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Preparing and developing an optimized model to determine cost-efficiency for urban waste water treatment plants

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ABSTRACT

Background and purpose: For the economic feasibility study of waste water treatment plants, we need a method capable of evaluating the waste water treatment plants in terms of their cost-efficiency and their economy. In order to make a correct comparison between the investments on waste water treatment plants, their treatment capabilities and quality of their facilities need to be compared against one another. Through cost-efficiency analysis, wise decisions can be made to achieve these goals. The present research seeks to prepared and develop an optimized cost-efficiency model for urban waste water treatment plants.

Methodology: one of the most important assessment methods utilized in this study is using two indicators of input and output. The method of using these indicators can be called the input-achievement method. This method utilizes environmental, social and economic parameters. Finally, the whole cost and efficiency of treatment procedure are studied and the above-said qualitative indicators are quantified and cost-efficiency index for waste water treatment plants will be calculated.

Results: As the results indicate, the highest score for the influence of waste water treatment on the physical and chemical factors is associated with water quantity (+60) and the least score corresponds with ground water quality (+26). The greatest influence of waste water treatment on economic factors corresponds to job and expertise (+119) and the least influence is on the structural integrity of population (+19).

Conclusion: We may generally conclude that further to operation costs, investment costs are also taken into consideration while studying the economic indicator, because this part of the expenditures is so great and causes high costs in the various procedures in different waste water treatment plants.

KEY WORDS: waste water treatment, cost-efficiency, optimized model

1. INTRODUCTION

With the rise of urbanization and life style changes and growing industrialization, the amount of the waste water produced in the urban areas is also increasing. As the incorrect disposal of domestic and industrial waste waters has adverse effects on the environment, the full treatment of waste waters gains great importance. Using water for different purposes and great need for water in every region of Iran persuades us to prevent wasting water by any means and take the appropriate measure to treat domestic and industrial waste waters produced in order to provide the required water (Almasi, 2014). Protecting water supplies requires various planning to reuse the water and waste water. Further to regenerating and developing water supplies, this action can also reduce the environmental effects (Almasi, 2014, Hernández-Sancho and Sala-Garrido, 2009). On the other hand, water shortage due to recurrent droughts along with a rise in population, the possibility of recycling and using waste water in different sectors such as agriculture and industry can be important factors to search in the fields of water and waste water. Special attention to public awareness concerning water pollution in environmental laws demonstrates the importance of establishing waste water treatment plants. Further to developing and generalizing waste water treatment plants, improving the quality of such systems is inevitable (Giurco, 2011). In the developing countries with little to average income, limited budget and high costs of investment forces the managers to make the best out of their resources and available capitals. Appropriate and correct decision making is a great responsibility of managers. Costing and analyzing the expenditures can be utilized by managers as important management tools which can aid them for the optimized budg, location and maximum utilization of the capitals which is one of their most important duties (Khamutian, 2014). To reduce and control the costs and improve the effectiveness of systems and promote the efficiency, the managers and planners need to pay attention to constant supervisory programs so as to make sure about the appropriate efficiency of waste water treatment systems. This goal can be accomplished only by the exact analysis of cost-efficiency. Through precise cost-efficiency analysis, managers can make the fundamental decisions to achieve their goals (Hadian, 2009). For the feasibility study of the waste water treatment plants, we need a method to study the costs capable of assessing the capabilities of waste water treatment plants in terms of their cost-efficiency and economy. The main goal of design and consulting professors, nowadays, is to reduce the costs. Engineers are trying to improve the utilization rate and working efficiency, reduce the waste caused by procedures and the final price of the products and increase the benefit of projects (Piadeh, 2014, Almasi, 2016, Sayyadi, 2013). Some benefits of treatment are not calculable as they have not been quantified. The environmental benefits of waste water treatment have been fully recognized and we may classify them as indirect benefits in our economic terminology. Assessing the benefit of protecting natural resources and environment is important of the economic feasibility study of projects (Hernandez-Sancho, 2011). One of the important goals of protecting the environment is to appropriately collect and treat the waste water in accordance with the available standards. Despite the importance of economic analysis in the field of waste water treatment in such projects, less attention is paid to environmental issues and this factor is usually neglected in the evaluations (Rodriguez-Garcia, 2011). Various treatment plants are active in Iran and a lot of capital has been invested on each one, however; not all of them have the appropriate efficiency and can fulfill the goals set by their designers (Rasolabadi, 2015). Through the cost-efficiency analysis of these systems, we may demonstrate their weakness and propose strategies to promote them. For the feasibility study of the waste water treatment plants, we need a method to study the costs capable of assessing the capabilities of waste water treatment plants in terms of their cost-efficiency and economy. The present research seeks to achieve an optimized model to study the cost-efficiency of waste water treatment plants. As one of our duties is the optimized and effective use of the available systems and in order to stabilize our national products and goods, achieving this model can help us determine the cost-efficiency of treatment plants and propose the appropriate measures to improve their efficiency and reduce their costs if any inefficiencies or faults are observed. The results of this research make it possible to correct the available systems and choose the appropriate procedure to develop waste water treatment plants. These corrected systems can also be generalized to other places with similar conditions.

