Decision Support system for Wastewater Treatment Plants

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Abstract

Choosing a treatment technology for a wastewater treatment plant is very decisive and sensitive for engineers, municipalities, decision makers, and policy makers. A decision support system (DSS) model is developed to facilitate the decision makers, policy makers, municipalities, and engineers in adjudicating a treatment technology for a wastewater treatment plant (WWTP). The DSS is developed based on the weighted percentage techniques. A practical approach is presented in evaluating the following treatment technologies, up-flow anaerobic sludge blanket (UASB), activated sludge process (ASP), moving bed bio-reactor (MBBR), membrane bio-reactor (MBR), and a sequential batch reactor (SBR) for a wastewater treatment process. The weighted percentage allotted to attributes is based on experience and varies from country to country and also on the requirement for the municipalities. Based on LCC and DSS for 3.3 MLD WWTP, that the treatment technologies suitable for adopting are in the following order UASB > ASP > SBR> MBBR > MBR.

Key word: Decision support system; wastewater treatment plants; life cycle cost analysis

1. Introduction

Over decades, many advanced treatment technologies have been developed to ameliorate wastewater treatment efficiency. Selecting the appropriate treatment technology for the treatment process is the vital decision for the wastewater treatment plants (WWTPs) to meet the disposal standards. To meet the disposal regulations (on environmental and health) of the treated wastewater and to minimize the greenhouse gas emissions, there is a need to adopt sustainable treatment technology. The decision makers have adopted a treatment technology for WWTPs based on following parameters, (i) available technology considering climatic conditions, treatment efficiency, volume of the wastewater treated, (ii) characteristics of wastewater, (iii) economics of the project, and (iv) sustainability of the treatment technology.

The various treatment technologies adopted around the world over the past two-three decades are as follows, (1) activated sludge process, (2) up-flow sludge blanket reactor, (3) moving bed biological reactors, (4) membrane bio-reactor, (5) sequential batch reactors (6) two stage trickling filter, (7) waste stabilization ponds, (8) biological filtration and oxygenated reactor, (9) anaerobic digestion, (10) submerged aeration fixed film technology. Design of the treatment process (for a WWTP) will be an important challenge for the designers, since these treatment technologies adopted in the treatment process are based on the complex biological treatment configurations (combinations of aerobic, anoxic and anaerobic reactors and internal recycling between the unit-processes) (Karimi et al., 2011). During the biological degradation of wastewater, substrate is converted to carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (are the principal greenhouse gases) which are contributing to greenhouse gases (GHG) emissions from the wastewater treatment plants (Keller and Hartley, 2003).

Von Sperling et al. (2005) suggested that treatment process adopted for WWTPs should be derived from a balance between technical and economic criteria, considering quantitative and qualitative aspects of each alternative. For adopting any wastewater treatment technology, capital and operation cost of WWTPs are major factors (Zeng et al., 2007). Life cycle assessment has been used to compare technologies and processes of WWTPs using a wide range of factors, but due to lack of direct relationships to the factors (design, operation, or management of environmental processes) influencing the decisions, the overall assessment cannot be related (Keller and Hartley, 2003). Further, multicriteria decision making techniques egressed considering both qualitative and quantitative aspects of a decision; it also reduces the level of comparison from large number of factors to fewer. The multicriteria decision making techniques that have been developed during the last decade are summarized in the Table 1. For implementing of appropriate wastewater treatment technology Pophali et al. (2011) utilized analytical hierarchy process and grey relation analysis, which can be applied to complicated multicriteria decision-making to obtain scientific and reasonable results.

The multicriteria decision-making techniques developed for WWTP did not consider many factors that may be important to the decision-making process, including land area, life cycle cost analysis, river ecology, GHG, reuse and recycle, local factors (includes power consumption, technical skills, etc.). Multicriteria decision-making techniques (include qualitative and quantitative aspects) are utilized in the decision-making process, but during the lifetime of the WWTP there might be adverse changes in the river ecology. In addition WWTPs will also consume considerable energy with the course of time which accounts to GHG emissions, and further re-utilization of treated water for irrigation or other purposes are supposed to be considered. Life cycle cost analysis (including capital cost, net present value of operation and maintenance cost, equipment replacement cost, depreciation cost, present worth salvage value) of the treatment technology will have higher influence on the decision-making process.

