Pertanika J. Sci. & Technol. 26 (4): 1591 - 1603 (2018)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

A Selection of the Best Location for a Small Hydro Power Project using the AHP-Weighted Sum and PROMETHEE Method

Jayantilal N. Patel* and Shilpesh C. Rana

Civil Engineering Department, Sarda Vallabhbhai National Institute of Technology, Surat, Gujarat, India

ABSTRACT

Hydro power is one of the renewable sources of energy which plays a significant role in the development of any country. Ranoli Branch Canal splits from Sakarda Branch Canal, one of the branch canals of Narmada Main Canal. The objective of this study is to find the best location for a small hydro power project out of four feasible locations on Ranoli Branch, using the Analytical Hierarchy Process (AHP)-weighted sum method. Result of weighted sum method has been validated using PROMETHEE method. The problem has been evaluated based on criteria for project cost, rated power, distance of the power house to the grid line, distance of the power house to the road, and distance of the power house to the village, and four canal fall locations, at chainage 7525 m, 9825 m, 17367 m, and 19844 m, as alternatives. The project cost was calculated by designing hydro power components (using Indian Standards Guideline) and applying actual market rates. The distance of the power house to the grid line, road, and village were obtained with the Google Play Store application called 'Map Distance Ruler Lite'. Optimisation resulted in the best location for hydro power generation in each canal. The fourth alternative, A_4 at chainage 19844 m, is the best location.

Keywords: AHP, branch canal, small hydro power project, weighted sum method

INTRODUCTION

The Sardar Sarovar project is one of the largest water resources projects of India. The Narmada Main Canal is a part of the Sardar Sarovar project, having 1133 m^3/s capacity at the head regulator. The length of the canal is 532 km. Narmada Main Canal has been divided in three phases. There are 25 branch canals, branching from the main canal phase-1 (Narmada Main Canal chainage-0 to144.50 km). Sakarda Branch Canal branches off from Narmada Main Canal at 102.95 km

ARTICLE INFO

Article history:
Received: 10 July 2017
Accepted: 03 April 2018
Published: 24 October 2018

E-mail addresses:
jnp@ced.svnit.ac.in (Jayantilal N. Patel)
shilpesh1978@yahoo.co.in (Shilpesh C. Rana)
* Corresponding author

ISSN: 0128-7680
e-ISSN: 2231-8526

and is 35.13 km long. Ranoli Sub-Branch Canal branches off from Sakarda Branch Canal at 6.46 km downstream as shown in Figure 1.

On Ranoli Sub-Branch Canal, four falls have been identified as the locations to execute a small hydro power project, as shown in Figure 2. Out of four locations for a small hydro power project, the best location has been identified using AHP-weighted sum method. Four canal fall locations, at chainage 7525 m, 9825 m, 17367 m, and 19844 m, have been identified for the power house location. Five criteria, including project cost, rated power, distance of the power house from the grid line, distance of the power house from the road, and distance of the power house from the village, were considered in the selection of best the power house location.

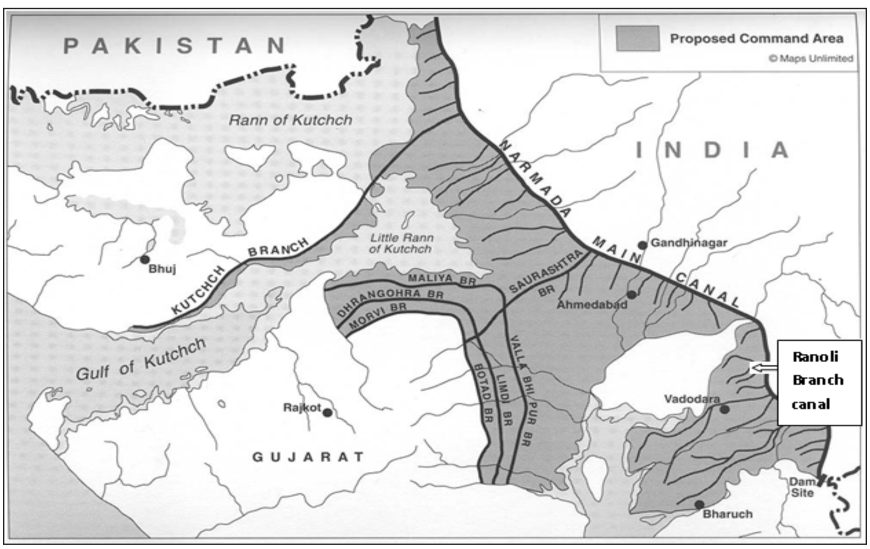

Figure1. Map of Narmada canal *(*Adapted from http://www.narmada.org/sardarsarovar.html*)*

