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Efficiency Evaluation of Water and Municipal Wastewater, Using Data Envelopment Analysis Approach: A Case Study in Markazi Province

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Abstract

Nowadays productivity evaluation and its components, and efficiency and effectiveness, is one of the concerns of businesses and government agencies. Water and sewerage companies, given its resource constraints, are intended to increase the efficiency of their activities in order to provide drinking water and industry, and hence, increasing the efficiency of water and municipal wastewater plants in each province, will be the development of the whole province. This paper presents a method based upon data envelopment analysis to measure the efficiency affairs of water and wastewater cities in Markazi province, and carried out with real data, related to the cities, and analyzing the results.

Key words: Efficiency Evaluation, Wastewater, Data Envelopment Analysis

Introduction

In a general perspective, the productivity of an organization, defined as the ratio between the outputs produced (products or services), to the inputs used to produce them. Looking at and more accurately, the productivity can be, combining efficiency and effectiveness. In other words, it is organizational productivity, which is both efficient and effective. Performance is a means of the organization empowerment, in the efficient use of inputs in producing outputs, and effectiveness measures are the achievement of expected goals.

However, new definitions, given the productivity, and efficiency, not only in the efficiency and effectiveness, they are linked to the quality of outputs, inputs and processes. In the early years of the third millennium, the world is trying to get a bigger share of world trade, devoting itself. To achieve this goal, countries need to increase their competitiveness, and this will be possible only through, enhancing productivity, and improving quality. Improving productivity and quality, nowadays, is becoming a national movement, in many developing countries, and as one of the main axes of development, large investments should be made in this respect.

At present, the low level of productivity, and poor share in GDP is required for all companies, organizations and government agencies in the country, which provides a mechanism labor productivity growth in their operations, so that overall productivity growth can have the annual increase rate of 2.5 percent, and the share of productivity growth in GDP can have an increase of 33.3 percent. For the implementation of this act, it is required to be able to increase productivity growth rate, which is calculated at each performance period, the organization's strengths and weaknesses, and determine the potential for increasing the productivity of the organization.

Now, with the implementation of targeted subsidies, and rising energy costs, it is important to increase the company's findings. Improved management, in use of existing resources, and increasing the efficiency of various departments, which ultimately leads to lower costs or increasing production, leading to the productivity in the company.

Water and sewerage companies have been suggested as the primary custodian, water needs of citizens, and industries, as well as wastewater collection, and therefore play an important role in the sustainable development of the country. In the process leading to the drinking water supply, as well as in process by which the sewage in the best way possible, the collection and reusing productivity, finds a special place in all sectors, for which, water resources in the country are considered as limited resources. In the current century, in whole world water crisis, as the crisis ahead, have been identified by international organizations.

WWC of Markazi Province, correctly, understands the need to improve efficiency and productivity measurement units, headquarters, and affairs of City's Water and Wastewater, defined in terms of a project of research - applied in 2012, and implemented in collaboration with the Behin Gostar Giti. This paper presents part of the implementation process, and the result shows the performance assessment affairs of cities waste water.

Methodology and data analysis

Data envelopment analysis (DEA) is one of the most advanced techniques based on mathematical programming, which is used widely in organizations and industries, to calculate efficiency units with similar functions, or a unit over time.This technique is the main methodology used in this project.

In recent years, a wide variety of practical applications, from the DEA, was observed in the evaluation and analysis of financial and economic activities, industrial and service organizations. One reason for the success of this branch of science is the decision-making and management. It is binding to the highly successful branch of applied mathematics, which significance is not covered on the experts today. This makes it possible to evaluate the performance of the receiver, the complex nature of such units that are multi-input and multi-output data (possibly) quality, and as you know, most organizations are with such a complex nature.

This method from the Decision Making Units series, introduces the best performing units, as units efficiently, and help them form the boundaries of performance, then, this border, puts another unit assessment criteria. The best performance units are units that, according to their size, with minimum input, maximum output can be produced. Efficiency rating inefficient units, calculated based on the distance that they have to limit performance, as well as strategies to improve the inefficient Unit, which is determined based on the amount of growth that should be in every index to match on efficiency frontier.

