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Evaluating the process efficiency of industrial wastewater treatment plants using data envelopment analysis approach case study: Khuzestan steel company treatment plant

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Designing a mathematical model with the possibility of changing the experimental parameters and variables not only helps to evaluate the performance of the treatment plant but also predicts its behavior. In this paper, to assess the efficiency of Khuzestan steel company treatment plant, data envelopment analysis (DEA) model was used. Input and output parameters of the treatment plant (Oil, COD, TSS, pH) were determined (2009-2014). Malmquist Productivity Index was used to express the changes in total productivity and Window Analysis was employed for calculation of efficiency and performance trends over time. The results showed that the treatment plant efficiency in the removal of COD, Oil, TSS and pH from the input wastewater was 68%, 62%, 81% and 4%, respectively. Treatment plant efficiency in removing pollutants (COD, TSS, Oil) was approximately 70%, so the performance of the system is efficient and the produced wastewater matches environmental standards. On the other hand, the results showed the high power of DEA models in the calculation and classification of years in terms of efficiency.

Keywords: Treatment plant, Khuzestan steel company, Evaluating efficiency, Data envelopment analysis

INTRODUCTION

One of the most important issues before the design and implementation of any wastewater treatment plant is the selection of the best treatment process. Although the wide variety of types of wastewater treatment plants, especially in terms of capacity and specific local conditions, makes it difficult to introduce a general rule that applies to all cases of selection of treatment process, in terms of priority of the treatment process, certain criteria may be applied that will be usable in most treatment plants. It is important to choose the best process for wastewater treatment, and in this regard, few studies have been conducted using a variety of mathematical techniques. If industrial treatment plants are efficient and sewage is collected and re-used in the best way, the possible efficiency and productivity will gain a special place in all sectors and can play an important role in sustainable development of Iran.

Some research has been conducted in the world which has used mathematical models to measure the efficiency and evaluate the performance of the systems. One of these mathematical models is the Data Envelopment Analysis (DEA). Few studies in the world have used this model to assess the performance of wastewater treatment plants. This technical model is adopted to measure the relative efficiency of decision making units by calculating the ratio of weighted total output variables to weighted total input variables. This efficiency is a good indicator to identify optimum units [2]. In 2009, Venkata Mohan *et al.* used DEA and Taguchi's methodology of experimental design to assess and optimize hydrogen production and wastewater treatment processes [3]. In 2009, Hernández and Sala-Garrido used DEA approach to analyze the technical efficiency and cost of wastewater treatment processes. In 2011, in order to compare the efficiency of wastewater treatment technologies, Sala-Garrido *et al.* used the DEA model. In 2012, they also evaluated the efficiency of wastewater treatment plants under the conditions of uncertainty by using DEA approach with tolerance [4].

Also in Iran, some research has been conducted in the field of evaluating the performance of treatment plants, some of which will be mentioned. It should be noted that so far in Iran DEA models have not been employed to measure the performance of treatment plants.

In 2003, Miranzadeh and Babamir evaluated the efficiency of Ekbatan wastewater treatment plant by reviewing COD, BOD and TSS parameters over the

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period of one year. The results showed that, with the removal of 92, 94 and 96% of pollutants, respectively, the aforementioned treatment plant has a good efficiency in wastewater treatment [5].

In another study in Bukan conducted by Hosseini and Rahimzadeh (2006), the efficiency of the aeration lagoon of a treatment plant with values of 82, 38 and 4.3 mg/L for COD, Oil and TSS, respectively, in the output wastewater was confirmed. Efficiency of removal at this treatment plant during the four seasons was an average of 9.82, 45.88 and 75.80% respectively, for the abovementioned parameters [6].

The steel industry is one of the most important consumers of water and Khuzestan Steel Complex, due to climatic conditions of its location, consumes large amounts of water for various purposes.

This research designs and presents a new approach based on models of data envelopment analysis (DEA) to assess the performance of wastewater treatment plant of Khuzestan Steel Company that can be adopted to evaluate the current performance of the treatment plant in removal of pollutants and also forecast the quality of the output wastewater in the future. Therefore, to measure the performance of the treatment plant during the studied years (2009-2014), first the treatment processes were examined and input and output parameters of the treatment plant (Oil, COD, TSS, pH) were determined. Then, a CCR multiplier model was used for ranking efficient units and for measuring the performance of the treatment plant compared to the previous year; Malmquist Productivity Index (MPI) was used for calculating the efficiency and performance trends over time; Window Analysis was used in the form of data envelopment analysis models (DEA). The results of the analysis of the efficiency of the treatment plant over the studied years using these models demonstrated the power of DEA models to calculate and distinguish the years in terms of efficiency.

RESEARCH METHOD

Studied area: Khuzestan Steel Company Treatment Plant

With an area of 8.3 square kilometers, Khuzestan Steel Company is located on the 10th kilometer of Ahwaz-Imam Khomeini Port road. Khuzestan Steel Company wastewater treatment plant was established in 2006 and began operation in 2008. Wastewater treatment plant was constructed next to the south wing of the factory. The current capacity of the wastewater treatment plant is 3000 m^3/h and in the future, it can be increased to 5715 m^3/h. The wastewater produced by various units of Khuzestan Steel Complex enters the main canal through two (eastern- southern) canals.

