The Selection of Wastewater Treatment Units Based on Analytical Hierarchical Process

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Abstract Nowadays, various recognized technologies exist for the treatment of municipal wastewater. Each technology has its own advantages and limitations depending on appropriateness to fulfill the desired requirements. In this study, an effort is made to use the MCDM tool to select the most appropriate technology for municipal wastewater treatment in a small to medium city, where availability of land is not a major constraint. The Analytical hierarchy process (AHP) has been used as a decision-making tool, the expert opinions and judgments are used to assign quantitative and qualitative weights to different criterion and sub-criterion. The available options were compared based on three main criteria, i.e., economical aspects, technological aspects, and environmental and health aspects, and thirteen sub-criteria. In the present scenario in India, the three simple and effective treatment technologies were used in this study: (A) Trickling filter system (B) Waste stabilization pond system, and (C) Activated sludge process. The AHP analysis on three options revealed that the waste stabilization pond technology is an appropriate technology with the highest priority value of 40% among the other options.

Keywords Wastewater technology selection · AHP · Trickling filter · Waste stabilization pond · Activated sludge process

1 Introduction

The population in urban boundaries is increasing exponentially. Water is one of the most essential needs of every living entity. Nowadays, the disposal of untreated wastewater is becoming one of the major concerns for society. Since many municipal corporations in India still don't have a wastewater treatment facility, they directly disposed off wastewater into local water bodies or streams, which in due course

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of time meet to main rivers and pollute them. Since conventional sewage treatment methods are costly and require skilled manpower for their operation and maintenance, many small municipal corporations do not give sufficient weightage to sewage treatment. As per CPHEEO, approximately 70–80% of domestic water supplied becomes discharged as wastewater. There is a significant gap between wastewater generation and available installed wastewater treatment plant capacity. The CPCB 2009 reports, urban areas are generating 35254 MLD sewage while treatment facilities for 11777 MLD only available. Recently, the answer to Lok Sabha's question given by the Ministry of Environment and Forest, Government of India revealed that total wastewater generation from urban areas in the country has grown up to 61948 MLD and the available installed treatment capacity is 23277 MLD only. i.e., total of 920 numbers of STPs are working to treat wastewater. There is a huge gap between the generation and wastewater treatment system and numbers of STPs are required to fill these gaps by choosing appropriate treatment technologies.

In India, The local authorities, i.e., Nagar Nigam are mainly responsible for the collection and treatment of wastewater in the city. The insufficient funds and lack of infrastructural facilitates are quite negligent toward wastewater collection and its treatment. In this situation, the selection of the most suitable municipal wastewater treatment options among the alternatives is a complex decision-making problem with limited available resources. The various treatment technologies options like Activated Sludge Process, Trickling Filter, Rotating Biological Contactor, Oxidation ditch, Waste Stabilization Pond, etc., are commonly used to treat wastewater. The MCDM tools can be used to deal with such a problem choosing appropriate treatment technologies. There are numerous MCDM tools that are available and used, depending upon the nature of the decision-making problem [1]. The MCDM tools are used by different researchers for addressing complex decision-making problems for several decades. Many researchers used numbers of MCDM tools like AHP, ANP, Fuzzy set theory, case-based reasoning, MAUT, simple multi-attribute rating technique, goal programming, SAW and ELECTRE, etc., and each tool has its own merits and shortcomings and limitation in the area of applications. The MCDM techniques also applied in many areas like environmental sciences, management, economics, and product design and in business for giving ranking to alternatives available [2]. An important step of these methods is the involvement of decision makers and their opinion in the whole process of evaluation [3]. ELECTRE is one of the MCDM techniques applied in water management, transportation problems, energy, and environmental field. Uncertainty and vagueness in problem can be addressed through this method [4]. The environmental problem of contaminated groundwater assessment used the cost-benefit method [5]. The AHP tool used for the urban water supply system in Nigeria [6]. The selection of hospital waste suppliers by the AHP tool [7]. The AHP and PROMETHEE tools were used for the selection of proper excavation machines and concluded that the final results of both the method are identical [8].