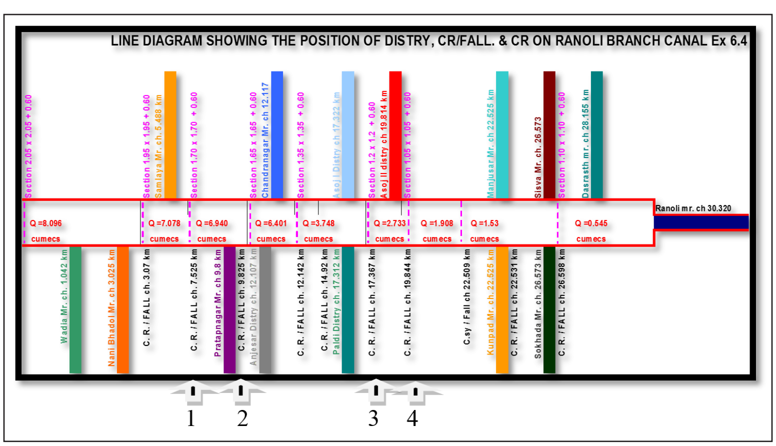

Figure 2. Proposed power house locations (adapted from Sardar Sarovar Narmada Nigam Limited, Kalol division)

METHODS

Analytical Hierarchy Process (AHP) method was used to select the best location for the power house. Calculations were based on expert opinion, project cost, rated power, distance of the power house from the grid line, distance of the power house from the road, and distance of the power house from the village. Canal falls at different chainages, as given in Table 1, were considered as alternatives.

Table 1
Canal fall locations

Fall No.	Chainage distance (m)
1	7525
2	9825
3	17367
4	19844

Analytical Hierarchy Process (AHP) Method

The analytical hierarchy process method was developed by Saaty (1977, 1980, 1982, and 1995) as a method for analysing decisions by structuring the decision's components (Bana & Vansnick, 2008; Turcksinaet al., 2011). AHP method was used to organise and analyse complex decisions (Saracoglu, 2013). The AHP method proves to be one of the most applicable methods of multi-criteria analysis (MCA) (Roman, 2012).

The method employs the following steps to solve a problem (Ioan et al., 2017):

(i) Identifying the problem.

(ii) Establishing the decision-making criteria. The criteria (objectives) are defined that shall be used for the selection of the alternatives. The data are written in a decision criteria matrix C = [C_J]. Here j = l...m represents the number of criteria (Naghiu et al., 2016).

(iii) Establishing the decision-making alternatives. In this stage, the set of alternatives that can be applied are identified, while the data are written in the alternatives matrix A = [Ai]. Here i = in, representing the number of alternatives (Naghiu et al., 2016).

(iv) Determining relative weight of criteria by comparing the criteria in pairs. In this step, the relative weight of the criteria c = [c_{ij}] is compared to their importance in making the decision (Prejmecrean, 2012).The relative weight of criteria is determined by performing pair-wise comparison.

(v) Normalising the comparisons between criteria. The normalised values "n_{ij}" are obtained by dividing the value found from comparison with the total value of their column (Dobrea, 2006) the calculation is based on

$$n_{ij} = \frac{Cij}{Sj} \qquad [1]$$

Then, the pair-wise comparison between criteria is transformed into weights, which are calculated as an average of the normalised values on each row as:

$$kj = \frac{\sum_{j=1}^{m} nij}{m} \qquad [2]$$

where kj represents the importance coefficients (weights) of the decision criteria. To use normalised values, the following condition must be satisfied:

$$\sum_{j=1}^{m} kj = 1 \qquad [3]$$

(vi) Determining the consistency factor of the decision criteria matrix. To determine the consistency factor of the matrixes, the following steps are performed (Dobrea, 2006):

a) Determining the vector of priorities - λmax. The vector of priorities is calculated as an average of multiplication between the matrix of relative weights of decision criteria and the average weight of decision criteria as follows:

$$\lambda max = \sum_{j=1}^{m} \frac{(c\,x\,k)j}{m\,x\;kj} \qquad [4]$$

where (c k) j represent the elements of the matrix vector determined because of multiplying the "c" matrix with "k" vector (Dobrea, 2006).

b) Determining the uniformity coefficient. The uniformity coefficient "CI" is calculated as:

$$CI = \frac{\lambda max - m}{m-1} \qquad [5]$$

c) Determining the consistency factor of the matrixes. The consistency factor of matrixes "CR" is calculated as:

$$CR = \frac{CI}{R} \qquad [6]$$

When determining the consistency relation, one considers the following rule: if CR< 0.10, then the matrix is consistent, meaning that the vector of the weights is well-determined.