Considering the quantitative and qualitative aspects of each alternative, the decision on a process, should have a balance on the main categories of impact criteria. Most of the situations, aspects are intangible but the final decision can still contain a level of subjectivity. Criteria or weightings can be attributed to the various categories essentially associated with impact criteria. There is no generalized formula for weighting the attributes, common sense and experience should be used while attributing the relative importance for each category. Thus, there is a need in developing a model considering all categories that influence the decision making process in adopting the treatment technology. Therefore, this article mainly outlines the development of decision support system for adopting a treatment technology for a WWTP based on the weight percentage techniques.

2. Decision support system (DSS)

The decision support system refers to an interactive computerized system that collects and analyzes the data and present data from a wide range of sources in a way that can be interpreted. The DSS assists decision-makers to choose the technology based on data that is culled from a wide range of sources. DSS methods should be able to provide the necessary perspective on the nature of the decision process and the various requirements of supporting it. The key steps behind the conceptual basis of the DSS includes

1. Data collection and utilization of the data in making the decision.
2. The second step includes the process selection to combine the data.
3. Final step is the evaluation/learning process that compares decisions, and further, to verify either the data used in the process or the process that combines data need to change. The process steps in DSS are defined in the Figure 1.

A decision support system could reduce or potentially eliminate the impact of the attributes. Tsagarakis et al. (2001) have outlined the important factors in selecting the treatment technology for developed and developing countries. DSS method is flexible enough to account for the user's preferences in weighing the main categories of impact criteria (or depending on location). The DSS for choosing the wastewater treatment technology for the wastewater treatment process is developed in MS Excel using weighted percentage techniques and compares between various alternative technologies, alternatives bestowed to corresponding site location. Weighted percentage techniques are a method of computing an average in which each category is assigned by a weight. The weighting determines the relative importance of each category on the average and it adjusts for the frequency of individual values. The first step behind the conceptual basis of the DSS is to identify the selection criteria that have influence on selection of treatment technologies. The impact criteria are mainly categorized into seven attributes i.e., (i) life cycle cost (LCC), (ii) land, (iii) technology acceptance and operation & maintenance issues, (iv) reuse & recycle, (v) green house gas emissions (vi) local attributes, and (vii) river ecology. The weighted percentage could be finalized using data capturing instrument and the weighted percentage ascribed to each attribute is given in Table 2. The weighted percentage can be varied from country to country. Acquiring land may be more difficult for countries; in that situation percentage weighting for land will be eminent. For developed countries river ecology is a major concern, thus weighted percentage assigned to attributes depending upon the importance and impact.

Further, each attribute is again sub-divided into different sub-aspects, which will be evaluated by using 'Impact Score' instrument, which is given in Table 3. The score of each selection criteria of each group will be evaluated by using the "Impact Score Instrument". The expected positive and negative impacts to be relatively associated with the different factors and conditions will be integrated in the DSS worksheets and the overall impact of the alternative technologies will be calculated. Based on the highest marks scored, the best technology option will be finalized.

The seven attributes and their impact on decision making are explained below.

2.1. Life cycle cost analysis

Projects with good engineering proposal and with economic justification provide good economics for the business success. First cost decisions for the project have to assess the cost effectiveness of projects. The basic motive of an environmental engineer is to suggest and recommend cost effective alternatives, thus LCC is a tool for engineers to provide the best alternative with low ownership costs. The difference between the LCC and LCA is as follows: "Life cycle assessment refers to the valuation of environmental impacts associated with all stages of a product, process, or services (from cradle to grave)". Whereas, the "LCC refers to the estimating the total cost of owning, operating and maintaining equipment or assets over a number of years".

LCC are summations of cost estimates from inception to disposal for both equipment and projects and the results of LCC should be summarized in net present value (NPV) format considering depreciation, taxes and the time value of money. Government organizations need to consider only the time value of money, as they don't require inclusion of depreciation or taxes for LCC decisions. Barringer and Barringer associates (2003) provided an excellent summary on LCC and here it's not repeated. LCC equation, mainly contains two components, cost and time. Further, the cost has two major categories, initial expenses and future expenses by which projects are to be evaluated in an LCC analysis. The second component time, is the study period of time over which ownership and operations expenses are to be evaluated. Typically the study period can range from twenty to thirty years (Note**:** if the study period is changed in 100 years does not have any impact on the cost ranking of the alternate approaches). Different components of a wastewater system maintain different life spans (i.e., years of effective operation) are the prime consideration, that will be undertaken during the LCC analysis. For example, electronic instrumentation is generally replaced every 25 years, process equipment and mechanical components are replaced every 20 years, and buildings and related engineering earth work is redone on a 50-year replacement cycle. An LCA model takes these different life spans into account in projecting overall costs. The basis and major consideration of LCC is "time value of money" which is the most challenging LCC analysis concepts to explain and understand (Barringer and Barringer associates, 2003). The base concept behind the time value of money is that the value of $ 1 million today is not the same as $1 million in 10 or 20 years.