The AHP tool is one of the most widely used and internationally accepted techniques developed by Prof. Satty [9] in the decision-making problem. The AHP tool allows qualitative and quantitative elements in analysis through field data and experts' subjective judgments. The parameters related to environmental, social, and human health can easily incorporate through the use of AHP [10]. The provision of consistency checks makes it more reliable than in another method like TOPSIS which doesn't allow such facility [11]. The selection of best municipal solid waste disposal site facility by AHP tool and different sustainability criteria [12]. In this study, an attempt has been made to select the most appropriate wastewater treatment technology from Activated Sludge Process (ASP), Trickling Filter (TF), and Waste Stabilization Pond (WSP) options by Economic, Technological, and Environmental Aspects. The Expert Choice software was used for the AHP analysis.

2 Methodology

2.1 Identification of Design Options

This study is used to select the appropriate wastewater technology among the three technologies for WWT plant in central India. The three technologies are [13, 14]:

(A) Option 1: Wastewater Treatment Plant with trickling filter (TF)
(B) Option 2: Waste Stabilization Pond (WSP)
(C) Option 3: Activated Sludge Process (ASP).

Option 1. Trickling filter (TF) has various advantages like low initial and maintenance cost, low sludge production, and good performance for developing countries like India (Metcalf and Eddy 2003).

Option 2. Waste stabilization pond (WSP) has advantages of low construction cost and uses low energy-consuming systems that treat by natural processes (Metcalf and Eddy 2003).

Option 3. Activated sludge process (ASP) is a suspended-culture system that has been in use since the early 1900s. It has high removal efficiency and the quality of effluent is better than other conventional treatment methods. (Metcalf and Eddy 2003).

A comprehensive judgment is prepared for the collection of information from experts, the practitioner (consultants and plant designers), academicians, and government officials working in WWT and management.

2.2 Analytical Hierarchical Process

The AHP tool developed by Saaty in 1980 is one of the most accepted and widely used MCDM tools for many complex decision-making problems. It is a systematic approach that considers feeling intuition and logic in the final decision-making and the relation of the importance of different criteria and sub-criteria are taken through questionnaires and expert judgments. The subjective decision of an individual can be easily handled through the AHP tool. The basic steps involved in AHP tool are [9]:

(1) Firstly the decision problem is broken down into simple elements.
(2) Place each of the elements in a proper hierarchic level.
(3) Assign a weight to subjective judgment.
(4) Synthesize the judgment for getting the final ranking of performances through the aggregation of relative weights.

The Pair-wise comparison is the most important part of the analysis. In AHP relative preferences are assigned from 1 to 9 in Table 1, where a higher value indicates increasing importance. Consistency index (CI) value Eq. 1 and randomness index value Table 2 is used to find CR. Consistency ratio (CR) Eq. 2 is the indicator of consistency in judgments. If CR value exceeds 0.10 it indicates inconsistent judgment. Higher values of inconsistency reflect a lack of understanding or information.

$$CI = (\lambda_{max} - n) / (n - 1) \quad (1)$$

where:

λ_{max} = maximum Eigenvalue and
n = matrix size

.. (2)

Development of priority ranking: the overall ranking of the alternatives is obtained by constructing a decision matrix, which contains different criteria and sub-criteria

Table 1 Pair-wise comparison scale

Numerical rating	Judgments of preferences
9	Extremely important
7	Very strongly preferred
5	Strongly preferred
3	Moderately preferred
1	Equally preferred
2,4,6,8	Intermediate values

Table 2 Average randomness (RI)

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

and their relative weighting. So by multiplying their priority vector with weight and adding all of them together, the final priority value of alternatives is obtained.

2.3 Criteria and Sub-criteria Selection

The three main criteria, i.e., economic aspect, technological aspect, and environmental and social aspect, respectively, with respect to the goal, are formed using literature and considering expert opinions [15, 16]. The brief description of criteria and sub-criteria are given in Table 3.

Using selected criteria and sub-criteria the AHP decision network is formed following the basic steps in analyzing procedure and represented in Fig. 1.

3 Results and Discussion

The pair-wise comparisons were conducted by the decision maker for different criteria and sub-criterion. Then normalized priority vectors and consistency ratios are calculated which is presented in Tables 4, 5, 6, 7, 8, 9, and 10.

It is depicted from the graphical representation of Fig. 2 that among the criteria aspects the environmental and social aspects are acquired the highest priority (0.49) than the economic aspects (0.31) and technological aspects which has less priority (0.20). In making comparisons between sub-criteria Figs. 3, 4, and 5, in Economic aspects criteria O & M cost sub-criteria, has the highest priority vector (0.439), similarly effluent quality has the highest priority (0.334) in technological aspect and public acceptance has the highest priority (0.414) in the environmental and social aspect. The overall weighting of Option 2 waste stabilization pond is highest (0.40) considering all the criteria and sub-criteria.