Weighted Sum Model

In decision theory, the weighted sum model (WSM) is the best known and simplest multi-criteria decision analysis (MCDA) or method for evaluating a number of alternatives with a number of decision criteria. The WSM is probably the most commonly used approach, especially in single dimension problems (Triantaphyllou & Mann, 1989). It is very important to state here that it is applicable only when all the data are expressed in exactly the same unit. If this is not the case, then the result is equivalent to "adding apples and oranges." Importance of alternative A_i, denoted as $A_i^{WSM\text{-}score}$, is defined as follows:

$$A_i^{WSM\text{-}score} = \sum_{n=1}^{\infty} (w_j a_{ij,}) \text{ for } i = 1, 2, 3, \ldots, m \text{ and } j=1, 2, 3, \ldots, n \quad [7]$$

For the maximisation case, the best alternative is the one that yields the maximum total performance value (Fishburn, 1967).

PROMETHEE Method

The PROMETHEE method is one of the MCDM methods that have been developed by Brans (Mohammad et al., 2017). It is a quite simple ranking method in conception and application compared with other methods for multi-criteria analysis. (Amir et al., 2007). The advantage of PROMETHEE is ranking and selecting among criteria which are conflicting (Mohammad et al., 2017). As per Ivica et al. (2015) an input for PROMETHEE method was a matrix consisting of set of potential alternatives (actions) A, where each a element of A has its $f_j(a)$ which represented evaluation of criteria j. Each evaluation fj(ai) must be a real number. Method PROMETHEE I rank actions by a partial pre-order, with the leaving flow:

$$\phi^+(a) = \frac{1}{n-1} \sum_{x \in A}^{q} \pi(a, x) \quad [8]$$

and entering flow:

$$\phi^-(a) = \frac{1}{n-1} \sum_{x \in A}^{q} \pi(x, a) \quad [9]$$

Where n denotes the number of actions, 'a' is a set of actions and π is the aggregated preference index defined for each couple of actions. The PROMETHEE I method gives partial pre-order. PROMETHEE II gives a net outranking flow which ranks the actions by total pre-order:

Ranking of actions is possible by determining the net outranking flow φ(a) (Tijana et al., 2017)

$$\phi(a) = \phi^+(a) - \phi^-(a) \quad [10]$$

Where $\phi^+(a)$ is leaving flow and $\phi^-(a)$ is entering flow.

ANALYSIS AND RESULTS

The best location for the power house has been found stepwise, as below using AHP, WSM and PROMETHEE.

Analytical Hierarchy Process (AHP) Method

(I) Identification of Problem. The problem is to find out the best location of the power house from four available alternatives.

(II) Criteria Consideration. Five criteria have been considered, as provided in Table 2.

Table 2
Set of decision criteria for selection of best location of a hydro power station

No.	Criteria	Name of criteria
1	C1	Project cost
2	C2	Rated power
3	C3	Distance of power house from grid line
4	C4	Distance of power house from road
5	C5	Distance of power house from village

(III) Determining alternatives. Canal falls located at various chainages have been considered as alternatives, as shown in Table 3.

Table 3
Set of alternatives for selection of the best location of a hydro-power station

No.	Fall location from the head regulator in meter	Alternative
1	7525	A1
2	9825	A2
3	17367	A3
4	19844	A4

(IV) Comparison of Criteria of the Pair to Determine Relative Weight of Criteria. Relative weights of five decision-making criteria have been compared to the next upper hierarchy rank, as given in Table 4. In the matrix, the diagonal values have been assigned as 1. The entire matrix has been prepared, considering that if C1 is 1.5 times more preferred than C2, and then criteria C2 is1/1.5 times less preferred than criteria C1.