LCC is evaluated using the following Equation 1; it gives the present value of the total cost of your investment.

LCC = initial cost + present worth of maintenance and energy cost - (depreciation cost + present worth of salvage value) (1)

Where

i) Initial cost = civil cost + equipment cost + land cost
ii) NPV of O&M cost = 29.96 x net operating cost
iii) Equipment replacement cost = 15% of the equipment cost

Regardless of how the project is financed and the cost is always considered as a single payment occurring in the initial year of the project, and the initial capital expense for equipment, the system design, engineering, and installation are the capital cost of the project. The discounting factor for operation and maintenance for 30 years LCC is 29.96, is evaluated using the Equation 2.

$$\text{Discounting factor } (DF_{O\&M}) = C \times (1+i)^{-j} \quad (2)$$

Where "C" is the present value of the money, and "*i*" is the interest rate, "*j*" is the number of years in the future. The depreciation factor is evaluated using the Equation 3 (Sato et al., 2007).

$$DF = \frac{i\,(1+i)^{t}}{(1+i)^{t} - 1} \quad (3)$$

where "*i*" is the interest rate and "t" is the economic life

The salvage value (S) is the net worth in the final year of the life-cycle period and it is assigned a salvage value of 20% of the original cost of mechanical equipment that can be moved.

Depreciation cost = 0.0889 * costs of civil works (4)

Present worth salvage value = 20% of the equipment cost (present wroth of salvage value (5)

2.2. Land

Land requirement for the different treatment technologies are summarized in the Table 4. Availability of land is the major problems for the congested and unplanned cities; moreover, establishing WWTPs outside the city will increase the pumping cost and maintenance (Massoud et al., 2009). In developing countries acquiring the suitable land (based on the initial survey for WWTP) from the public is a major concern. The municipalities have to pay millions to acquire the land, which will increase the capital cost of the project. Therefore, land is also considered as a major factor, which influences the decision making for the decision makers or municipalities.

2.3 Technology acceptance and operation and maintenance issues

Technology acceptance is the major problem in the developing countries due to lack of research and development activities (Massoud et al., 2009). Moreover, local climatic and physical conditions, social acceptance, and budget will also influence the technology acceptance in the developing countries. Operation and maintenance will also influence while choosing the treatment technology for a wastewater treatment process in the developing countries (Sahely et al., 2005; Massoud et al., 2009). Non-availability of the funds and required materials for maintaining the treatment technology will lead to breakdown of treatment technology (Sahely et al., 2005). For example, MBBR treatment technology requires special grade plastics with high surface area. These materials have to be imported and transported to the WWTP site will take a long time, which will eventually lead to breakdown of the treatment process. Therefore, technology acceptance and operation & maintenance issues are considered as attribute which influence the decision making.

2.4 Reuse & recycle

Reuse and recycle treated wastewater is the best way of conserving water, due to depletion of water sources and widening gap between the demand and supply. The socio-economic, health and environmental impacts of wastewater use in agriculture was presented by Hussain et al. (2002). The treated wastewater is also used for watering the garden. The treated wastewater effluent quality will impact reuse and recycle. The effluent quality is depended on the type of the treatment technology. Therefore, reuse and recycle is also considered as potential attribute during the decision making process.

2.5 Greenhouse gas emissions

Greenhouse gas (GHG) emissions during the biological wastewater treatment are mainly dependent on the type of treatment technology (Keller and Hartley, 2003). Moreover, during the biological treatment process, sludge produced will also contribute to GHG emissions. The resultant effect of GHG emissions, global warming and climate change are currently threatening and will continue to threaten the quality of life for humanity and ecosystems. Developed countries are imposing a carbon tax on companies to minimize the fossil fuel usage and reduce the GHG emissions. The energy required for the treatment process was mainly generated from the fossil fuels, which will substantially contribute to GHG emissions. Therefore, the GHG emissions have an impact on the decision support system, and it is also considered as an attribute during the decision making process of adopting a treatment technology.