Efficiency is defined as the ratio of output to input. In case of multiple input and output, efficiency is defined as the sum of weighted outputs to weighted sum of inputs. If the value of the inputs and outputs are known, then the efficiency is calculated simply as follows.

$$TE_i = \frac{u_1 y_{1i} + ... + u_s y_{si}}{v_1 x_{1i} + ... + v_m x_{mi}}$$

In which vi, is the input value, and ui, is the output value Unit the i. The problem, however, is the value of inputs and outputs. If the units under evaluation are production units, the problem is not give a value or pricing of inputs and outputs, but if units are produced, it is difficult and perhaps impossible to determine the true value of inputs and outputs. Therefore, the DEA, the inputs and outputs are assumed variable and for calculating efficiency, below deficit model proposed in 1978 by Charnez, Cooper and Rhodes, who was known to the CCR (Charnes, Cooper & Rhodes, 1978).

$$\max \frac{\sum_r u_r y_{rp}}{\sum_i v_i x_{ip}}$$

$$\frac{\sum_r u_r y_{rj}}{\sum_i v_i x_{ij}} \le c$$

$$st \quad u_r, v_i \ge 0$$

c is the arbitrary constant, which is usually considered as one. In fact, the model above considers all possible weights for the input and output Unit p, and weight gains that are, for them, is the highest objective function. Given the constraints of the problem, the objective function value, the maximum can be c. If the unit p, is inefficient compared to other units, in the process maximizing the objective function, constraints related to the performance of the constraint set, the sooner reach to the value of c, and p-force Unit, placed at a level below c, However, if the Unit is efficient p, objective function reaches to the value of c, disappear without feasibility constraints.

It should be noted that, CCR has been stated above, is the deficit, and in practice, from the line used in it. In the following, we explain some of the models applied to the Data envelopment analysis.

Multiple forms of BCC model

$$
\begin{aligned}
Max \quad & \sum_{r=1}^{s} u_r y_{rp} + u_0 \\
st \quad & \sum_{i=1}^{m} v_i x_{ip} = 1, \\
& \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} + u_0 \le 0, \quad j = 1, \dots, n \\
& u_r \ge \varepsilon, \qquad r = 1, \dots, s \\
& v_i \ge \varepsilon, \qquad i = 1, \dots, m \\
& u_0 \ \textit{free in sign}
\end{aligned}
$$

Multiple forms of CCR model

$$
\begin{aligned}
Max \quad & \sum_{r=1}^{s} u_r y_{rp} \\
st \quad & \sum_{i=1}^{m} v_i x_{ip} = 1, \\
& \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, \quad j = 1, \dots, n \\
& u_r \ge \varepsilon, \qquad r = 1, \dots, s \\
& v_i \ge \varepsilon, \qquad i = 1, \dots, m
\end{aligned}
$$

All above models are based on the input, which moved the efficient frontier, in order to minimize the input until the output is not reduced. Similar models can be written for the nature of the output. The nature of the output models calculates efficient frontier, and the maximum output until the input does not increase.

Weight limitations

Basically, DEA models do not apply any restrictions on the input and output weights, and models is free for the choice of weights. This freedom in the choice of weights is useful in determining the inefficient units. For, if in this case, the unit is inefficient, meaning that the same weights in optimal allocation, which is seeking the highest level of performance, was also inefficient, and therefore, the same cannot change the weights, which is more efficient. On the other hand, the freedom to determine the weights may cause deviations in the determination of functional units. In other words, there may be a unit by assigning zero weight to some of its inputs or outputs, which have a bad performance, and is efficient. And, it means that we should not have input or output in the evaluation. This deviation may not be acceptable by the decision, which will affect some of the inputs or outputs, in evaluation. In addition, if you have spent a lot of time and accuracy in determining the inputs and outputs.

Even if the weight is zero, it does not have the inputs and outputs, and the results may not be consistent with the understanding the decision on performance. This deviation occurs when weights assigned to inputs and outputs is inconsistent with their relative importance, relative to each other.