Table 4
Values of relative weight for comparison between criteria (A_1 matrix)

	C1	C2	C3	C4	C5
C1	1	1.5	2	2.5	3
C2	1/1.5	1	2	3	3
C3	1/2.0	1/2.0	1	2	2
C4	1/2.5	1/3.0	1/2.0	1	1
C5	1/3.0	1/3.0	1/2.0	1	1

$$A_2 = \begin{bmatrix} 1.86/5.651 = 0.33 \\ 1.644/5.651 = 0.3 \\ 1.000/5.651 = 0.177 \\ 0.582/5.651 = 0.103 \\ 0.561/5.651 = 0.1 \end{bmatrix}$$

$A_3 = A_1 \text{ X } A_2$ [11]

$$A_3 = \begin{bmatrix} 1.6615 \\ 1.483 \\ 0.9 \\ 0.5235 \\ 0.5236 \end{bmatrix}$$

Relative normalised weights (w_j) of the attribute are calculated:

W_{C1}= 1.6615, W_{C2}=.300, W_{C3}=0.90, W_{C4}=0.5235, W_{C5}=0.5015

$A_4 = A_3 / A_2$ [12]

Avg. A_4 = 5.051

λ_{max} = Avg. A_4 [13]

= 5.051

Uniformity Co-efficient (C. I.) = (λ_{max}-M) / (M-1) [14]

= 0.013

Consistency Factor (C.R.) = C.I. /R.I. [15]

= 0.0112< 0.1

Weighted Sum Method

Using the relation $A_i^{WSM\text{-}score} = \sum_{n=1}^{\infty} (w_j a_{ij,})$ for i= 1, 2, 3…m. [16]
The scores of four alternatives were calculated.

Table 5
Normalised relative weights for decision criteria matrix

	C_1	C_2	C_3	C_4	C_5
Weightage	0.330	0.300	0.177	0.103	0.100
A_1	0.461	1.000	0.136	1.000	0.346
A_2	0.437	0.810	0.142	0.438	0.385
A_3	0.815	0.517	0.624	0.348	0.230
A_4	1.000	0.380	1.000	0.672	1.000

The WSM score for the four alternatives are:

$A_1^{WSM\text{-}score}$ = 0.461 x 0.330 + 1x0.3 + 0.136 x 0.177 + 1x.103 + 0.346 x .1= 0.4769 Similarly,

$A_2^{WSM\text{-}score}$ = 0.4959, $A_3^{WSM\text{-}score}$=0.5934 and $A_4^{WSM\text{-}score}$ = 0.7902

PROMETHEE Method

The original evaluation matrix is shown in Table 6.

Table 6
The original evaluation matrix

Power House Location	Project Cost	Rated Power	Grid line distance from site	Road distance from site	Village distance fron site
Chainage	C_1	C_2	C_3	C_4	C_5
M	₹	kW	km	km	km
7525	8143274	230.0	3.900	1.790	1.590
9825	8592458	185.4	3.740	4.090	1.430
17367	4609490	119.0	0.850	5.142	2.410
19844	3755189	87.9	0.530	2.665	0.550

Pair wise difference between values of alternatives for each criteria (five) has been performed. For criteria C1 (Project cost), Pair wise difference between A1 and A2 are 8143274-8592458 =-449184. Similarly pair wise difference between alternatives A2 and A1 are 8592458-8143274= 449184. Pair wise difference between alternative A1 with A1 is zero. The matrix has been generated considering 0 values for negative differences 1 value for positive differences.

Pair wise difference matrix and preference function values for criteria C1 to C5 are shown follows.

$$a = \begin{bmatrix} - & 1 & 0 & 0 \\ 0 & - & 0 & 0 \\ 1 & 1 & - & 0 \\ 1 & 1 & 1 & - \end{bmatrix} \quad b = \begin{bmatrix} - & 1 & 1 & 1 \\ 0 & - & 1 & 1 \\ 0 & 0 & - & 1 \\ 0 & 0 & 0 & - \end{bmatrix} \quad c = \begin{bmatrix} - & 0 & 0 & 0 \\ 1 & - & 0 & 0 \\ 1 & - & 0 & 0 \\ 1 & 1 & 1 & - \end{bmatrix}$$

$$d = \begin{bmatrix} - & 1 & 1 & 1 \\ 0 & - & 1 & 0 \\ 0 & 0 & - & 0 \\ 0 & 1 & 1 & - \end{bmatrix} \quad e = \begin{bmatrix} - & 0 & 1 & 0 \\ 1 & - & 1 & 0 \\ 0 & 0 & - & 0 \\ 1 & 1 & 1 & - \end{bmatrix}$$

Multi-criteria preference Index π(a, x) for pair wise alternatives (A1,A2) is computed as follows: preference function values for A1 and A2 for criteria C1 to C5 are 1,1,0,1,0 and corresponding weights of criteria are 0.330, 0.300, 0.177, 0.103, 0.100

π(A1, A2)= .33X1+.30X1+.177X0 +.103X1+.1X0 = .733

Similarly,
A_1A_1= - , A_1A_2=0.733, A_1A_3=0.503, A_1A_4=0.403, A_2A_1=0.277, A_2A_2= - , A_2A_3=0.503, A_2A_4=0.3, A_3A_1=0.507, A_3A_2=0.507, A_3A_3= - , A_3A_4=0.3, A_4A_1=0.607, A_4A_2=0.71, A_4A_3=0.71, A_4A_4= -.

