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Application of Analytical Hierarchy Process in Evaluation of Best Sewage Treatment Plant

Kshitij Upadhyay

Civil Engineering Department Rajkiya Engineering College, Bijnor

Abstract: ***This paper presents the application of AHP in environment engineering. In many environment engineering applications the final decision is based on the evaluation of a number of alternatives in terms of a number of criteria. This problem may become a very difficult one when the criteria are expressed in different units or the pertinent data are difficult to be quantified. The Analytic Hierarchy Process (AHP) is an effective approach in dealing with this kind of decision problems. This may be a difficult task and the Analytic Hierarchy Process seems to provide an effective way for properly quantifying the pertinent data. This paper examines some of the practical and computational issues involved when the AHP method used in environment engineering applications. Various economic, environment and technical data are thorough analysed in this paper to compare sewage treatment plant of Kanpur and Lucknow for gainful research purpose with the help of AHP.***

Keywords: Analytical hierarchy process, multi-criteria decision making, sewage treatment plant, Biological oxygen demand (BOD), Chemical oxygen demand (COD), Total suspended solid (TSS), Total dissolved solid (TDS).

1. Introduction

The AHP is multi-criteria decision making tool which was introduced by L. Saaty (1977). AHP is important tool in determining the final decision based on mathematics of any multicriteria decision whose units are different. It's been widely used in the area of industrial management and decision making. This method uses pairwise comparison to determine the final result. Pairwise comparison is done with the help of expertise and study about the subject.

Selection of an appropriate treatment plant is an important issue before designing and implementing any sewage treatment plant. As we know in past decades the alternatives of waste water treatment plant are compared only based on the economic data provided in pre design studies of waste water treatment plant project therefore, the alternative with min capital and operation cost is chosen

Treatment plant selection involves the detail evaluation of the various factors that must be considered when evolving various processes in treatment plant processes and methods to meet the current and future treatment objectives. So selection of treatment plant is an important issue due to its capital cost and function. Sir Saaty give a technological view and consideration to select best treatment who give best efficiency in removing hazardous component from the sewage so that disposal of waste water are not able to contaminate surface water and underground water.

2. Study Area

The study of two sewage treatment plant is done to compare between them. The first treatment plant is Jajmau sewage treatment plant, Kanpur and second treatment plant is Bharwara sewage treatment plant, Lucknow. Both the treatment plant are chosen because of the feasibility of obtaining data and similar environmental factor.

BHARWARA sewage treatment plant is the Asia largest sewage treatment which has capacity to treat 345mld sewage. In India, first sewage treatment plant is introduced in Kanpur in 1989. Bharwara treatment plant is situated at the bank of Gomti River and receive waste from total Trans Gomti side including Indira nagar, Gomti nagar and Sitapur road areas.

JAJMAU sewage treatment plant receives sewage from area bounded by the Ganga river to the north, Armapur state, dada nagar and Kidwai nagar to south. The area is mixed residential and commercial area with industrial area.

3. Methodology

Analytical Hierarchy Process (AHP)

The analytic hierarchy process is a mathematical device in multi-criteria decision making which designing the decision factors in a hierarchic problem structure (Saaty, 1990). The main target of the AHP is to decide and help decision makers in making resolutions for the complex problems by structuring the criterion hierarchy of Multi-criteria decision making. The first element in AHP procedures is determining the focus or aim of the problem identified. It is considered as the first level for the AHP hierarchy. Next would be multiple criterion that define alternatives and the last level is the contributing alternatives (causes/factors) for the focus. The standard scale with absolute numbers used as a measurement in order to manage the weight of each alternative.

The scale measurement from 1 to 9 in a fundamental scale of measurement listed in Table 1.

Table 1: Pair-wise comparison scale for AHP preference (Saaty and Windi, 1980; Saaty, 2008)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong Importance	Experience and judgment strongly favor one activity over

		another
7	Demonstrated Importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

Application of AHP to decision making involves four steps:-

1) Structuring of the decision problem into a hierarchical model.
2) Making pair-wise comparisons of criteria and obtaining the matrix.
3) Making pair-wise comparison for alternatives and obtaining matrix.
4) Aggregation of all priorities

Structuring of the decision problem into hierarchical model

In this paper waste water treatment plant is divided into 4 criteria which is further divided into sub criteria. The criteria or factor are decided on the basis of study about plant and treatment process.