For these reasons, the concept of weight restrictions is introduced in order to apply the relative importance of the right, between the inputs and outputs in data envelopment analysis. There are several ways to implement the decision maker judgments about the units, and reduce flexibility in the choice of weights in data envelopment analysis models. A full application of relative weight restrictions, applies the lower and upper bounds on the relative weights of the input and output of the model (Thompson, et al, 1996; Thompson, et al, 1995).

The relative weight limits, defined as follows:

$$a_r^l \le \frac{u_r}{u_1} \le a_r^h \qquad r = 2,...,s$$

$$b_i^l \le \frac{v_i}{v_1} \le b_i^h \qquad i = 2,...,m$$

Fixed values a_r^l, a_r^h, b_i^l, b_i^h, Determined based on the information from the price, or the cost of inputs and outputs, or based on expert opinion, about the relative importance of each indicator.

Research background

Many applications from the data analysis have been reported in Iran and other countries. In the following, we introduce some of the research done in the field of water and wastewater companies.

Technical efficiency and cost analysis in wastewater treatment processes, by using data envelopment analysis (Hernández-Sancho and Sala-Garrido, 2006). In this study, conducted in 2009, Valencia region in Spain, was examined, A total of 338 water and sewage companies were selected . Given the importance of increasing the use of limited water resources and the need to reuse of wastewater or sewage, this study tried to improve companies efficiency, in reusing wastewater produced. The method of data envelopment analysis was used, and the results indicated the impact of equipment maintenance, and waste management costs, which have the greatest impact on the performance of the units.

An important factor is that the re-use of wastewater, is useful not only for businesses, but this contribution is effective in reducing the adverse environmental impacts on the community. In this study, all units are operating in the same environment, the same technology and the same work processes. The main input and output indicators in this study are shown in table 1:

Table 1. The main input and output indicators

Output indicators	Input indicators
Reducing emissions	Energy Costs
	Cost of labor
	Repair and maintenance costs
	Waste management costs
	Other costs

One of the results that are obtained in this research is that the units that operate at higher volumes, the better, and probably this was due to the use of returns to scale are increasing. In addition, the following diagram, which represents the largest number of companies have between 20 to 30% efficiency.

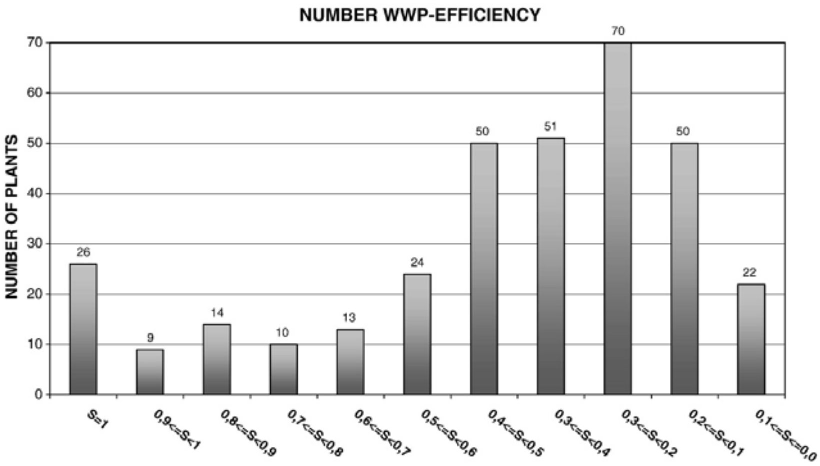


Figure 1. The performance of different units in companies

Economic efficiency of urban water corporations was done in Victoria and New South Wales (Byrnes, et al, 2010). In this study, the 52 companies in the City of Victoria and New South Wales, Australia were selected during the 4-year period from 2000 to 2004. Some factors such as the relative technical efficiency and productivity the company, including exogenous variables, state structures, properties of transmission, and distribution, and tools, and equipment available were considere. In the end, the performance of companies is decomposed into pure efficiency and scale efficiency.

Malmekoiyst productivity index method was used in this study, based on the assessment of productivity changes. Finally, it is concluded that the majority of global politics, with regard to water restrictions, leading to reduction in economic performance of the company, including the companies listed in the Victoria area, and despite the aforementioned companies, they are possessed of administrative efficiency fairly well.