This treatment plant uses physical/chemical treatment methods in several stages during the operation (such as increasing polyelectrolyte and alum and directing the wastewater to settling basins in order to reduce suspended materials, etc.). The effluent is discharged directly to Maleh River by considering environmental standards and eventually enters Shadegan international wetland and some of it is employed to irrigate the company’s green area. (Khuzestan Steel Company Public Relations Department, 2012). The treatment process of this plant is shown in Figure 1.

Sampling and analysis methods

In this research, the data from raw sewage and output wastewater of Khuzestan Steel Company industrial wastewater treatment plant were studied. Since for modeling data that have a high degree of accuracy and richness in the studied period are required, parameters and quality indicators were used that create an output for an input (2009-2014). Thus, Oil, COD, TSS and pH factors were selected. Raw sewage and output wastewater were sampled to measure and monitor the above-mentioned parameters and based on the book *Standard Methods for the Examination of Water and Wastewater*, input sewage samples were kept in polyethylene and glass containers on which the date, time and place of sampling, as well as the water temperature at the time of sampling had been written and these containers were immediately transferred to the laboratory of Khuzestan Steel Company where tests were performed on the parameters.

Algorithm of evaluating the performance and efficiency of the process using DEA

First step: Collecting the data related to Decision Making Units (DMUs) input/output. In the study of real systems, to calculate the efficiency, the first step is to determine the inputs and outputs of each DMU or decision making unit so that they reflect the efficiency. In analyzing the efficiency of treatment plants, determining inputs and outputs is particularly important because each DMU or time period has numerous inputs and outputs, considering a lot of them or ignoring them will cause some problems. After determining

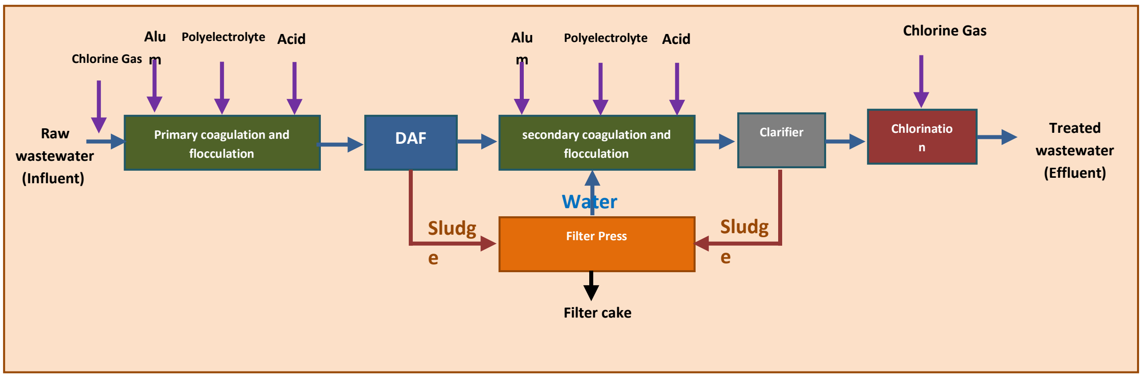


Figure 1. Schematic of the process of Khuzestan Steel Company industrial wastewater treatment plant

the inputs and outputs of each DMU, to compare and measure the efficiency of DMUs, the data related to each DMU were collected.Each year, 24 samples (2 samples per month) were taken for the 4 input and output parameters (Oil, COD, TSS, pH) and it could be stated that each year we had 24 DMUs and over a six-year research period, a total of 144 DMUs were calculated.

Second step: After collecting the data, efficiency of all DMUs was calculated using a CCR model. In this research, the data related to all DMUs from 2009 to 2014 (each year includes 24 DMUs, where DMU-1 represents August and DMU-24 represents July) were used for the input (Oil, COD, TSS, pH) and output (Oil, COD, TSS, pH) parameters. (Similar input and output parameters).

Third step: Using Malmquist criterion, the performance of units was compared to the previous year.

Fourth step: Using Windows Analysis, the performance trend of a single unit over time was calculated.

Analysis of the data and modeling

It is noteworthy that for analyzing the data, modeling the evaluation of the performance of the treatment house and determining its efficiency, GAMS software was used.

Treatment process inputs and outputs

As mentioned above, input and output parameters have been assumed to be similar, that is, for any number of inputs, there will be the same number of outputs. Table 1 shows the input and output parameters. In Table 1, I stands for the number of input parameters and O stands for the number of output parameters. It should be noted that the number of DMUs for each input and output parameter is 144 (144 inputs and 144 outputs for each parameter).