Considering normalized priorities of all the criterion and sub-criterion, decision matrix (Table 11) is formed and priorities of alternatives are determined. The final priorities of alternatives are presented through Table 12 and Fig. 6.

3.1 Sensitivity Analysis

The final outcomes of AHP analysis reveal that WSP has a priority of 40% while ASP and TF have priorities of 31% and 29%, respectively. These final priorities of alternatives are dependent on the weightage of different criteria which are assigned through experts' opinion. Therefore, any change in assigned weightage will affect the final choice of alternative. So sensitivity analysis is conducted to check the impact of variation in weightage of key criteria parameters. The sensitivity graphs are prepared by varying the weightage from 0 to 1 for all three criteria with respect to our goal than

Table 3 Selection of criteria and sub-criteria

Criteria	Sub-criteria	Description
1. Economic aspects	1.1 Capital investment	It includes expenses for the construction of the plant
	1.2 Residual value	Monitory value at the end of the utility period
	1.3 O & M	Related to expenses in the operation and maintenance of the treatment plant
	1.4 Electricity	Expenses on electricity requirements for various processes
2. Technological aspects	2.1 Effluent quality	BOD, Nitrogen, and Phosphorus removal efficiency
	2.2 Sludge handling	The processing, reuse, and disposal of sewage sludge
	2.3 Flow variation	The sensitivity of plant due to variation in wastewater flow rate
	2.4 Simplicity	Simplicity in operation, the requirement of skilled manpower for operation
3. Environmental and social aspects	3.1 Odor	Smell impact, foul smells surrounding the treatment facility
	3.2 Noise	Production of noise on the surrounding area
	3.3 Visual impact	Aesthetic appearance affects due to the sitting of the plant in the surrounding area
	3.4 Public acceptance	The opinion of the local people affected by the plant
	3.5 Use of natural resources	Consumption of natural resources (technology which consumes more resources will have an adverse impact on the environment)

from each criterion one sub-criterion is chosen which has the highest priority in that criteria aspect and sensitivity analysis with respect to the goal is performed similarly. From the sensitivity analysis, it is found that the choice of WSP remains stable in a wide range. So the stability of ranking can arrive through sensitivity analysis and sensitive parameters are identified which needs careful attention. Sensitivity analysis is performed with goal node and various criterions so that the results to be interpreted are described and shown here through Figs. 7, 8, 9, 10, 11, 12, and 13. Now considering the sub-criteria node in economic aspect O & M has a weight of