In another study, Hu, Wang, and Yeh (2006) studied the overall performance factors in the water sector in different areas of China. The emphasis is on the importance of water on people's lives, and on economic growth, due to water restrictions. In China, in the past two decades, efficient water distribution system was used, which is very effective in urban infrastructure development, as well as in the lives of citizens, where the study was named the water, along with two of the most important economic inputs, such as labor and capital, and examined the relationship between economic factors, as well as total factor productivity.

In this study, we considered the four factors of labor, capital, housing, water and industrial water, as inputs in the production function, and GDP or Gross domestic product, as the only output was presented in the 30 provinces or regions in China in three western, central and eastern as it is clear from table 2.

Table 2. Input and output of 30 provinces or regions in China

Output indicators	Input indicators
Gross domestic product or GDP	Workforce
	Investors
	Residential water
	Industrial water

The results show that total factor productivity, as well as China's GDP, is highly correlated with factors related to water entry. The final section of this paper was an attempt to describe the relationship between the levels of development of the various regions of China, with the technical efficiency of water distribution.

Thanassoulis (1997) studied the use of data envelopment analysis in the assessing water distribution companies in the UK. They analyzed 32 distribution companies, water and water services provider in the UK, as table 3 indicates the input and output variables as follows:

Table 3. Input and output variables of 32 distribution companies

Output indicators	Input indicators
Number, or the amount of fitting in distribution network	Operating costs
The amount of Subscribers geographical scattering	
The amount of water distributed	
Costs arising from accidents Network	

The model used in this study, is a constant returns to scale, and it is proved that assumption elsewhere in the study by using statistical methods. In another episode, The results showed that the correlation between the output variables is a high positive number. Finally, the resulting efficiency scores, is placed under the micro-sighted analysis, ranking companies.

It follows from the above studies that, because of the importance of water services, water availability is limited in the whole world, and issues such as rapid population growth, increasing attention to efficiency and productivity in recent years. Therefore, preventing the waste of water resources in the network, as well as creating new resources through reusing of used water (wastewater) is necessary.

In most studies, the indicators considered have the same meaning. For example, input parameters are provided in table 4.

Table 4. Input and output parameters

Outputs	Inputs
Reducing emissions	Energy Costs
Gross domestic product or GDP	Cost of labor
Number, or the amount of fitting in distribution network	Repair and maintenance costs
The amount of Subscribers geographical scattering	Waste management costs
The amount of water distributed	Other costs
Costs arising from accidents Network	Workforce
The volume of water produced	Investors
Number of Subscribers	Operating costs
Waste collection refined	Other Operating costs