The criteria used for comparing are as follows:

1) **Economic criteria analysed into next three sub-criteria.**
   a) Capital cost: includes cost of construction both civil and electro-mechanical works.
   b) Land requirement: includes cost of land required for construction of WWTP.
   c) Operation and maintenance cost: includes repair cost and energy cost.
2) **Environmental criteria analyzed into next four sub-criteria.**
   a) BOD removal
   b) COD removal
   c) TSS removal
   d) pH
3) **Technical /administrative criteria**
   a) performance
   b) reliability

Making pair wise comparison and obtaining judgemental matrix

Comparing first level criteria we get the judgemental matrix given below:

	Environment Factor	Economic Factor	Technical Factor	Priority Factor
Environment Factor	1	3-Jan	5	0.643
Economic Factor	3	1	7	0.283
Technical Factor	5-Jan	7-Jan	1	0.074

The normalized principal eigen vector is also called priority vector. Since it is normalized, the sum of all elements in priority vector is 1. The priority vector shows relative weights among the factor that we compare.

Aside from the relative weight, we can also check the consistency. For that we have to find principal eigen value. Principal Eigen value is obtained from the summation of products between each element of Eigen vector and the sum of columns of the reciprocal matrix.

λ_{max}=21/5(.2828)+31/21(.6434)+13(.0738)=3.0967

Consistency

Since judgments may lack a minimum level of consistency, mechanisms to improve consistency are necessary.

CI=λ_{max}-n/(n-1)
=3.0967-3/(3-1)
=0.0484

Random Consistency Index

Prof. Saaty proposed that we use this index by comparing it with the appropriate one. The appropriate Consistency index is called Random Consistency Index

(RI). He randomly generated reciprocal matrix using scale 1/9, 1/8, …, 1, …, 8, 9 (similar to the idea of Bootstrap) and get the random consistency index to see if it is about 10% or less. The average random consistency index of sample size 500 matrices is shown in the table below:

Table 8: Random Consistency Index (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Then, he proposed what is called Consistency Ratio, which is a comparison between Consistency Index and Random Consistency Index, or in formula

$$CR = \frac{CI}{RI}$$

If the value of Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, we need to revise the subjective judgment. Here,

Consistency Ratio

CR=0.0484/0.58
=8.3% < 10%

Thus acceptable

Comparing environment factor we get the judgemental matrix given beow:

	BOD Removal	COD Removal	PH Removal	TSS Removal	Piority Vector
BOD Removal	1	3	5	7	0.548
COD Removal	1/3	1	3	5	0.256
PH Removal	1/5	1/3	1	5	0.145
TSS Removal	1/7	1/5	1/5	1	0.050

λ_{max}=176/105(0.548)+68/15(0.256)+46/5(0.145)+18(0.050)
=4.23

Consistency Index

$CI=\lambda_{max}-n/(n-1)$
$=4.23-4/(4-1)$
$=0.0766$

Consistency Ratio

CR=CI/RI
=0.0766/0.9
=8.5% < 10% , hence applicable

Comparing economic factor we get the judgemental matrix given below:

	Operational Cost	Capital Cost	Land Requirement	Prority Vector
Operational Cost	1	3	7	0.643
Capital Cost	1/3	1	5	0.283
Land Requirement	1/7	1/5	1	0.074

$\lambda_{max}=31/21(0.643)+21/5(0.284)+13(0.073)$
$=3.0649$

Consistency Index

Since judgments may lack a minimum level of consistency, mechanisms to improve consistency are necessary.

$CI=\lambda_{max}-n/(n-1)$
$=3.0649-3/(3-1)$
$=0.03245$

Consistency Ratio

CR=CI/RI
=0.03245/0.58
=5.6% < 10% ,
hence applicable

Comparing technical factor we get the judgemental matrix given beow:

	Performance	Reliability	Priority Vector
Performance	1	1/5	0.167
Reliability	5	1	0.833

$\lambda_{max}=6(0.167)+6/5(0.833)$
$=2.0016$

Consistency Index

Since judgments may lack a minimum level of consistency, mechanisms to improve consistency are necessary.

$CI=\lambda_{max}-n/(n-1)$
$=2.0016-2/(2-1)$
$=0.0016$

Consistency Ratio

CR=CI/RI
=0.0016/RI

According to Saaty for 2x2 matrix the value of RI is 0, hence consistency ratio can't be evaluated