Table 1. Inputs and outputs of the model

Parameter	Output	Parameter	Input
Oil	O_1	Oil	I_1
COD	O_2	COD	I_2
TSS	O_3	TSS	I_3
pH	O_4	pH	I_4

Data Envelopment Analysis (DEA)

DEA is a method adopted to measure the relative efficiency of decision making units (DMUs). In DEA, the criteria are not weighted by the decision maker and this is done by the model in a way that each decision making unit (DMU) achieves its highest level of efficiency.

Efficiency is defined as the ratio of output to input. When there are multiple inputs and outputs, efficiency is defined as the ratio of weighted total outputs to weighted total inputs. If the values of the inputs and outputs are known, efficiency is simply calculated as follows:

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

where v is the input value and u is the output value of the i-th unit.

DEA-CCR model: In this method, with the help of some simple assumptions and using the data obtained from the units, the efficiency frontier is determined and by calculating the distance of each unit from the determined frontier (in one direction) the efficiency of units is calculated. CCR can be considered as the most rudimentary model of this family which was developed by Charnes, Cooper and Rhodes in 1987 inspired by the work of Farrell (1957) [10].

The linear programming model which is employed to calculate the efficiency of CCR is as follows:

$$\text{Max}\,\theta = \frac{1}{Eff^{O}_{DEA-CCR}}, \qquad \sum_{j=1}^{n} \lambda_j Y_j \le X_o, \sum_{j=1}^{n} \lambda_j Y_j \ge \theta Y_o$$

Malmquist Productivity Index (MPI): To set a quantitative goal related to the value of efficiency, the past trends of the evaluated units should be examined and MPI is a powerful tool to study the past. MPI considers two factors: the unit's changes compared to its previous condition and the changes in production frontier which is determined by the best members of the target population.

$$MPI = \frac{\theta^{t+1}\left(x_p^{t+1}, y_p^{t+1}\right)}{\theta^{t}\left(x_p^{t}, y_p^{t}\right)} \sqrt{\frac{\theta^{t}\left(x_p^{t}, y_p^{t}\right) \times \theta^{t}\left(x_p^{t+1}, y_p^{t+1}\right)}{\theta^{t+1}\left(x_p^{t}, y_p^{t}\right) \times \theta^{t+1}\left(x_p^{t+1}, y_p^{t+1}\right)}}$$

The first fraction measures the efficiency change between the periods t+1 and t and the second fraction shows the technical change or, in other words, the change in production frontier. The amount of technical change, efficiency change and MPI change for each unit was presented. As mentioned previously, productivity index is divided into the two factors of efficiency change and technical change. The slightest change in either one affects MPI and the following cases are possible:

MPI>1 indicates an increase in efficiency and progress is observed.

MPI<1 indicates a decrease in efficiency and progress is not observed.

MPI=1 indicates that no efficiency change has occurred between t and t+1. [10]

Windows Analysis model: One criticism of DEA models is that the efficiency calculated using this method is past efficiency. In other words, the efficiency calculated using this method is forgotten efficiency.

Window analysis is a time-dependent version of data envelopment analysis models. The main idea of this approach is that each unit in each period is considered as a separate unit from other periods. But each unit is not compared with all units in all the periods. A subset of the total time data is selected and each unit is measured separately from other periods of that subset. Window analysis generalizes the concept of moving means to detect the efficiency of the units over time. According to this model, each unit in each time window is treated as an independent unit at other times. This approach enables us to compare the efficiency of each unit at different periods. By increasing the number of units, window analysis also increases the separability of the DEA models. Remember that selecting the width of the window (a subset of the overall data) is the most important part. This choice should be small enough to minimize unfair comparisons over time and also large enough to provide a suitable data sample [9].

RESULTS

The present research was conducted based on the data gathered over a period of six years from 2009 to 2014. The results of the analyses conducted on Oil, COD, TSS and pH parameters of the raw sewage entering the treatment plant and the output wastewater are presented in Table 2 in the form of decision making units (DMUs).

Table 2. Inputs and outputs of decision making units (DMUs). The measurement unit of Oil, COD and TSS parameters in the input and output of the treatment plant is mg/L.

Year		Input (Oil)	Input (COD)	Input (TSS)	Input (pH)	Output (Oil)	Output (COD)	Output (TSS)	Output (pH)
	Mean	9.733	85.817	58.092	7.938	4.242	43.929	14.000	7.700
2009	Std. Dev.	8.470	59.619	53.557	0.186	4.311	23.760	7.945	0.232
	Min	1.3	26	9	7.5	0.3	11	3	7.2
	Max	37	254	271	8.3	20	115	35	8.1
	Mean	4.317	69.333	45.775	8.075	1.883	25.458	12.896	7.850
2010	Std. Dev.	4.473	53.921	35.277	0.217	2.676	10.371	4.191	0.159
	Min	0.6	25	14	7.8	0.2	3	6	7.6
	Max	22	261	150	8.6	11	40	22	8.2
	Mean	4.279	55.133	55.825	7.942	2.333	38.500	21.750	7.725
2011	Std. Dev.	2.960	9.644	26.411	0.289	1.001	6.711	8.774	0.285
	Min	1.2	40	26	7.1	0.6	25	6	6.9
	Max	15	81	129	8.5	4.5	53	48	8.2
	Mean	7.435	62.058	71.446	7.982	2.863	33.083	13.917	7.663
2012	Std. Dev.	8.430	20.317	38.274	0.261	0.283	13.897	5.770	0.300
	Min	2.9	22	17	7.5	2.4	6	4	7
	Max	40	103	162	8.6	3.5	62	32	8.5
	Mean	4.571	65.221	74.168	8.079	3.596	20.747	15.333	7.854
2013	Std. Dev.	1.926	23.135	39.179	0.257	1.434	10.448	11.126	0.195
	Min	2.9	33.8	20	7.6	2.6	13	9	7.5
	Max	11.3	111	210	8.6	10.1	64	66	8.2
	Mean	3.617	46.625	61.583	8.004	2.775	23.417	20.833	7.800
2014	Std. Dev.	0.725	14.832	33.628	0.146	0.182	6.928	17.264	0.147
	Min	2.8	29	23	7.7	2.2	12	11	7.4
	Max	5.1	98	143	8.3	3.1	40	99	8