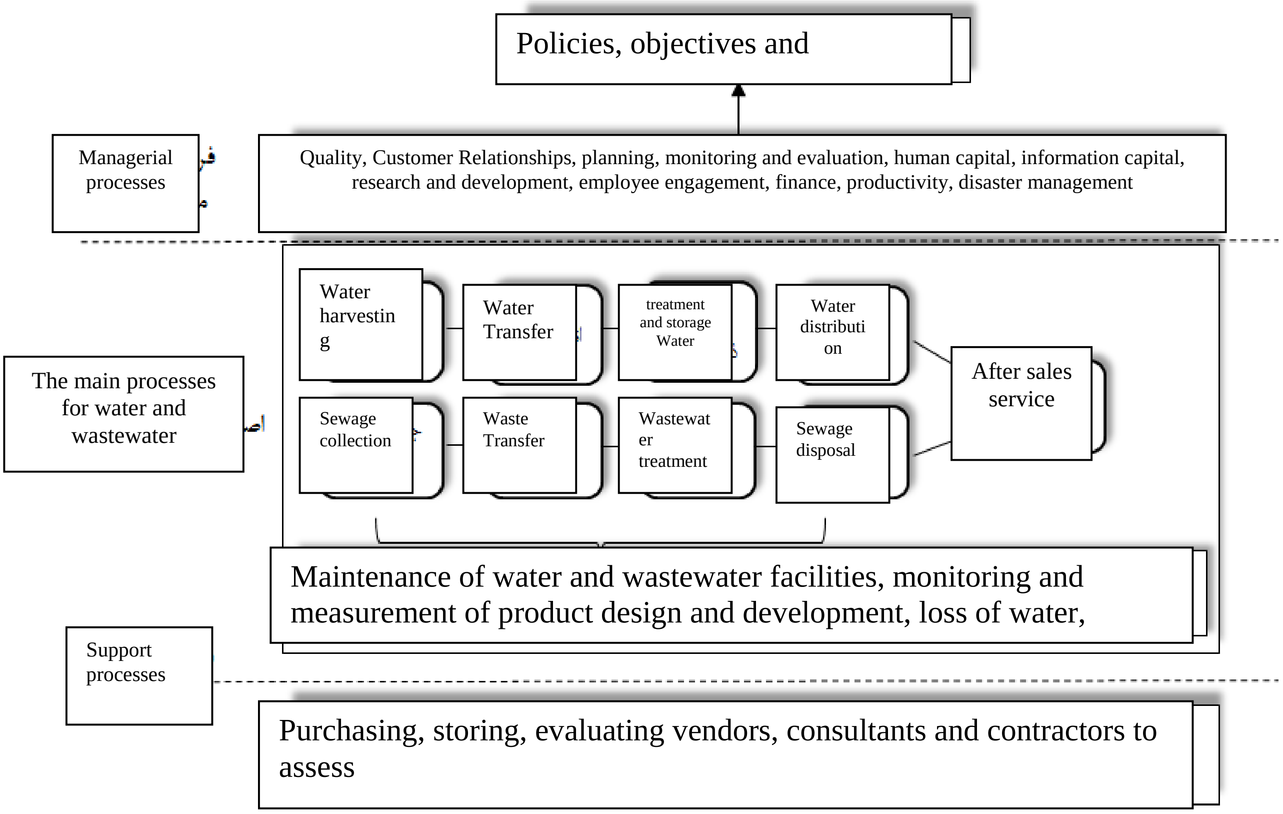
An introduction to Markazi Province Water and Wastewater Company

According to the law, Markazi Province Water and Wastewater Company comprised of water and sanitation established facilities related to the water distribution, as well as the collection, transportation, and urban waste water treatment. The company now operates in 28 cities. It should be noted that, affairs of water and wastewater town of Saveh, leadership and management, in the form of an independent company. Markazi Province Water and Wastewater Company is responsible for the operation of the mission, urban water supply and distribution facilities, and operation of collection systems, and wastewater disposal. According to the mission of the company, the company's processes are defined in terms of two main processes, municipal water supply and distribution, and wastewater collection and disposal according to table 5.

Urban water supply and distribution process begins with the extraction of water from surface and underground sources, and then the transmission facilities, and pumping stations, reservoirs transferring, are implemented. Then, before entering the distribution system, chlorination and disinfection gets into the distribution network. Finally, the process ends with providing after sales services.

Waste collection and disposal process start with the collection of wastewater, sewage connection, and then they are transferred to the treatment plant. Next, the action is taken, refined, and ultimately disposed of treated wastewater, or delivered to the Regional Water Company. Some of these processes are mainly administrative and support processes are designed to be centralized at headquarters, and a number of other cities in the surrounding water and sanitation, which are lined units. Because, the cities, in both water and wastewater are separated from each other, in this research, the performance of the city in two parts, is calculated separately.

Table 5. Municipal water supply and distribution, and wastewater collection and disposal



Input and output factors considered in two parts water and sanitation, according to comparative studies, as well as several meetings with managers and experts in the company, which has been formulated as follows.

Water efficiency

Figure 2 indicates the performance indicators of urban in the water sector, which has been finalized and approved.