2. METHODS & MATERIALS

Methodology: One of the most important methods utilized in this research is using two indicators of inputs and outputs which need to be calculated and placed in the equation. The practice of using such indicators can be titled the “input-achievement” method. In this method, we calculate how much we have spent and how much we have gained. The input parameter in this design include investment costs such as cost of constructing the site, buying and installing the electromechanical facilities and costs of designing, executing, operating, and maintaining the project and human capital which result in gain parameters such as social welfare, environmental status, selling the products of treatment, and pollution and disease control. There are certain methods available to calculate the costs. Using these methods, including Verben-Wooters method, the total costs can be calculated as a set of cost parameters. If we seek to calculate cost-efficiency for multiple treatment plants with the goal of comparing them with one another, it is better to alter the costs and coordinate them with one another (after they have been calculated) according to the principles of engineering economy so that they can be compared against each other. One of such methods is to calculate the annual invariable cost. In this method, the total cost of investment and salvage value are transformed into annual invariable cost using social value rate and age of projects. The final result will then be added to the costs of operation and maintenance during one year. To compare the cost-efficiency of several treatment plants with one another, the information concerning the expenditure of the treatment plants need to be integrated based on the indicators available for construction of the site, electrical equipment, mechanical installations and services in various years and added to annual costs of the unit.

Using the resulting annual invariable cost and the amount of waste water treated during a year in each treatment plant, the expenditures for 1 m^3 of waste water shall be calculated.

The method of identifying and predicting the effects: Considering the plan presented by the employer, the procedural factors of the project are identified. Then, considering the current state of environment, the affected social and environmental indicators within the scope of research are determined. Next, using the form under questionnaire, the various types and dimensions of environmental and social effects in terms of effect quality (positive and negative), how the effect influences (directly and indirectly), when the effect influences (short-term and long-term), the durability of effect (temporary and permanent) and the scope of the effect (local, regional, and international) are placed in the row. In the column, the effects of each procedural factor on social and environmental factors are measured based on the types and scope of the effects.

The procedural factors studied

1. Treatment plant procedures
2. Pumping station
3. Waste water disposal
4. Waste disposal

The environmental indicators studied

1- Physical and chemical environment

a. Air quality

b. Noise quality

c. Water quantity

d. Water quality

e. Soil quality

2- Economic and social environment
a. Farmers and land users
b. Industry and attracting investment
c. Job, expertise and technical skills
d. Structural integrity of population
e. Safety and accidents
f. Health and wellbeing of people
g. Public welfare

Findings

Calculating the value of water quantity: With respect to quantitative effects, one can calculate how much waste water enters the river every day. This amount of waste water can have a positive influence in the rise of flow and self-purification of the river. The waste water entering into the river can be a good source to provide the water required for agricultural lands and orchards and it can be used by farmers. This requires the constant training of farmers. As the treated waste water is sold to local water distributing agencies through specific contracts, its value can be measured using such contracts.