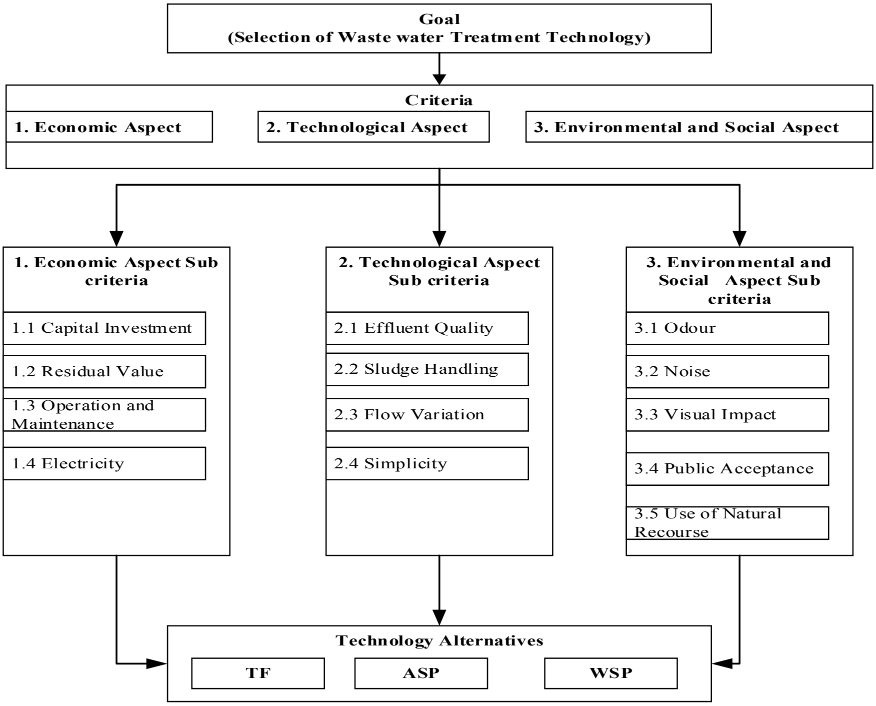


Fig. 1 Systematic representation of AHP decision model

Table 4 Pair-wise comparison matrix for criteria aspect with respect to the goal

Main criteria	1. Economic aspects	2. Technological aspects	3. Environmental and social aspects	Normalized priority vector	
1. Economic aspects	1	2	1/2	0.31	Consistency ratio (CR) = 0.05
2. Technological aspects	1/2	1	1/2	0.20	
3. Environmental and social aspects	2	2	1	0.49	

0.439 (Fig. 3) but the sensitivity graph is flatter and any change in parameter value does not affect the alternative ranks.

The effluent quality has a weightage of 0.334 (Fig. 8) in the technological aspects but with respect to goal node any change in this value will not affect the final choice of alternatives. The public acceptance having a weightage of 0.414 (Fig. 9) and it belongs to environmental and social aspects having the highest importance. From the sensitivity graph, it is found that at a parameter value of 0.85 ASP becomes the first choice and WSP comes down to the second. On the other hand, decreasing the

Table 5 Pair-wise comparison matrix for economic aspect

Economic aspects	1.1 Capital investment	1.2 Residual value	1.3 Operation and maintenance	1.4 Electricity	Normalized priority vector	
1.1 Capital investment	1	1/2	1/3	1/3	0.10	Consistency ratio (CR) = 0.05
1.2 Residual value	2	1	1/3	1/3	0.15	
1.3 Operation and maintenance	3	3	1	2	0.44	
1.4 Electricity	3	3	1/2	1	0.31	

Table 6 Pair-wise comparison matrix for technological aspect

Technology aspect	2.1 Effluent quality	2.2 Sludge handling	2.3 Flow variation	2.4 Simplicity in operation	Normalized priority vector	
2.1 Effluent quality	1	2	1	2	0.33	Consistency ratio (CR) = 0.09
2.2 Sludge handling	1/2	1	2	1	0.25	
2.3 Flow variation	1	1/2	1	2	0.24	
2.4 Simplicity in operation	1/2	1	1/2	1	0.17	

Table 7 Pair-wise comparison matrix for environmental and social aspect

Env. and social aspect	3.1 Odor	3.2 Noise	3.3 Visual impact	3.4 Public acceptance	3.5 Use of natural resources	Normalized priority vector	
3.1 Odor	1	3	2	1/3	1/2	0.17	Consistency ratio (CR) = 0.05
3.2 Noise	1/3	1	1/2	1/3	1/2	0.08	
3.3 Visual impact	½	2	1	1/3	1/2	0.12	
3.4 Public acceptance	3	3	3	1	3	0.41	
3.5 Use of natural resources	2	2	2	1/3	1	0.21	

parameter value WSP remains the first choice while a value below 0.15 TF becomes the second choice, and ASP becomes the last alternative.

The weight of economic aspects is 0.311 if this weight is increased beyond 0.311 the WSP is the best choice (Fig. 10), however, if the weightage is reduced then still WSP remains the first choice up to a weight of 0.11 then ASP becomes the first choice. At a weight of 0.55 among ASP and TF, trickling filter becomes second choice and ASP the last alternative. In technological aspects weight is 0.196 (Fig. 11) this parameter is insensitive, any change in this value does not affect the choice of alternatives.

In environmental and social aspect weight is 0.493 (Fig. 12) if this value is reduced no change in alternatives but at the value lower than 0.27 TF becomes the second choice and value higher than 0.72 ASP becomes the first choice and WSP comes down to the second alternative. So from sensitivity analysis in AHP, we can conclude that even doing substantial changes in different parameter values the final choice remains the same and ranking of the alternatives is highly stable.