Table 6. The main input indicators, and the corresponding indicators

Sub- indicators	The main indicators
Number of Subscribers	Number of Subscribers
The total flow rate of the well	Infrastructure
Water transmission line	
The water distribution network	
Reservoirs Size	
Cost of sales staffing	Manpower costs (Million rials)
Cost of labor exploitation	
Engineering Expenses of human forces	
Administrative and support staffing costs	
Purchase cost raw water	Operating costs
costs power consumption	
Maintenance costs	
Cost of Consumables	

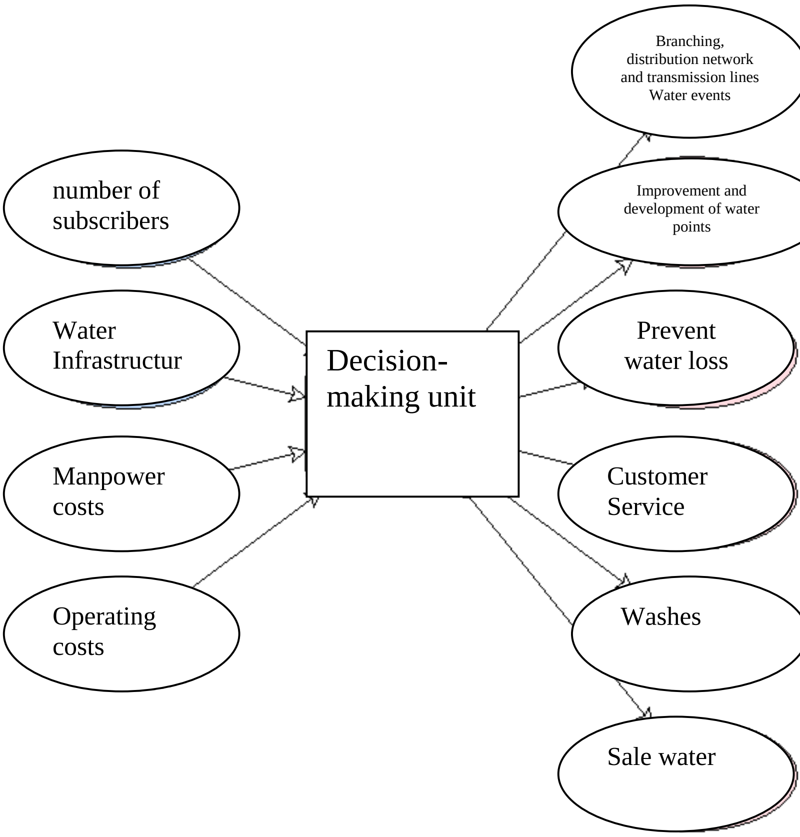


Figure 2. The performance indicators of urban in the water sector

Of course, each of the input and output indicators, consisting of one or more sub- indicators, and is calculated on the basis of them. Table 6 shows the sub- indicators, each of the inputs and outputs.

Table 7. Main indicators of output and the corresponding indicators

Sub- indicators	The main indicators
Branching , distribution network and transmission lines Water events	Events
Development of transmission and distribution networks	Reform and Development
Modified transmission and distribution networks	
Volume of water lost	Prevent the loss
Bifurcation of water sold	Customer Service
Replaced Counters	
Increased proceeds	
The number of normal readings	
The number of health bills	
Wash water tanks	Network utilization
Wash water transmission lines	
Wash water distribution network	
The volume of water sold	Sale