Calculating the value of influence on the quality of water and soil supplies: A large portion of water through the waste water collection system and after treatment is sent back to rivers or underground waters. Entrance of treated waste water to rivers or underground waters may result in more suspended solids, higher BOD, and pathogens (parasites, viruses, and bacteria). To calculate the value of influence on water supply quality in this research, we utilized environmental crimes calculation method proposed by the Environment Bureau to confront with the current pollutions. The environmental benefits gained by waste water treatment can be calculated using this method for reduced pollution, and the environmental losses due to unauthorized disposal of waste water can also be calculated using this method and considered in determining the cost-efficiency of treatment plants. To calculate the value of soil quality indicator, a method similar to the one adopted for water quality is utilized. The only difference is that in the case of soil quality, concentration is mostly focused on the heavy metals entering the soil and the level of pollution is calculated for heavy metals.

As the results indicate, the highest score for the influence of waste water treatment on the physical and chemical factors is associated with water quantity (+60) and the least score corresponds with ground water quality (+26). The greatest influence of waste water treatment on economic factors corresponds to job and expertise (+119) and the least influence is on the structural integrity of population (+19). (table 1)

Table.1. Matrix corresponding to the effects of waste water treatment on social and environmental factors

Environ	Indicator	Treatment procedures	Pumping wastewater	Wastewater disposal	Waste disposal	Storing chemicals	Total + scores	Total -scores
Physical and chemical	Air and noise quality	-21			-23			-44
	Water quantity			+36	+24		+60	
	Surface water quality	+33		-28	-23		+33	-51
	Underground water quality	+26			-17		+26	-17
	Soil quality	+27		-30	-31		+27	-61
Economic and social	Agriculture and land use			+27	+24		+51	
	Industry and attracting capital	+19	+18	+24	+21	+22	+104	
	Job and expertise	+26	+23	+24	+23	+23	+119	
	Structural integrity of population	-20	-19	+19		-19	+19	-58
	Safety and accidents	-19	-19		-21			-59
	Public health and well being	+32		-21	-21	-19	+32	-61
	Public welfare	+32		-21	-21		+32	-42

Calculating the value of effect on social structures and job and public acceptance: Building wastewater treatment plant would build up hope and willingness among the people to live in cities. This will prevent immigration and attract people to their cities and results in a greater sense of safety and welfare among the people living there. During the construction of treatment plants, some local people (even a small number of them) will work there. This value can easily be calculated according to the number of people working there and the salary paid to them by the employer. It can also have indirect effects on people's jobs such as jobs created due to higher amounts of accessible water which will result in more agriculture and also establishment of aquaculture farms. Only the people living in the suburbs who are far from the treatment plant due to observation of environmental principles might feel worried. This issue can be easily solved by correct management in maintaining and operating waste water treatment plant.

Calculating the value of influence on health and wellbeing of the society and public welfare: Upon the first glance, establishment of systems for collecting and treating waste water is one of the most fundamental measures taken in order to enhance the public health, improve the environment, and create social welfare. Thus, such projects possess positive and strong environmental and health sides. In the case of having no waste water treatment plants, people will have to use absorbing wells to for waste water disposal which will result in soil and underground water contamination, especially in the areas where the underground aquifers are closer to the surface. On the other hand, the waste water gathered might be released in natural waterways. Due to the low flow in these waterways, they are usually intensely polluted. Using this non-treated waste water (which has been partially diluted) may cause health problems. The dangerous factors in this case are pathogens and their spread among local people, workers and the nearby human communities and also those who use the products. Proliferation of insects and rodents around the waste water treatment plant is another problem which may cause environmental and health issues. Based on the above-said issues, information concerning diseases which can spread through polluted water such as diarrhea, dysentery, hepatitis A, typhoid, etc can be used to calculate the value of influence on the health and wellbeing of society. For this purpose, the periodical statistics about the above-said diseases is collected and analyzed by T-test with a certainty of 95% and a confidence of 5% to see if there are any significant differences between the average occurrence of those diseases before and after the establishment of waste water treatment plant. On the other hand, the costs associated with the disease are also calculated and the costs associated with the rise or reduction of the disease are also calculated and used (based on the results of statistical test) as the indicators for the effect on health and wellbeing in the society.