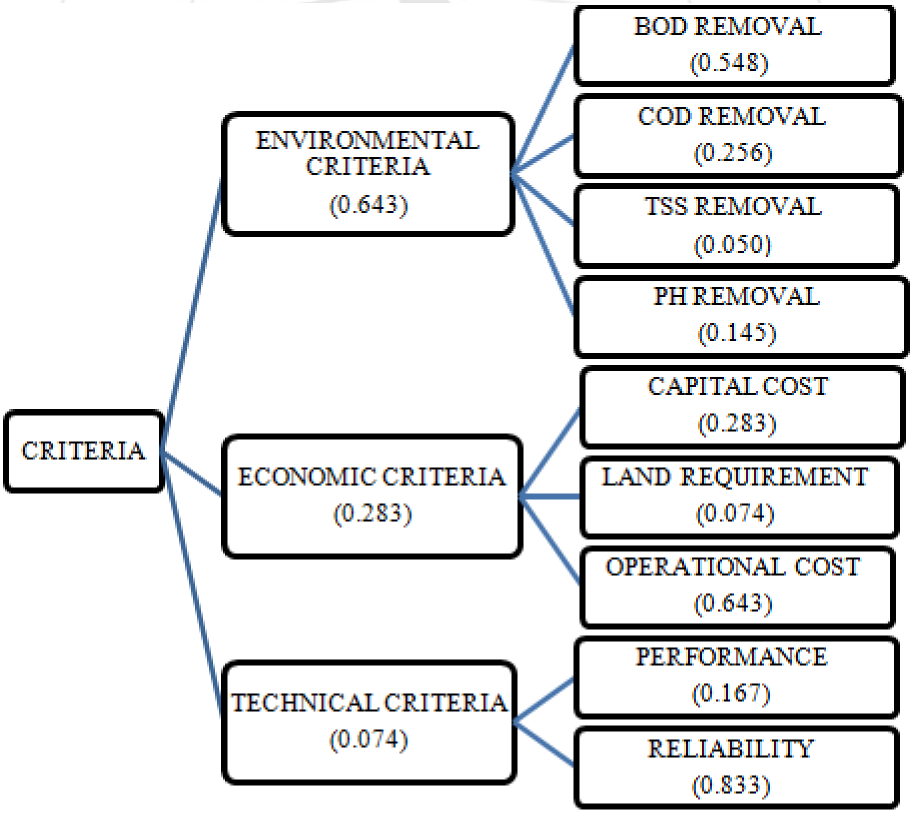


Figure: hierarchy diagram

Alternative Calculation

We have two alternatives for the criteria we have decided namely, Kanpur and Lucknow waste water treatment plant. we are going to one by one decide the in of the alternative for each criteria with the help of study and psychology of group study .

Matrix for alternative selection for BOD removal

BOD Removal	Kanpur	Lucknow	Prority Vector
Kanpur	1	1/5	0.167
Lucknow	5	1	0.833

$\lambda_{max}=6(0.167)+6/5(0.833)$
$=2.0016$

Consistency Index

$CI=\lambda_{max}-n/(n-1)$
$=2.0016-2/(2-1)$
$=0.0016$

According to Saaty for 2x2 matrix the value of RI is 0, hence consistency ratio can't be evaluated

Matrix for alternative selection for COD removal

COD Removal	Kanpur	Lucknow	Prority Vector
KANPUR	1	3	0.75
LUCKNOW	1/3	1	0.25

$\lambda_{max}=4/3(0..75)+4(0.25)$
$=2.00$

Consistency Index

$CI=\lambda_{max}-n/(n-1)$
$=2.0016-2/(2-1)$
$=0.0016$

According to Saaty for 2x2 matrix the value of RI is 0, hence consistency ratio can't be evaluated

Matrix for alternative selection for TSS removal

TSS REMOVAL	KANPUR	LUCKNOW	PRORITY VECTOR
KANPUR	1	2	0.667
LUCKNOW	1/2	1	0.333

$\lambda_{max}=3/2(0.667)+3(0.333)$
$=1.9995$

Consistency Index

$CI=\lambda_{max}-n/(n-1)$
$=2.0016-2/(2-1)$
$=0.0016$

According to Saaty for 2x2 matrix the value of RI is 0, hence consistency ratio can't be evaluated

Matrix for alternative selection for pH removal

pH Removal	Kanpur	Lucknow	Prority Vector
Kanpur	1	1/3	0.25
Lucknow	3	1	0.75

$\lambda_{max}=4(0.25)+4/3(0.75)$
$=2.00$

Consistency Index

$CI=\lambda_{max}-n/(n-1)$
$=2.0016-2/(2-1)$
$=0.0016$

According to Saaty for 2x2 matrix the value of RI is 0, hence consistency ratio can't be evaluated

Matrix for alternative selection for capital cost

Capital Cost	Kanpur	Lucknow	Prority Vector
Kanpur	1	3	0.75
Lucknow	1/3	1	0.25

$\lambda_{max}=4/3(0.75)+4(0.25)$
$=2$

Consistency Index

$CI=\lambda_{max}-n/(n-1)$
$=2-2/(2-1)$
$=0$

According to Saaty for 2x2 matrix the value of RI is 0, hence consistency ratio can't be evaluated

Matrix for alternative selection for land requirement

Land Requirement	Kanpur	Lucknow	Prority Vector
Kanpur	1	1/5	0.167
Lucknow	5	1	0.833