Table 8. The results of the calculations during the year 2012

Outputs						Inputs				Cities
Sale water (Million rials)	Washes	Customer Service	Prevent water loss	Improvement and development of water points	Branching , distribution network and transmission lines Water events	Operating costs (Million rials)	Manpower costs (Million rials)	Water Infrastructure	Number of Subscribers	
39273470	11720000	86.105	0	1,051,115	0	45,225	34,345.66	100	110,838	Arak
676790	511200	8.785	98	59,310	96.699	230	1,209.20	3.268	2,869	Astaneh
1411433	1295800	6.041	96	110,045	96.106	1,124	2,779.54	11.841	3,718	Ashtian
633227	657000	7.239	99	188,300	98.781	365	946.68	8.207	2,204	Parandak
1268919	1410000	10.119	97	203,740	95.545	1,715	13,365.29	10.943	7,027	Tafresh
160566	27000	11.418	100	2,800	98.813	220	140.75	1.216	656	Toreh
347911	213000	7.003	99	61,530	98.772	135	126.27	1.409	1,622	Khoshkrood
4716146	1723200	29.012	88	483,545	82.571	4,171	2,598.24	13.244	20,372	Khomein
588379	223600	8.388	99	119,680	98.333	223	698.13	2.1	2,381	Khandab
386526	613600	7.637	99	56,590	99.943	124	344.27	1.338	1,965	Davood Abad
3117280	1402000	13.604	92	116,635	89.082	4,313	3,217.72	20.652	11,102	Delijan
49631	29600	1.136	100	66,235	100	29	121.58	1.052	356	Razeghan
562455	450000	9.443	99	77,280	98.22	301	1,260.16	4.505	2,418	Zavieh
12766391	4990000	39.118	66	851,475	66.921	8,798	11,438.78	37.791	45,234	Saveh
1129157	823600	12.601	97	130,015	96.22	459	795.40	2.976	3,277	Sanjan
1642547	1177800	15.603	96	148,915	93.789	575	1,525.87	5.543	5,987	Shazand
358663	456000	10.694	99	141,510	97.512	101	750.69	5.569	1,903	Ghargh A bad
368615	169000	5.367	99	91,780	98.342	146	924.40	2.628	2,362	Gharmahin
98645	227000	8.868	100	67,605	99.342	83	129.28	1.64	526	Ghorchi Bashi
572084	283600	8.89	99	113,845	96.512	250	1,284.98	4.131	3,141	Komijan
1818434	708000	12.376	96	108,970	94.635	1,135	2,847.06	9.412	7,130	Mamoonieh
2795309	994000	17.492	93	281,515	89.773	5,184	2,106.97	13.749	13,099	Mahallat
1583406	920720	28.163	96	355,225	93.667	1,868	1,042.77	9.781	4,806	Mohajeran
564204	674000	7.264	99	147,990	97.496	239	1,018.40	3.055	2,513	Milajerd
198108	214000	9.829	100	80,745	96.813	34	270.00	2.633	1,418	Naragh
216588	72600	7.619	100	96,800	98.764	270	959.68	1.345	1,143	Nobaran
589798	713400	5.222	99	117,945	97.781	567	806.49	6.433	2,874	Nimoor
121009	436600	12.885	100	11,655	98.415	49	369.01	2.333	693	Hendoodar

Each input and output indicators, was calculated from a weighted combination of its sub-components, and finally, after extraction and sub data collection, the amount of each input and output was calculated.

DEA model for efficiency

As the towns in Markazi province operate at different scales, and there are subordinate units in some cities, and because of the low number of participants, the BCC was used, which is a variable returns to prevent and allocate zero weight, and given the same importance, the various indicators of inputs and outputs in assessment is used to weight restrictions on the model. The final model is as follows:

$$\mathrm{Min} \sum v_i x_{ip} - v_0$$
$$\sum v_i x_{ip} = 1$$
$$\sum v_i x_{ij} - \sum u_r y_{rj} - v_0 \geq 0$$
$$0.8 \leq \frac{u_r}{u_1} \leq 1.2$$
$$0.8 \leq \frac{v_i}{v_1} \leq 1.2$$

Following the model above, the software DEA Master was used, and marked the most effective towns regarding the water. Efficiency of urban water sector is given in the following table.

Table 9. Efficiency of urban water sector

Efficiency	Cities	Efficiency	Cities	Efficiency	Cities
63.45	Mahallat	86.01	Parandak	100	Arak
60.4	Zavieh	83.55	Khomein	100	Ashtian
58.95	Khandab	80.35	Delijan	100	Razeghan
53.93	Naragh	78.46	Milajerd	100	Saveh
46.43	Toreh	73.08	Nimoor	100	Sanjan
44.69	Komijan	71.99	Tafresh	100	Ghorchi Bashi
37.94	Farmahin	70.99	Mamoonieh	100	Hendoodar
30.14	Nobaran	69.99	Khoshkrood	99.6	Shazand
		68.41	Ghargh Abad	94.26	Davood Abad
		65.7	Astaneh	91.51	Mohajeran

The Efficiency results, which is observed in above table, are efficient for very large cities like Arak, Saveh, and is very small for the cities such as like Razeghan, and Hendoodar. The efficiency in large cities is due to large output, and in small towns, can be due to the very low inputs, and other cities have achieved Efficiency levels between 30 to 99.