As you can see, the range of annual mean of Oil in the raw input sewage varies from 62.3 mg/L in 2014 to 73.9 in 2009 and in the output wastewater from 88.1 mg/L in 2010 to 24.4 in 2009. The total mean in the raw input sewage and the output wastewater has been estimated to be 66.5 and 95.2 mg/L, respectively. Also, regarding TSS, BOD and pH parameters, according to Table 2, the range of annual mean of COD in the raw input sewage varies from 63.46 mg/L in 2014 to 82.85 in 2009 and in the output wastewater from 75.20 mg/L in 2013 to 93.43 mg/L in 2009. The total mean in the raw input sewage and output wastewater were estimated to be 84.63 and 86.30 mg/L, respectively. The range of annual mean of TSS in the raw input sewage varies from 78.45 mg/L in 2010 to 17.74 in 2013 and in the output wastewater from 92.12 mg/L in 2010 to 75.21 in 2011. The total mean in the raw input sewage and the output wastewater was estimated to be 15.61 and 45.16 mg/L, respectively. Finally, the annual mean of pH in the range of the raw input sewage varies from 93.7 in 2009 to 98.8 in 2013 and the output wastewater varies from 66.7 mg/L in 2012 to 86.7 in 2013. The total mean in the raw input sewage and the output wastewater was estimated to be 8 and 77.7, respectively.

Results of process performance evaluation using DEA: As explained above, in order to measure efficiency and compare the units, the data from 2009 till 2014 were used. Decision making units (DMUs), which are the years studied in this research, are presented in Table 3. Efficiency of the treatment system during these years was calculated based on inputs and outputs using DEA-RCC, the results of which are shown in Table 3. According to the results, the number of efficient units in 2014, 2013, 2012, 2011, 2010 and 2009 was 7, 7, 9, 8, 12 and 10, respectively, and the number of inefficient units in 2014, 2013, 2012, 2011, 2010 and 2009 was 17, 17, 15, 16, 12 and 14, respectively (Table 3).

In order to compare the performance of the units with the previous year, Malmquist Productivity Index was used, the results of which are presented in Table 4. Furthermore, to compare the efficiency of each unit in different periods and, in other words, determine the efficiency of each unit over time, Window Analysis was used, the results of which are presented in Table 5.

Results of Malmquist productivity index (MPI) model based on CCR: A summary of the results obtained from the MPI model based on DEA distance function over the studied years (2009-2014) is presented in Table 4. It should be noted that TC represents Technical Change, EC represents Efficiency Change and MPI represents Malmquist Productivity Index.

Results of Window Analysis: In the present study, the length of the window was 3 years. The first window (W1) includes Oil, TSS, COD and pH parameters in 2009, 2010 and 2011; the second window (W2) includes Oil, TSS, COD and pH parameters in 2010, 2011 and 2012; the third window (W3) includes COD, TSS, Oil and pH parameters in 2011, 2012 and 2013 and the fourth window (W4) includes Oil, TSS, COD and pH parameters in 2012, 2013 and 2014.