Table 7
Multi-criterion preference index values

Alternative	A1	A2	A3	A4
A1	0	0.733	0.503	0.403
A2	0.277	0	0.503	0.300
A3	0.507	0.507	0	0.300
A4	0.607	0.710	0.710	0

Computation of leaving, entering and net flow values

Table 8
Leaving, entering and net flow values for different alternatives

Alternative	$\phi^+(a)$	$\phi^-(a)$	$\phi(a)$	Rank
A1	0.546	0.464	0.0826	2
A2	0.360	0.650	-0.290	4
A3	0.438	0.572	-0.134	3
A4	0.676	0.334	0.342	1

Table 9
Normalised relative weights for decision criteria matrix

	C_1	C_2	C_3	C_4	C_5
Weightage	0.330	0.300	0.177	0.103	0.100
A_1	0.461	1.000	0.136	1.000	0.346
A_2	0.437	0.810	0.142	0.438	0.385
A_3	0.815	0.517	0.624	0.348	0.230
A_4	1.000	0.380	1.000	0.672	1.000

Table 10
Leaving, entering and net flow values for different alternatives

Alternative	$\phi^+(a)$	$\phi^-(a)$	$\phi(a)$	Rank
A1	0.546	0.464	0.0826	2
A2	0.360	0.650	-0.290	4
A3	0.438	0.572	-0.134	3
A4	0.676	0.334	0.342	1

Using the relation:

$$A_i^{\text{WSM-score}} = \sum_{n=1}^{\infty} (w_j a_{ij,}) \quad \text{for I} = 1, 2, 3\ldots\text{m.} \qquad [17],$$

the scores of four alternatives were calculated.

Table 11
Normalised relative weights for decision criteria matrix

	C_1	C_2	C_3	C_4	C_5
Weightage	0.330	0.300	0.177	0.103	0.100
A_1	0.461	1.000	0.136	1.000	0.346
A_2	0.437	0.810	0.142	0.438	0.385
A_3	0.815	0.517	0.624	0.348	0.230
A_4	1.000	0.380	1.000	0.672	1.000

The WSM score for the four alternatives are:

$A_1^{\text{WSM-score}} = 0.461 \text{ x } 0.330 + 1\text{x}0.3 + 0.136 \text{ x } 0.177 + 1\text{x}.103 + 0.346 \text{ x } .1$
$= 0.4769$

Similarly,

$A_2^{\text{WSM-score}} = 0.4959$, $A_3^{\text{WSM-score}} = 0.5934$ and $A_4^{\text{WSM-score}} = 0.7902$

DISCUSSION

Present study was to select the best location of small hydro-power plant. Five criteria project cost, rated power, distance of the power house from the grid line, distance of the power house from the road, and distance of the power house from the village, were considered in the selection of best the power house location. Four canal fall locations, at chainage 7525 m, 9825 m, 17367 m, and 19844 m, had been identified for the power house location as an alternative.

Here the weightage were given to project cost (33%), followed by rated power (30%), distance of the power house from the grid line (17.7%), distance of the power house from the road (10.3%), distance of the power house from the village (10%). The AHP method provided a consistency factor of 0.0112.

The values of the WSM score, *net flow values* and ranks for the four alternatives are listed in Table 12.

Table 12
Values of WSM-Score, Net flow values and rank

Alternative	Fall location from the head regulator in meter	WSM		PROMETHEE	
		Score	Rank	Net flow values	Rank
A1	7525	0.4769	4	0.0826	2
A2	9825	0.4959	3	-0.290	4
A3	17367	0.5934	2	-0.134	3
A4	19844	0.7902	1	0.342	1

As a result of WSM and PROMETHEE alternative 4 is the best alternative for the location of small hydro power project.

CONCLUSION

As a result of AHP method the Consistency Factor (C.R.) is 0.0112 which is less then 0.10, which indicates that the decision criteria matrix is consistent.

Weighted Sum and PROMETHEE method were used to find the best location of small hydro power project out of four alternatives (Canal fall locations at chainage 7525 m, at chainage 9825 m, at chainage 17367 m and at chainage 19844 m).

From the results of both Weighted Sum and PROMETHEE methods the best location for small hydro power project is at 19844 m Chainage (A4 alternative).

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