Efficiency of wastewater

Input and output indicators, and the performance of urban wastewater were adopted as follows.

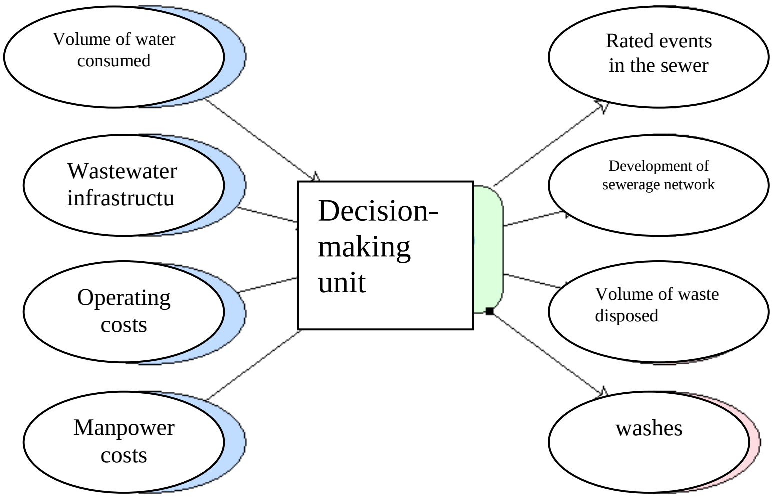


Figure 3. Input and output indicators and the performance of urban wastewater

The indicators of the input and output are as follows:

Table 10. Main indicators of sewage inputs, and corresponding sub-indicators

Sub-indicators	Main indicators
Volume of water consumed	Volume of water consumed
Length of sewer transmission lines	Wastewater Infrastructure
Length of wastewater collection system	
Cost of Consumables	Operating cost
Manpower Cost of Sale	Manpower costs
Cost of labor exploitation	

Table 11. Main indicators of output, wastewater, and the corresponding indicators

Sub-indicators	Main indicators
Branching , distribution network and transmission lines Water events	Events in sewer
Development of sewer transmission lines	Development of sewerage network
Development of wastewater collection system	
Volume of waste disposed	Volume of waste disposed
wastewater collection system Wash	Network utilization
sewer transmission lines Wash	
Spraying wastewater collection system	
Leveling of manhole	

In this section, the following weights to the sub, weighted combination of the parameters, and the values were obtained for each of the inputs and outputs of the sewer.

Table 12. Weights to the sub, weighted combination of the parameters, and the values

Output Indicators				Input indicators				Cities
washes	Volume of waste disposed	Development of sewerage network	Rated events in the sewer	Manpower costs	Operating cost	Wastewater infrastructure	Volume of water consumed	
100	19604352	15987.6	0	3279066040	298155805	526092	39273470	Arak
12.075	726786	895	98.172	306488876	0	75732	1268919	Tafresh
27.466	1548533	5280	88.208	880142707	129797512	145000	4716146	Khomein
23.092	2116521	2800	85.554	567489761	78787368	109000	3117280	Delijan
5.316	525214	0	100	7331818	0	13000	1129157	Sanjan
12.661	883000	4422	94.399	488475666	0	85500	2795309	Mahallat
9.15	1338828	531.2	63.974	155033239	60912000	100380	1583406	Mohajeran

It should be noted among the 28 cities, 7 cities are related to wastewater operations, and other cities have no function in this context. Therefore, in assessment of sewage, only 7 cities were involved.

Finally, after analyzing the data, the software DEA-Master, Efficiency urban wastewater was determined as follows.

Table 13. The determination of efficiency urban wastewater

Efficiency	cities
100	Arak
100	Sanjan
84.6	Mohajeran
54.57	Delijan
34.99	Tafresh
29.26	Mahallat
26.84	Khomein

Conclusion

The results of this study show that, in water sector, six cities had won maximum performance, and were identified with greater precision. The larger cities, which are more than the number of subscribers, have a relatively higher Efficiency rating, which could be due to the higher efficiency of scale. Also, in Arak and Sanjan, there are maximum Efficiency, compared to other towns and cities in the Efficiency wastewater, which are between 26.8 to 100.

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