Table 8 Pair-wise comparison matrix for economic aspects sub-criterion parameters and alternatives

Capital cost					Consistency ratio (CR)
	1 TF	2 WSP	3 ASP	Normalized priority vector	
1 TF	1	11/5	1	0.34	0.0
2 WSP	5/6	1	7/9	0.29	
3 ASP	1	1 2/7	1	0.37	
Residual value					0.0
1 TF	1	1/3	1	0.2	
2 WSP	3	1	3	0.6	
3 ASP	1	1/3	1	0.2	
O & M					0.01
1 TF	1	1/2	2	0.3	
2 WSP	2	1	3	0.54	
3 ASP	½	1/3	1	0.16	
Electricity					0.02
1 TF	1	1/4	2	0.2	
2 WSP	4	1	5	0.68	
3 ASP	½	1/5	1	0.12	

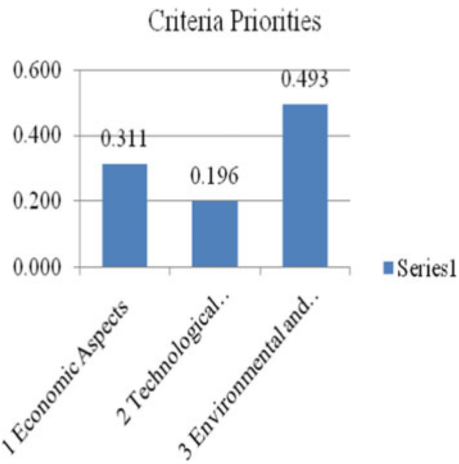
Table 9 Pair-wise comparison matrix for technological aspects sub-criterion parameters and alternatives

Effluent quality					Consistency ratio (CR)
	1 TF	2 WSP	3 ASP	Normalized priority vector	
1 TF	1	2	1/3	0.2631	0.1
2 WSP	1/2	1	1/2	0.1897	
3 ASP	3	2	1	0.5472	
Sludge handling					0.1
1 TF	1	1/2	2	0.3	
2 WSP	2	1	3	0.54	
3 ASP	1/2	1/3	1	0.16	
Flow variation					0.05
1 TF	1	1/2	2	0.31	
2 WSP	2	1	2	0.49	
3 ASP	1/2	1/2	1	0.2	
Simplicity					0.02
1 TF	1	1/3	2	0.24	
2 WSP	3	1	4	0.63	
3 ASP	1/2	1/4	1	0.14	

Table 10 Pair-wise comparison matrix for environmental and social aspects sub-criterion parameters and alternatives

Odor					Consistency ratio (CR)
	1 TF	2 WSP	3 ASP	Normalized priority vector	
1 TF	1	2	1	0.4	0.01
2 WSP	1/2	1	1/2	0.2	
3 ASP	1	2	1	0.4	
Noise					0.05
1 TF	1	1/3	2	0.25	
2 WSP	3	1	3	0.59	
3 ASP	1/2	1/3	1	0.16	
Visual impacts					0.05
1 TF	1	2	1/2	0.31	
2 WSP	1/2	1	1/2	0.2	
3 ASP	2	2	1	0.49	
Public acceptance					0.01
1 TF	1	2	1/2	0.3	
2 WSP	1/2	1	1/3	0.16	
3 ASP	2	3	1	0.54	
Use of natural resources					0.02
1 TF	1	1/2	1	0.24	
2 WSP	2	1	3	0.55	
3 ASP	1	1/3	1	0.21	

