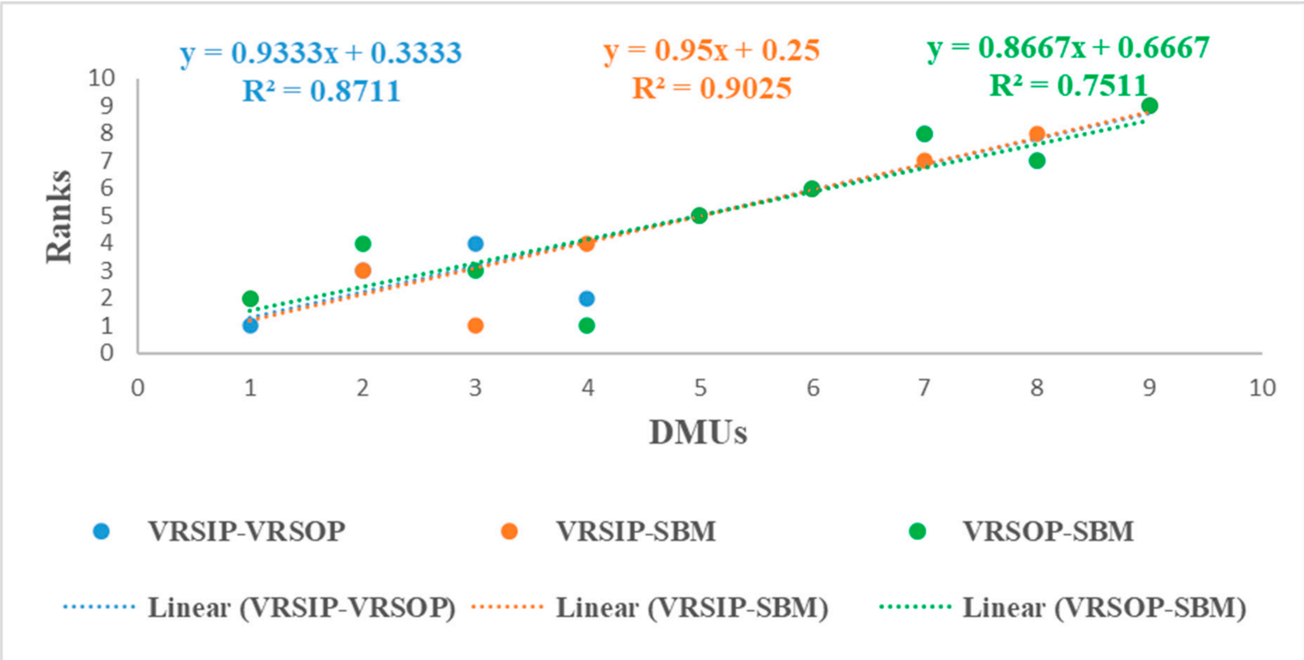


(**b**)



(**c**)

Figure 2. *Cont*.



(**d**)

Figure 2. Linear fit and Coefficient of determination values between ranks obtained by CES values evaluated using adopted methods from 2018 to 2021. (**a**) 2018; (**b**) 2019; (**c**) 2020; (**d**) 2021.

The statistical significance was examined at 95% confidence level (significance level of 0.05), and the Significance F results are mentioned below in Table 5 for your reference.

Table 5. Statistical significance of the results.

	2018	2019	2020	2021
VRSIP-VRSOP	0.0096	0.0199	0.0053	0.0002
VRSIP-SBM	0.0002	0.0009	0.0001	0.0001
VRSOP-SBM	0.0992	0.0009	0.0424	0.0025

5. Conclusions

DEA is a technique that evaluates the relative efficiency of multiple DMUs in achieving a specific set of outputs from a given set of inputs. The DEA methods used in the study include VRSIP, VRSOP, and SBM. VRSIP is an input-oriented method that compares the actual input–output ratios of a DMU with the optimal input–output ratios of other DMUs in the same dataset. VRSOP is an output-oriented method that evaluates technical efficiency from an output perspective. At the same time, SBM is a method that focuses on the degree of slack or unused resources associated with each DMU. Based on the analysis using different types of Data Envelopment Analysis (DEA) methods, the technical efficiency of different Decision-Making Units (DMUs) over a four-year period was observed in the study. The efficiency scores obtained from VRSOP were generally higher than those obtained from VRSIP, and the efficiency scores obtained from SBM were generally lower than those obtained from both VRSIP and VRSOP. Ranks obtained by CES values using VRSIP are mostly in medium and strong relation to ranks obtained using CES values of VRSOP and SBM methods, respectively. It emphasises that ranks obtained by CES values using VRSIP can be considered for further investigation of canals.

The efficiency scores of nine DMUs (Decision-Making Units) for four consecutive years, 2018–2021, using the VRSIP (Variable Returns to Scale—Input-oriented) approach in Data Envelopment Analysis (DEA) were obtained. The scores range from 0 to 1, with higher scores indicating higher efficiency. The efficiency of DMUs varied from year to year. Canal 5 was identified as the most efficient DMU overall, with comprehensive efficiency scores of 0.9667, 0.9604, 0.7245, and 0.9325 for the years 2018, 2019, 2020, and 2021, respectively. Canal 5 was the most consistently efficient DMU, with efficiencies of 1 in most years. Canal 7 was the least efficient DMU, with efficiencies ranging from 0.7346 to 0.879 over the four-year period. Comprehensive efficiency scores (CES) provide an overall picture of the efficiency of DMUs over the four-year period, considering all inputs and outputs. In the context of irrigation system management, DEA can be used to evaluate the technical efficiency of different DMUs. By identifying the most efficient DMUs and highlighting areas where others fall short, DEA can provide insights into ways to improve irrigation system management policies and practises.