2.6 Local attributes

The local attributes will influence in adopting the treatment technology for wastewater treatment process. For example, availability of skilled labor will influence the operation and maintenance of treatment technology. In developing countries the supply of electricity is not continuing, which will affect the wastewater treatment operations. The performance of the treatment technology will also be affected.

2. River ecology

The treated wastewater effluent discharge into the river bodies will have adverse changes on the river ecology. Recent studies have reported that discharging the treated wastewater effluent has resulted in feminization of male fish (Sowers, 2009; Gross-Sorokin et al., 2006). The temperature of treated wastewater effluent will be higher than the river water temperature. This will increase the temperature of the river which affects the ecology of the river (Welch, 2003). Concentration of nitrogen and phosphorus in the treated effluent leads to growth of weeds and algae in rivers. Due to excess growth of weeds and algae will minimize the oxygen concentration in the river, which affect the survival of fish communities in the river. The effluent quality and concentration of the nutrients depends upon the efficiency of the treatment technology. Therefore, river ecology is considered as an important attribute which influence the decision making.

3. A hypothetical case study/practical study in choosing a treatment technology for WWTP in developing countries based on DSS and LCC analysis

In order to choose a treatment technology for a WWTP, the UASB, ASP, MBBR, MBR, SBR are considered as available treatment technology options. The amount of wastewater generated from a population of 3 60 000 is assumed as 3.38 million liters per day (MLD). Following steps are followed in evaluating the decision support system for 3.38 MLD wastewater treatment plant.

Step-1: LCC of the different treatment technologies (UASB process, ASP, MBBR, and MBR, and SBR) are evaluated based on the land requirement, energy requirement, operation maintenance cost and capital cost. The capital cost and O&M cost for the different treatment technologies was collected from the treatment technology suppliers (of India) are summarised in Table 4. The LCC for UASB process, ASP, MBBR, and MBR, and SBR is evaluated and presented in Table 5.

From the life cycle cost analysis, the treatment technology suitable for a WWTP (3.38 MLD) is an UASB process (Table 5) with life cycle cost of 138 million/MLD wastewater treated. Following UASB the best treatment technology available for the decision makers is ASP and SBR with 155.5 and 157.9 million /MLD wastewater treated, respectively. By using LCC the ranking order of the treatment technology for treating 3.38 MLD are as follows UASB > ASP > SBR> MBBR > MBR.

Step-2: DSS is executed based on the impact score (from Table 3); feedback is computed as given in the Table 6.1. Further, analysis is done for DSS based on the feedback form (Table 6.1) and the results are summarized in the Table 6.2. The order of the treatment technologies based on DSS analysis is as follows UASB > ASP > SBR> MBBR > MBR. Thus, the DSS model and LCC will help the decision makers and policy makers in adopting a treatment technology for a WWTP. Application of DSS and LCC model is literally very easy to use and compare, it can be utilized for choosing the treatment technology for establishing a WWTP and also for upgrading wastewater treatment process.

4. Conclusion

The developed DSS model will help the decision makers and municipalities in arriving at a decision for choosing a treatment technology for a wastewater treatment process. DSS address life cycle cost, land, technology acceptance, operation & maintenance issues, reuse & recycle, GHG emissions, local attributes, and river ecology, which are influencing the decision making process. The weighted percentage allotted to attributes is based on experience and varies from country to country and also on the requirement for the municipalities. Based on LCC and DSS for 3.3 MLD WWTP, that the treatment technologies suitable for adopting are in the following order UASB > ASP > SBR> MBBR > MBR.

Abbreviation list

DSS: decision support system
UASB: up-flow anaerobic sludge blanket,
ASP: activated sludge process,
MBBR: moving bed bio-reactor,
MBR: membrane bio-reactor,
SBR: sequential batch reactor
WWTPs: wastewater treatment plants
GHGs: green house gases

CO_2: carbon dioxide

CH_4: methane

N_2O: nitrous oxide

LCC: life cycle cost

NPV: net present value

LCA: life cycle assessment

O&M: operation and maintenance

MLD: million liters per day

Reference

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