Fig. 2 Criteria priorities



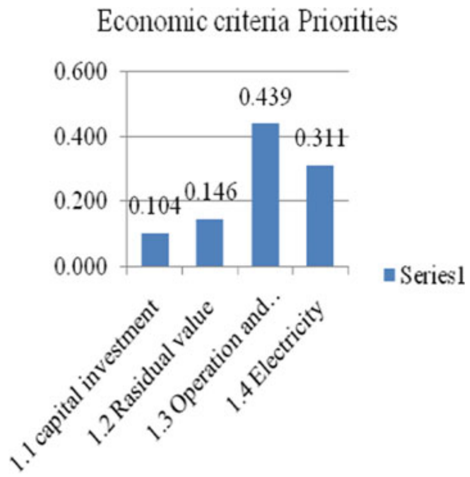


Fig. 3 Economic criteria priorities

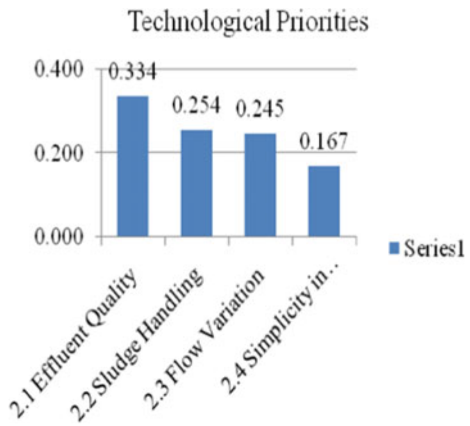


Fig. 4 Technological criteria priorities

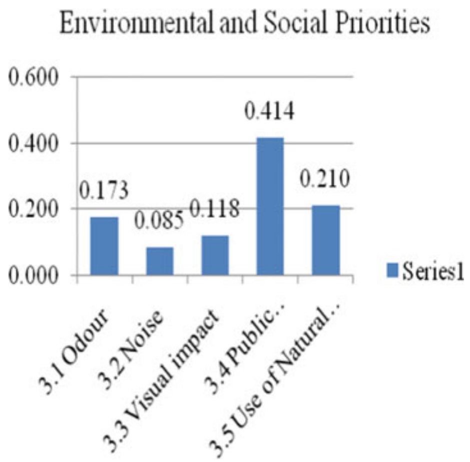


Fig. 5 Environ. and social criteria priorities

Table 11 Decision matrix

Criteria	1 Economic aspects (0.311)				2 Technological aspects (0.196)				3 Environmental and social aspects (0.493)				
Sub-criteria	1.1 Capital investment	1.2 Residual value	1.3 Operation and maintenance	1.4 Electricity	2.1 Effluent quality	2.2 Sludge handling	2.3 Flow Variation	2.4 Simplicity in operation	3.1 Odor	3.2 Noise	3.3 Visual impact	3.4 Public acceptance	3.5 Use of natural resources
Option ↓	**0.104**	**0.146**	**0.439**	**0.311**	**0.334**	**0.254**	**0.245**	**0.167**	**0.17**	**0.085**	**0.118**	**0.414**	**0.210**
1 TF	0.34	0.20	0.30	0.20	0.26	0.30	0.31	0.24	0.40	0.25	0.31	0.30	0.24
2 WSP	0.29	0.60	0.54	0.68	0.19	0.54	0.49	0.63	0.20	0.59	0.20	0.16	0.55
3 ASP	0.37	0.20	0.16	0.12	0.55	0.16	0.20	0.14	0.40	0.16	0.49	0.54	0.21