Table 3. Results obtained from the DEA-RCC model

	2009	2010	2011	2012	2013	2014
DMU01	0.7725	1	1	1	0.9133	1
DMU02	0.7844	0.9083	1	1	1	0.9727
DMU03	0.7958	0.8589	1	0.9398	0.8331	1
DMU04	0.8638	0.88	0.8658	0.9674	0.9204	0.9443
DMU05	0.785	0.8967	0.9551	0.9917	1	0.9429
DMU06	0.7956	1	0.8404	1	1	0.8661
DMU07	0.8907	0.8626	0.7691	0.9257	0.8966	1
DMU08	0.7252	1	1	1	0.9217	1
DMU09	0.8779	0.9269	0.9039	0.8701	0.7732	0.9047
DMU10	0.6869	0.9609	1	0.9368	1	0.9326
DMU11	1	1	0.9813	0.9499	0.8907	0.9573
DMU12	0.9331	0.9707	1	1	0.9405	0.9769
DMU13	1	0.9487	0.9815	0.8352	1	1
DMU14	0.8512	0.8611	1	0.9688	1	1
DMU15	1	1	0.955	0.967	0.8197	1
DMU16	0.8149	0.9298	0.89	0.9318	0.9185	0.9612
DMU17	0.9565	0.9084	1	1	1	1
DMU18	0.9006	0.9076	0.8591	0.9336	0.8992	0.9194
DMU19	1	0.8569	0.9433	0.9255	1	0.8817
DMU20	1	0.7996	0.9183	0.9683	1	1
DMU21	1	0.9231	0.7956	0.8819	0.8172	0.839
DMU22	0.8895	1	0.9532	0.8811	1	0.9161
DMU23	0.8362	1	0.8483	1	1	0.9657
DMU24	1	0.8827	1	1	1	1
# of efficient units	7	7	9	8	12	10
# of inefficient units	17	17	15	16	12	14

Table 4. Summary of the results obtained from Malmquist Productivity Index

Year	Mean(geometric)	Mean(arithmetic) MPI	Std. Dev.	Min	Max
2009/2010					
MPI	1.194	1.261	0.511	0.790	3.258
EC	1.047	1.049	0.067	0.948	1.197
TC	1.141	1.191	0.425	0.776	2.836
2010/2011					
MPI	0.572	0.603	0.189	0.219	1.006
EC	0.966	0.968	0.062	0.842	1.061
TC	0.593	0.624	0.193	0.252	1.060
2011/2012					
MPI	0.921	1.000	0.429	0.363	2.397
EC	1.034	1.036	0.065	0.924	1.165
TC	0.891	0.961	0.404	0.363	2.397
2012/2013					
MPI	0.870	0.885	0.153	0.431	1.150
EC	0.979	0.982	0.063	0.835	1.091
TC	0.888	0.900	0.136	0.464	*1.055
2013/2014					
MPI	1.062	1.071	0.143	*0.848	1.379
EC	1.021	1.023	0.071	0.911	1.183
TC	1.040	*1.045	0.097	0.848	1.281

In these windows, units of each period are independent of other periods.Thus, there are 72 units. (As stated in section 3 on methodology, each year includes 24 DMUs, DMU1 stands for August and DMU24 stands for July) In other words, these 72 units comprise the efficiency frontier. For each unit, there are 3 types of data that their efficiency should be calculated by using the frontier created by these 72 units. Table 5 shows the efficiency of the decision making units (DMUs) in multiple windows. For example, in the first row, it shows the data related to the mean of windows 1 to 4 for DMU01.

Table 5. Summary of the results obtained from Window Analysis model

	W1	W2	W3	W4	Mean
DMU01	0.9049	0.9254	0.9089	0.9622	0.925
DMU02	0.8658	0.8972	0.9143	0.9498	0.907
DMU03	0.8548	0.8647	0.8622	0.9257	0.877
DMU04	0.8484	0.8673	0.8676	0.9242	0.877
DMU05	0.8625	0.8983	0.9446	0.9703	0.919
DMU06	0.8641	0.913	0.8954	0.9105	0.896
DMU07	0.8529	0.8344	0.8206	0.9293	0.859
DMU08	0.9139	0.9779	0.9505	0.9607	0.951
DMU09	0.8673	0.8854	0.8123	0.8813	0.862
DMU10	0.9053	0.9107	0.9192	0.9623	0.924
DMU11	0.9659	0.9244	0.8774	0.9463	0.929
DMU12	0.9496	0.9797	0.929	0.9522	0.953
DMU13	0.9404	0.8882	0.9129	0.9696	0.928
DMU14	0.9376	0.9813	0.9371	0.9559	0.953
DMU15	0.9656	0.9646	0.9067	0.9534	0.948
DMU16	0.9101	0.9018	0.8862	0.9418	0.910
DMU17	0.9332	0.9853	0.9911	1	0.977
DMU18	0.8829	0.8807	0.8836	0.9425	0.897
DMU19	0.8872	0.8865	0.942	0.9441	0.915
DMU20	0.923	0.9083	0.895	0.9888	0.929
DMU21	0.8927	0.8458	0.7985	0.8773	0.854
DMU22	0.886	0.9035	0.8871	0.9365	0.903
DMU23	0.8742	0.9125	0.8848	0.9877	0.915
DMU24	0.9137	0.889	0.889	0.9498	0.910

Each of these windows has a mean value of efficiency that is associated with that unit. Finally, by calculating the mean of efficiencies calculated from these 4 windows, the mean efficiency of the first unit in the period 2009 to 2014 was calculated, which is equal to 92.0. The results of the Window Analysis model are summarized in Table 5.Then, in order to determine the most important factors affecting efficiency, sensitivity analysis was performed, in which the input and output parameters (TSS, Oil, COD and pH) were removed to determine which changes occur in the efficiency of the units. The results obtained from the sensitivity analysis are presented in Table 6.