Calculating the value of public welfare: To calculate the value of public welfare due to waste water treatment, we can interview people in every region to see how much people would like to pay to dispose of each cubic meter of wastewater so as not to get afflicted with diseases and other problems associated with waste water.

To calculate the cost-efficiency for the active treatment plants, we must use the operation data of waste water treatment plants in order to calculate the efficiency of removing pollutants such as COD, BOD_5, and TSS. We can later use their values to calculate the efficiency indicator.

Calculating cost-efficiency: Finally, all the costs and the efficiency of treatment procedures and qualitative indicators are quantified (according to the above-mentioned principles), and the cost-efficiency indicator is calculated for waste water treatment plants.

Calculating cost-efficiency ratio

$$Benefits = (\mathrm{Q_{eff}} \times \mathrm{a}) + \left(\mathrm{Q_{p.eff}} \times \frac{\mathrm{P_{in}} - \mathrm{P_{eff}}}{\mathrm{P_{eff}}} \times \mathrm{b} \times S_A \times S_E\right) + \left(\mathrm{Q_{p.eff}} \times \frac{\mathrm{P_{in}} - \mathrm{P_{eff}}}{\mathrm{P_{eff}}} \times \mathrm{c} \times S_A \times S_E\right) + (\mathrm{n} \times \mathrm{S}) + \sum_{i=1}^{i=n} n_i \times c_i + (C_{w.w.d} \times \mathrm{Q_{eff}})$$

Benefits: the benefits gained by waste water treatment
Q_{eff}: the annual discharge of the wastewater leaving the treatment plant
a: the price of each cubic meter waste water sold by Water and Wastewater Company
$Q_{p.eff}$: the annual discharge of the wastewater leaving the treatment plant in accordance to the standard conditions
P_{in}: the amount of pollutants in the waste water running to the treatment plant
P_{eff}: the amount of pollutants in the water running out of the treatment plant
b: the Rial coefficient of water pollutant
S_A: sensitivity of the area
S_E: sensitivity of the environment
C: the Rial coefficient of soil pollutant
n: the number of people working in the plant
S: the average salary of the workers
n_i: the reduced number of affliction with disease i
c_i: the treatment costs of someone afflicted with disease i
$C_{w.w.d}$: the average sum people would like to pay for disposal of each cubic meter of waste water

$$Losses = \left(\mathrm{Q_{un.eff}} \times \frac{\mathrm{P_{eff}} - \mathrm{P_{a.t}}}{\mathrm{P_{a.t}}} \times \mathrm{b} \times S_A \times S_E\right) + \left(\mathrm{Q_{un.eff}} \times \frac{\mathrm{P_{eff}} - \mathrm{P_{a.t}}}{\mathrm{P_{a.t}}} \times \mathrm{c} \times S_A \times S_E\right) + \sum_{i=1}^{i=n} n_i \times c_i$$

Losses: the losses caused as a result of inappropriate treatment of wastewater
$Q_{un.eff}$: the annual discharge of the water running out of the treatment plant with inappropriate conditions
P_{eff}: the level of pollutants in the water running out of the treatment plant
$P_{a.t}$: the limit for pollutants in the water running out of the treatment plant
n_i: the increased number of affliction with disease i
c_i: the treatment costs of someone afflicted with disease i

$$\mathrm{Cost - Effectiveness_{index}} = \mathrm{Efficiency} \times \frac{Benefits - Losses}{EUAC}$$