Table 12 Alternative priorities

Options	Priorities
1 TF	**0.28**
2 WSP	**0.40**
3 ASP	**0.31**

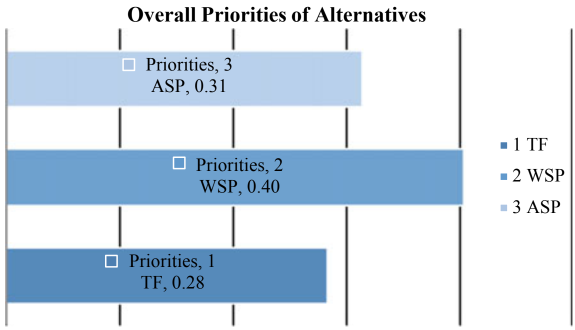


Fig. 6 Final priorities of alternatives

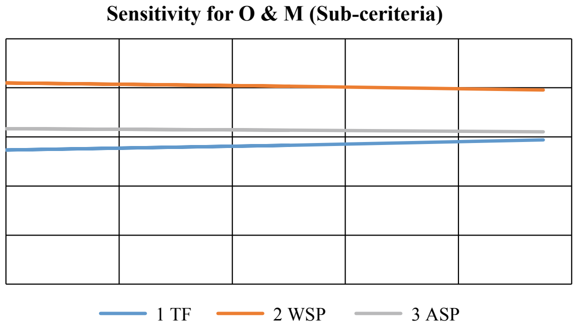


Fig. 7 Sensitivity of goal with operation and maintenance

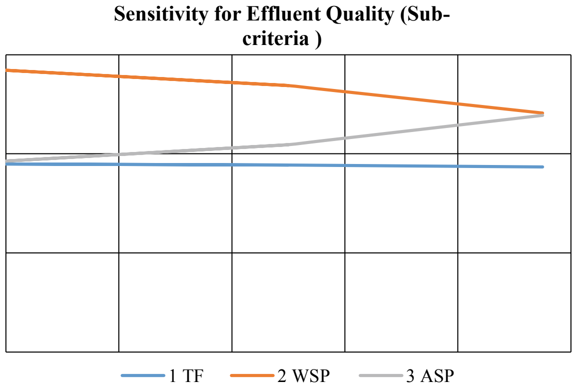


Fig. 8 Sensitivity of goal with effluent quality

Fig. 9 Sensitivity of goal with public acceptance

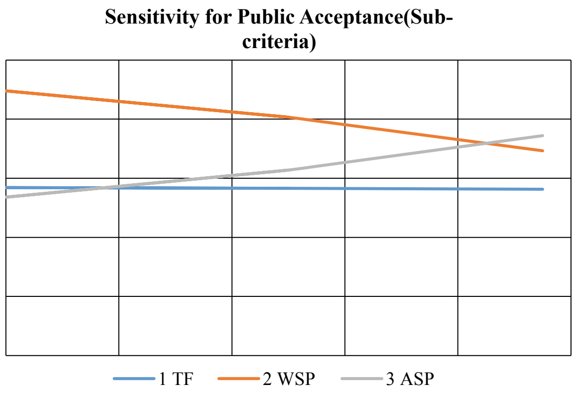


Fig. 10 Sensitivity of goal with economic aspects

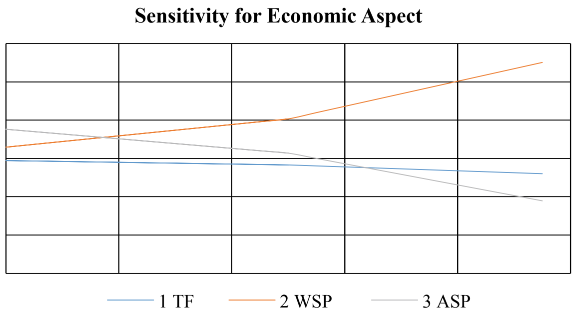
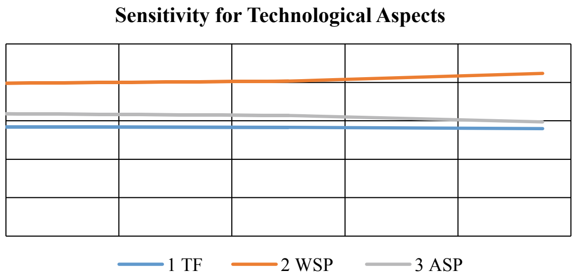


Fig. 11 Sensitivity of goal with technological aspects



4 Conclusions

Presently numerous wastewater technologies are available to treat municipal wastewater. But for Municipal Corporation where funds and skilled manpower is scarce, selection of most suitable and efficient treatment alternative is a complex decision-making task.

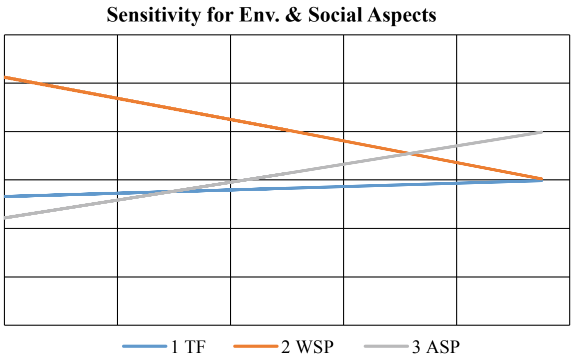


Fig. 12 Sensitivity of goal with environmental and social aspects

The aim of the present study was to evaluate different alternatives to municipal wastewater treatment alternatives for small Municipal Corporation. For the evaluation of alternatives, AHP methods are used, which is based on qualitative and quantitative expert's opinions and feedbacks. The assessment criteria are selected from the literature reviews and from practical field observations. The three main criteria aspects such as economic, technological, and environmental and social are considered. Among each aspect relevant sub-criteria are considered and based on these final choices of alternative is arrived. For comparison of alternatives most commonly used technologies in India are considered. This is trickling filter (TF), activated sludge process (ASP), and waste stabilization pond (WSP), respectively. AHP method is used to rank the alternatives. From the analysis, outcomes are obtained as:

- AHP recommend Option 2 [WSP] is best performance than Option 1 [TF] and Option 3 [ASP].

Since results are widely dependent on expert's subjective judgment and prone to change, so sensitivity analysis is also conducted for criteria having the highest impact on the final ranking of alternatives. Sensitivity analysis reveals the final ranking is consistent even substantial variation is made in key criteria parameters. It shows that expert opinions are consistent and the method used is robust and reliable for decision-making.

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