Table 6. Mean efficiency change of the units in the Window-Sensitivity analysis

	Oil	COD	TSS	pH
DMU01	0.0313	0.0281	0.0248	0.3526
DMU02	0.0535	0.0041	0.0418	0.3679
DMU03	0.0186	0.0154	0.0357	0.4038
DMU04	0.0254	0.0067	0.0095	0.5029
DMU05	0.0227	0.0062	0.0441	0.3640
DMU06	0.0094	0.0240	0.0832	0.3214
DMU07	0.0478	0.0239	0.0138	0.4301
DMU08	0.0141	0.0067	0.0313	0.2733
DMU09	0.0155	0.0065	0.0150	0.5228
DMU10	0.0366	0.0197	0.0352	0.4202
DMU11	0.0045	0.0261	0.0140	0.3842
DMU12	0.0111	0.0047	0.0365	0.4148
DMU13	0.0082	0.0111	0.0652	0.3983
DMU14	0.0377	0.0035	0.0269	0.4628
DMU15	0.0019	0.0200	0.0652	0.4370
DMU16	0.0203	0.0048	0.0450	0.4558
DMU17	0.0175	0.0133	0.0611	0.2950
DMU18	0.0272	0.0132	0.0141	0.4021
DMU19	0.0035	0.0283	0.0387	0.5134
DMU20	0.0300	0.0116	0.0188	0.4615
DMU21	0.0198	0.0173	0.0102	0.4589
DMU22	0.0260	0.0167	0.0389	0.4132
DMU23	0.0323	0.0100	0.0391	0.3095
DMU24	0.0144	0.0200	0.0532	0.3466
Mean	0.0220	0.0142	0.0359	0.4047
Std. Dev	0.0134	0.0081	0.0196	0.0674

DISCUSSION AND CONCLUSION

In this paper, the performance of Khuzestan Steel Company treatment plant was studied using Data Envelopment Analysis based on the model inputs and outputs. Based on the results related to 144 decision making units, evaluation of the performance of the treatment plant during 2009-2014 indicates that in removal of pollutants, the highest removal efficiency was that of COD in the wastewater entering the treatment plant with an efficiency of 68% in 2013, the highest removal efficiency of Oil was 62% in 2012, the highest removal efficiency of TSS was 81% in 2012 and the highest efficiency in reduction of pH was 4% in 2012. In general, it can be concluded that Khuzestan Steel Company industrial wastewater treatment plant with removal of 81% of TSS from wastewater accounts for the highest efficiency in the removal of the pollutants (Figure 1). Then, Malmquist Productivity Index (MPI) was adopted to explain the changes in total productivity. Based on the results obtained from this index presented in Table 4 and Figure 2, the performance of Khuzestan Steel Company wastewater treatment plant from 2009 to 2010 has made progress both in terms of efficiency and technique (values larger than one) and therefore, it has been efficient from 2009 to 2010 (Malmquist productivity index is larger than 1). However, during the 2010-2011 period, there has been a great technical drawback (value of 59.0 for TC) but in terms of efficiency, the performance has been the same as in the previous year and there has been no progress (the value of EC is close to 1).

By multiplying these two factors into each other, the productivity index for this unit during 2010-2011 will be 57.0 which indicates that during this period the unit has not been efficient and had negative progress. During the 2011-2012 period, it had progress in terms of technical and efficiency change (TC value is 89.0 and EC value is 03.1) and finally, the value of productivity index during the 2011-2012 period will be 1, which indicates that during this period, the unit has been efficient and has made progress. Figure 2 confirms the fact that during these periods (2009-2010 and 2011-2012), there has been no considerable progress in the performance of the treatment plant in terms of efficiency and the differences in the productivity index have been due to technical progress made in some units. However, in 2013 and 2014, the efficiency of the treatment plant had a considerable progress. Also, Window Analysis and Sensitivity Analysis were employed to measure efficiency and performance trend over time in the form of Data Envelopment Analysis (DEA) models. Based on the results obtained from Window

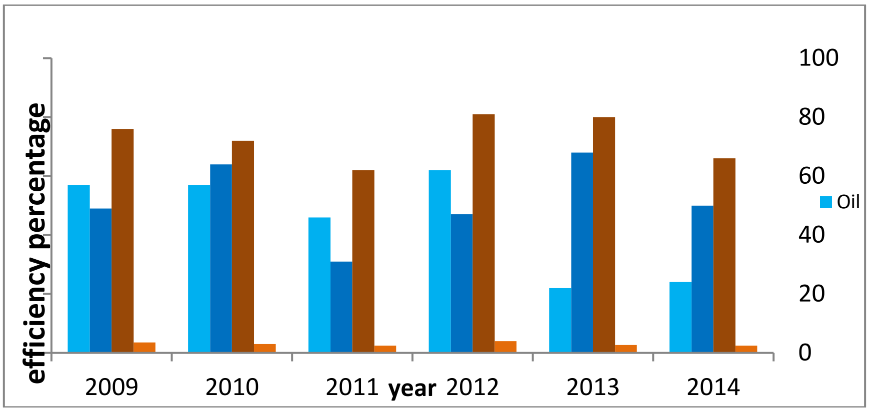
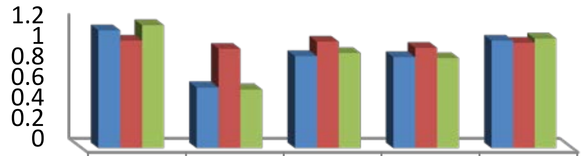