The Jharkhand State has implemented a policy of transferring the management of irrigation systems to farmer groups since 2014, when the Jharkhand Participatory Irrigation Management Rules were implemented. The policy and the rules involve the management of irrigation water supply and related infrastructure to ensure that water is distributed equitably and efficiently to farmers. The policies also involve measures to promote the use of modern irrigation technologies and farming practises that conserve water. Nine Water Users' Associations (WUAs) were selected from Kanchi canal command areas based on available data and discussions with irrigation department officials. Data for the study was collected from two sources: the sample farmers and the records of the nine selected Water Users' Associations (WUAs) in the study area. A total of 99 farmers were randomly selected for the study. The sample farmers were chosen randomly from lists provided by each WUA and represented a range of farm sizes, including small, medium, and large. According to the Input cost study, the formation and registration fees for the WUAs in Jharkhand were jointly paid by both the WUA members and the MoWR of the Jharkhand government, indicating a shared interest in establishing and recognising the WUAs as part of the government's policy to transfer irrigation system management to farmer groups. WUAs collect fees from their members to finance the operations and maintenance of the irrigation system, and the cost of holding regular meetings includes various expenses such as venue rental, transportation, refreshments, and materials.

The study's findings show that in the case of Canal 5 (Konkadih distributory), the WUAs were able to leverage the government's investment in meetings and training through a comparatively higher collection of user charges from their members. This was evident in the members participation in the meetings. The investment by the government in O&M costs was also leveraged to increase the contribution and value of such works undertaken by WUA. With better availability of water, the cropped area increased, and crop diversification happened. Whereas the area under food grain cultivation increased, the area under non-food grain crops also increased due to their higher profitability. The accountability for irrigation water use has increased with the introduction of WUAs, resulting in a rise in the irrigated area. The increase in the irrigated area was around 35% in the summer, while in the kharif and rabi seasons, it was around 23% and 16%, respectively. Field observation of Canal 7 (Hartaldih) revealed that the canal is providing only partial irrigation as it is damaged and in a poor state of maintenance. Overall, the analysis of technical efficiency using DEA methods provides insights into the performance of WUAs in Jharkhand. The findings can be used to identify best practises and areas for improvement and inform the development of policies and strategies to support the sustainable management of irrigation systems.

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Abbreviations

CES	Comprehensive Efficiency Scores
DEA	Data Envelopment Analysis
DMUs	Decision-Making Units
EXPROM	Extension of the PROMETHEE
GCA	Gross Command Area
IP	Input-oriented model
MATLAB	Matrix Laboratory
MCDM	Multi-Criteria Decision-Making
O&M	Operations and maintenance
OP	Output-oriented model
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
SBM	Slack-based method
SBM	Slack-based model
SFA	Suitability, Feasibility, and Acceptability
VRS	Variable Returns to Scale
VRSIP	Variable Returns to Scale–Input-oriented model
VRSOP	Variable Returns to Scale–Output-oriented model
WUA	Water Users' Association

Appendix A

		Year 2018		
DMUs Canal Names	**Input 1**	**Input 2**	**Output 1**	**Output 2**
Amlesha Distribution	0.17	7.77	10.28	12.23
Babaikund Distribution	0.13	9.10	11.56	9.35
Kokadih Distribution	0.16	7.18	9.66	13.22
Hesadih Distribution	0.21	6.60	9.89	11.25
Konkadih Distribution	0.20	7.21	12.45	12.67
Jargodih Distribution	0.17	6.23	10.48	10.56
Hartaldih Distribution	0.14	6.93	7.56	8.65
Chitri Distribution	0.15	4.72	8.56	9.15
Tiruldih Distribution	0.13	5.86	6.85	10.97
		Year 2019		
	Input 1	**Input 2**	**Output 1**	**Output 2**
Amlesha Distribution	0.07	6.74	6.57	15.89
Babaikund Distribution	0.04	7.90	7.55	13.25
Kokadih Distribution	0.04	6.23	7.42	14.68
Hesadih Distribution	0.06	5.73	6.31	16.89
Konkadih Distribution	0.04	6.26	8.54	14.56
Jargodih Distribution	0.03	5.41	5.34	14.55
Hartaldih Distribution	0.04	6.01	4.25	12.35
Chitri Distribution	0.02	4.10	2.58	10.23
Tiruldih Distribution	0.04	5.08	3.54	12.38
		Year 2020		
	Input 1	**Input 2**	**Output 1**	**Output 2**
Amlesha Distribution	0.15	3.69	8.35	18.95
Babaikund Distribution	0.11	4.32	6.39	16.54
Kokadih Distribution	0.08	3.41	7.45	15.64
Hesadih Distribution	0.08	3.13	8.53	15.64
Konkadih Distribution	0.11	3.42	7.42	15.64
Jargodih Distribution	0.12	2.96	6.58	14.88
Hartaldih Distribution	0.09	3.29	4.87	13.54
Chitri Distribution	0.07	2.24	4.67	11.34
Tiruldih Distribution	0.06	2.78	5.82	11.35

	Year 2021			
	Input 1	**Input 2**	**Output 1**	**Output 2**
Amlesha Distribution	0.21	5.13	5.63	19.56
Babaikund Distribution	0.19	6.01	7.21	18.56
Kokadih Distribution	0.23	4.75	5.34	19.88
Hesadih Distribution	0.25	4.36	4.58	18.54
Konkadih Distribution	0.19	4.76	6.58	20.65
Jargodih Distribution	0.23	4.12	7.55	18.65
Hartaldih Distribution	0.16	4.58	3.49	16.54
Chitri Distribution	0.17	3.12	3.19	9.35
Tiruldih Distribution	0.11	3.87	4.51	14.65

All the units are in Lakhs INR.

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