3. RESULTS AND DISCUSSION

The major difference between these functions and the previous researches is the effect of efficiency parameter in calculating cost-efficiency. None of the previous researches has used efficiency and performance of the treatment plant in removing the pollutants in order to calculate the indicators associated with economy or environmental issues. The only exception is the study conducted by Yuan, (2010) about the cost-efficiency of two operation models in Chinese industrial waste water treatment systems. In this research, the authors studied to models of decentralization and sharing in the industrial city of Shengze using cost-efficiency analysis which is a good method to study the economic feasibility of projects. Concerning the application of performance in calculating the ration, the researchers set a minimum value of 1 for the level of performance in the two models assessed. Presupposing that performance in both models is equal and maximum, the researchers then tried to find which model has a better cost-efficiency (Yuan, 2010).

Concerning the economic and environmental indicators used in other studies, we may refer to the following researches. In the research conducted by Molinus, (2011) in some locations of Spain about the environmental and economic profile of 6 types of wastewater treatment houses and where 24 treatment houses were classified into 6 quality categories based on the guidelines of European and Spanish urban wastewater rules, the environmental parameters taken into consideration were potentials of Eutrophication and global warming, while operating costs (energy, salary, etc) were also the economic parameters studied (Rodriguez-Garcia, 2011).

In the research conducted by Yuan, (2010) about the cost-efficiency of two models of operating Chinese industrial wastewater treatment systems where the researchers investigated two models of decentralization and sharing in the industrial city of Shengze using cost-efficiency analysis, wastewater COD loading and the number of recorded pollutions were environmental parameters taken into consideration and operation costs were also the economic parameters studied (Yuan, 2010).

In another research conducted by Moulinas Cenant, (2010) in Spain in order to study the economic feasibility of wastewater treatment using cost-benefit analysis, the researchers quantified the environmental benefits of wastewater treatment and studied the costs of treatment procedure. They used the cost-benefit analysis and the concept of shadow price to calculate the index of economic feasibility for each treatment plant. The economic parameter in this research is the operation cost which falls into 5 categories: energy, workers, chemicals, waste management, and maintenance costs. The most important variable in these treatment plants is the salary they pay to their workers which comprises 33% of the whole expenditures. Variables of maintenance costs, energy, waste management, and chemicals comprise 21, 18, 15 and 14 percent of the whole costs respectively. The results of this research indicate operating the treatment houses studied is quite economic although none has tried selling the water resulting from treatment. Selling the treated wastewater and the benefits associated with removing the pollutants are the environmental benefits of wastewater treatment, while the economic indicator studied includes the operating costs, such as: energy, workers, chemicals, waste management and maintenance costs (Molinos-Senante, 2010).

In the research conducted by Bendeti, (2006) to evaluate the alternatives for designing and updating the treatment plants, the researchers were trying to evaluate the treatment systems using the numerical models for design or update. In this research, the comparison between the choices available is accomplished based on their effectiveness criteria including economic and environmental criteria. The weight of each variable is dependent upon the situation of project. The environmental criteria selected for evaluation included three indicators, namely wastewater quality, time and the frequency of violating the limits defined for wastewater and operating costs (Benedetti, 2006).

4. CONCLUSION

Economic, environmental and social indicators were utilized in order to calculate the cost-efficiency ratio for wastewater treatment plants. Further to the operating costs, the investigation costs were also taken into consideration for the economic indicator because this part of the expenditures is so great and causes high costs in the various procedures in different waste water treatment plants. The losses caused by the inappropriate treatment of wastewater to the environment and the losses caused by higher rates of some contagious diseases (as a result of wastewater) were not considered and studied in any of the above-mentioned researches. If we compare this study to the above-said researches, it is noteworthy to mention that none of them has taken the social benefits of wastewater treatment into consideration.

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