Fig. 1. Percentage of efficiency of removal of COD, TSS, Oil and pH from the output wastewater of Khuzestan Steel Company treatment plant during 2009-2014



	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014
(TC)Technical Change	1.14	0.59	0.89	0.88	1.04
(EC)Efficiency Change	1.04	0.96	1.03	0.97	1.02
(MPI)Malmquist Productivity Index	1.19	0.57	0.92	0.87	1.06

Fig. 2. Results of mean changes of Malmquist productivity index during the studied period (2009-2014)

Analysis presented in Table 5, there is no considerable difference between the amounts of efficiency obtained in Window Analysis of the units over the studied years. Table 6 and Figure 3 confirm that removing COD, Oil, TSS and pH indices change the mean efficiency of each unit 01.0, 02.0, 03.0 and 40.0, respectively. In case of pH, this change is considerable. Generally, it could be stated that, considering the used models and conducted analyses in each part, it is clear that based on the results obtained from the models used in this article, except for few of the units, no conspicuous difference between the performances of the units was observed. Regardless of the individual performance of the units, it could be stated that there is a conspicuous balance in the system.

Finally, in order to reuse the wastewater or discharge it to surface water resources, the amount of each of Oil, COD, TSS and pH parameters should be within the standard limits. In this regard, the Iranian Environmental Protection Agency has provided guidelines based on the type of use of the wastewater. According to these standards, in order to discharge the wastewater into the surface water resources, density of Oil, COD and TSS must be 10, 40 and 60 mg/L, respectively and pH must be 5.6-5,8 [10].

The average density of the abovementioned parameters during the studied years in the output wastewater of Khuzestan Steel Company treatment plant is as follows: Oil=95.2, COD=86.30 and TSS=45.16 mg/L and pH is 5.6-5.8, which indicates compliance with the standards of the Iranian Environmental Protection Agency for discharging wastewater into surface water resources.

Comparisons were made between the present research and previous studies in this area, some of which are mentioned in the following. In a study, the efficiency of the aeration lagoon of Bukan treatment plant conducted by Hoseini and Rahimzadeh (2006), with values of 82, 38 and 4.3 mg/L for COD, Oil and TSS, respectively, in the output wastewater was confirmed. The efficiency of the system with values of 82, 38 and 4.3 mg/L for COD, Oil and TSS, respectively, in the output wastewater was confirmed. Efficiency of removal at this treatment plant during the studied seasons was an average of 9.82, 45.88 and 75.80%, respectively, for the abovementioned parameters [3] which is consistent with the present research.

In a study conducted by Kimiyai *et al.*, Oil, TSS and COD qualitative parameters in the input and output sewage of the wastewater treatment plant of Buali Industrial City, Hamedan were evaluated and pollutants removal efficiency for the studied parameters was calculated as 68, 88.89 and 25.79%, respectively [11], which is consistent with the data of the present research. In a study conducted by Ardabilian *et al.*, the efficiency of removal of BOD, TSS and COD from the input sewage of Zanjan City treatment plant was found to be 25.87, 91.77 and 29.87%, respectively [12], which is consistent with the data of the present research. Also, given the limitation of water resources in Iran and Ahvaz City, as well as the current critical condition of the local area and considering the high efficiency of Khuzestan Steel Company industrial wastewater treatment plant system in removing pollutants and the level of the studied key parameters (Oil, COD, TSS) which is lower than the permissible environmental level in the output wastewater, it is recommended that advanced treatment methods be used for treatment of output wastewater and the treated wastewater be used for industrial plants which do not need high-quality water.