$\lambda_{max}=6(0.167)+6/5(0.833)$
$=2.0016$

Consistency Index

$CI=\lambda max-n/(n-1)$
$=2.0016-2/(2-1)$
$=0.0016$

According to Saaty for 2x2 matrix the value of RI is 0, hence consistency ratio can't be evaluated

Matrix for alternative selection for operating cost

Operating Cost	Kanpur	Lucknow	Prority Vector
Kanpur	1	4	0.8
Lucknow	1/4	1	0.2

$\lambda_{max}=5/4(0.8)+5(0.2)$
$=2$

Consistency Index

$CI=\lambda_{max}-n/(n-1)$
$=2-2/(2-1)$
$=0$

According to Saaty for 2x2 matrix the value of RI is 0, hence consistency ratio can't be evaluated

Matrix for alternative selection for performance

Performance	Kanpur	Lucknow	Prority Vector
Kanpur	1	1/3	0.25
Lucknow	3	1	0.75

$\lambda_{max}= 4(0.25)+4/3(0.75)$
$=2$

Consistency Index

$CI=\lambda_{max}-n/(n-1)$
$=2-2/(2-1)$
$=0$

According to Saaty for 2x2 matrix the value of RI is 0, hence consistency ratio can't be evaluated

Matrix for alternative selection for reliability

Reliability	Kanpur	Lucknow	Prority Vector
Kanpur	1	1/3	0.25
Lucknow	3	1	0.75

$\lambda_{max}= 4(0.25)+4/3(0.75)$
$=2$

Consistency Index

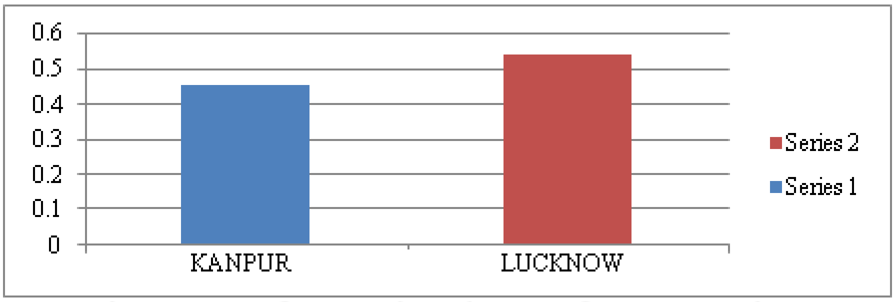
$CI=\lambda_{max}-n/(n-1)$
$=2-2/(2-1)$
$=0$

According to Saaty for 2x2 matrix the value of RI is 0, hence consistency ratio can't be evaluated

Aggregation of All Priorities
Final matrix for comparing the alternative. All the calculations and alternative are put together for decision making.

	Weightage	Kanpur	Lucknow
BOD REMOVAL	0.352	0.167	0.833
COD REMOVAL	0.165	0.75	0.25
TSS REMOVAL	0.032	0.667	0.33
PH REMOVAL	0.093	0.25	0.75
CAPITAL COST	0.08	0.75	0.25
LAND REQUIREMENT	0.021	0.167	0.833
OPERATING COST	0.182	0.8	0.2
PERFORMANCE	0.0123	0.25	0.75
RELIABILITY	0.062	0.25	0.75
SUM	1		

4. Result



Final result graph **presents** the final results of the analysis. The graph shows that Lucknow sewage treatment plant is better evaluated than Kanpur sewage treatment plant. The overall score of Lucknow sewage treatment plant is 0.545 and Kanpur sewage treatment plant is 0.455. Result shows that without the help of AHP it is very hard to compare between the two sewage treatment plant as the difference between the value is very small (0.09) ,but with the help of AHP we can say that Lucknow sewage treatment plant is better than Kanpur sewage treatment plant.

5. Conclusion

The selection of sewage treatment plant is a complicated multi-criteria decision making process, in which uncertainty, complexity and hierarchy are the most. In this paper, a practical approach is presented for selecting and weighing the waste water treatment plant based on the treatment technique, processes, environmental affects, and capital cost and land requirements. The decision criteria were technical / administrative, economic and environmental criteria as well as their sub-criteria. These criteria were evaluated to determine the best treatment plant for the sewage treatment before deposition to the under-ground or land surfaces. The best treatment plant for treatment of waste water is Bharwara waste water treatment plant, Lucknow among Kanpur and Lucknow sewage treatment plant in AHP method.

From the above study, the following conclusions were made:
1) Application of AHP method in multi-criteria decision making is easy to use and easily understandable by the users as it handles multiple criteria with a certain value of consistency is allowed.
2) The appropriate plant selected from the above study is Bharwara treatment plant which gives guide lines in future construction of treatment plant for sewage.
3) The above observations suggest that MCDM methods should be used as **decision support tools** and not as the means for deriving the final answer.

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