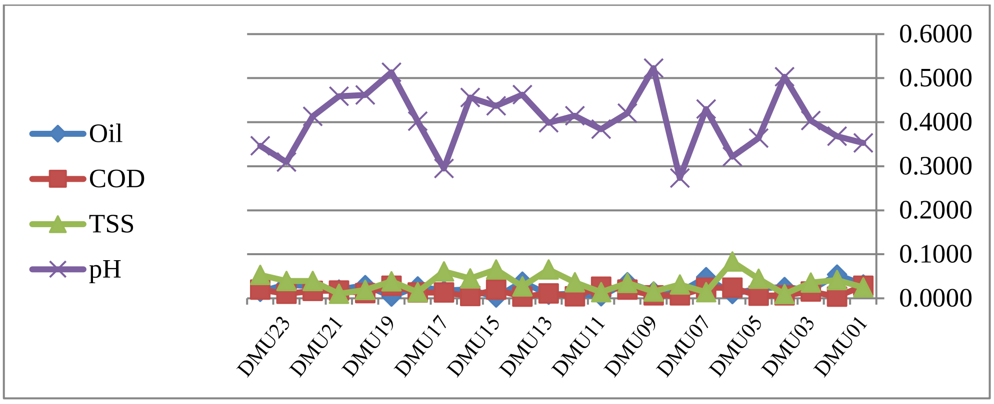


Fig. 3. Mean efficiency changes of the units in the Window-Sensitivity analysis

REFERENCES

1. J.-L. Hu, Sh.-Ch. Wang, F.-Y. Yeh, Total-factor water efficiency of regions in China. *Resources Policy*. 31, 217, 2006.
2. R. Khorram, Mehdi. Modern Steps in Fundamental Studies of Comprehensive Urban Sewage Plans, Daneshjoo Publication, 2002.
3. S. Venkata Mohan, S. Veer Raghavulu, G. Mohanakrishna, S. Srikanth, P.N. Sarma, Optimization and evaluation of fermentative hydrogen production and wastewater treatment processes using data enveloping analysis (DEA) and Taguchi design of experimental (DOE) methodology, *International Journal of Hydrogen Energy*. **34** (1), 216 (2009).
4. R. Sala-Garrido, F. Hernández-Sancho, M. Molinos-Senante, Assessing the efficiency of wastewater treatment plants in an uncertain context: a DEA with tolerances approach, *Environmental Science & Policy*. **18**, 34 (2012).
5. M. M. Bagher, B. Sh. O'Sadat, A Study of the Efficiency of Ekbatan City Wastewater Treatment Plant during 2000-2001. *Feyz Scientific-Research Quarterly, Kashan University of Medical Sciences and Healthcare, Iran*, **25**, 40 (2003).
6. H. M. Mokhtar, R. Esmail, A Study of the Efficiency of the Lagoon Using Mechanical Aerator in Reducing the Level of TSS and COD in Bukan Wastewater Treatment Plant in 2006. *The Tenth National Conference on Environmental Health, Hamedan, Iran*. 2007.
7. M. Pourtarghabeh, Alireza, M. Shokouhiyan, Evaluation of the Performance of Industrial Wastewater Treatment Plants Using Artificial Neural Network. *The Sixth National Conference on Environmental Engineering, Faculty of Environmental Sciences*, University of Tehran, Tehran, Iran. 2012.
8. L. Castelli, R. Pesenti, W.Ukovich, DEA- like models for the efficiency evaluation of hierarchically structured units, *European Journal of Operational Research*, **154**, 465 (2004).
9. L. Liang, F. Yang, W.D. Cook, J. Zhu, DEA models for supply chain efficiency evaluation, *Annals of Operations Research*, **145**, 35 (2006).
10. The Environmental Protection Agency. Environmental Regulations and Standards. Published by The Environmental Protection Agency. 1999.
11. K. Alireza, A. Ghasem, J. M. Javad, M. T. Abulfazl, A Study of the Performance of Aeration Lagoons in the wastewater treatment of Buali Industrial City, Hamedan, *The Tenth National Conference on Environmental Health*, Hamedan, Iran. 2007.
12. P. Ardabilian, H. Sadeghi, A. Nabai, M. Ardabilian, Evaluation of the Performance of Zanjan Sewage Treatment Plant, *Health and Hygiene Quarterly*. 1(3), 67 (2010).

ОЦЕНКА НА ЕФЕКТИВНОСТТА НА ПРЕЧИСТВАТЕЛНИ СТАНЦИИ ЗА ИНДУСТРИАЛНА ОТПАДНА ВОДА С ИЗПОЛЗВАНЕ НА АНАЛИЗ НА ОБХВАТА НА ДАННИТЕ С ПРИМЕРЕН СЛУЧАЙ ПРЕЧИСТВАТЕЛНАТА СТАНЦИЯ НА ХУЗЕСТАНСКИЯ ЗАВОД ЗА ПРОИЗВОДСТВО НА СТОМАНА

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(Резюме)

Разработването на математически модел, позволяващ промяна на експерименталните параметри и променливи дава възможност не само за оценка, но и за прогнозиране на работата на пречиствателни станции. В настоящата статия, за оценка на ефективността на пречиствателната станция на Хузестанския завод за стомана е използван моделът на анализ на обхвата на данните (АОД). Входните и изходните параметри (химически необходим кислород, масло, общоо количество на твърди вещества и pH) са определени през периода (2009-2014 г.). Коефициентът на продуктивност на Malmquist е използван за изразяване на промените в тоталната продуктивност, а Window анализът – за изчисляване на ефективността и тенденциите за работа с времето. Резултатите показват, че ефективността на пречиствателната станция по отношение на химически необходимия кислород, маслото, общото количество на твърди вещества и pH е съответно 68%, 62%, 81% и 4%. Ефективността на станцията за отстраняване на замърсители е около 70%, така че системата работи ефективно и изходящата вода съответства на стандартите за околна среда. Резултатите показват също така широките възможности на АОД моделите за изчисляване и класифициране на ефективността по години.