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RESEARCH ARTICLE

FUZZY MODELLING FOR SELECTION OF MOST SUITABLE LOCATION FOR A DAM

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ABSTRACT

Construction of a dam directly influence the major development of a country as population receives domestic and economic benefits from a single investment. Dam are usually constructed for supplying water for domestic, industrial and irrigation purposes, electricity generation, flood control, navigation, recreation works etc. Thus selection of most suitable site for construction of a dam is one of the important decisions to an engineer. The selection of dam site depends upon lot of factors such as topography of area, width of river, foundation conditions, water quality, erosion, environmental issues, social impacts, economic development, cost of construction etc [11,13]. Out of above mentioned factors some are quantitative and some qualitative which makes decision making a difficult task. The qualitative attributes require a significant amount of input from experts .The perception level from experts may vary person to person. Consequently it is required to use right approach so that proper judgment of site for dam selection can be done. In this study we present the methodology of generalised fuzzy logic of Prof. Lotfi Zadeh [15] for selection of most suitable location out of n alternatives for a dam to be setup. To understand the methodology, a case study is presented here.

INTRODUCTION

With rapid industrialization and urbanization, construction of a dam has become a most necessity to fulfill the various demands of it's population. For development of any country it is most essential to improve the quality of water supply, irrigation, flood control, navigation, sediment control and generation of energy which can only be served by construction of a suitable and economical dam. In addition to all above, hydro power generation is also one of the important purposes for construction of dam [1,6]. For selection of a dam site out of alternatives, an engineer always compares the river discharge, cost of project and environmental weighted average value **(EWAV)** for the project and thereafter determine whether a community could benefit for a dam. Each factor has it's own importance. It is often found that total cost of the dam, foundation condition, and total discharge of the river and overall EWAV are not same for all locations. Sometimes discharge of river may be high and suitable but cost of construction at particular site may be high which may haeomargge expert's decision [2]. Similarly sometimes EWAV may be suitable for a site but other factors may not be in favour. Thus selection of a dam out of alternative is one kind of big prediction process which involves lots of uncertainty and directly influences the overall decision of the expert [8]. Even in EWAV study, most of the data are not always found crisp or numeric rather linguistic and hedges like 'high BOD', 'low discharge', 'very high soil erosion', 'heavy rainfall', 'large catchment area', etc. to list a few only out of infinity. All these data are fuzzy in nature [4,12]. Evaluation of many objects here is not possible with numerical valued descriptions. As human being every expert has a certain limitation of knowledge and intellectual functionaries to tackle this type of uncertainty. Because his decision depends on his neural network functions i.e nature of functions of dendrite and axon of his nervous system. Naturally any expert can feel much more confidence and can better guess a degree of belongingness or a degree of non-belongingness independently within the interval [1,0] instead of defining the project as 'most economical' or 'less suitable' or 'high discharge' etc [14-16]. This study deals with the basic concept of fuzzy logic and fuzzy set theory of Prof Latfi Zadeh which plays an important role to tackle the uncertainty involved in the perception of expert in selection of most suitable location for a dam out of alternatives.

Preliminaries Used in the Case Study

To evaluate the degree of membership function of an object of a crisp set or a fuzzy set, it is very essential to discuss the logic

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on which basis it can be determined. In below we have discussed few preliminaries for better understanding of fuzzy logic concept which is used as a main tool in the methodology.

Crisp set and Fuzzy Set

Without basic concept of crisp set, the definition of fuzzy set theory can't be in complete shape. In a crisp set, the individuals from the universal set X are determined to be either members or non-members of a set and defined by a characteristic function or discrimination function of set A where,

«$_A$ (x)   = 1   iff   x Č A
= 0   iff   x č A

Thus from the logic of crisp set it is quite easy to determine whether an element belongs to a set A or not [4-5].

But many sets encountered in reality do not have precisely defined boundary in between set A and it's universal set X. Such a function is called membership function and the set defined as fuzzy set [14-15]. Suppose the turbidity of a river water sample is estimated as "**high**". If we denote by **A,** the set of **"high turbidity",** the question logically arises as to the bounds of such a defined set. In other words, we must establish which elements belong to this set. Does the turbidity 3000 NTU belong to this set? What about 200 NTU or 1500 NTU or 6500 NTU? To solve our daily life problems involving such type of uncertainty, Prof. Latfi Zadeh, Dept. of Electrical Engineering and Computer Science, University of California first laid the foundation of fuzzy set theory in 1965 by modification of the crisp set theory. According to his concept, a 'Fuzzy Set A' is defined as the set of ordered pairs A = { (x_1, $\mu_A(x_1)$) , (x_2, $\mu_A(x_2)$) , ….. , (x_n, $\mu_A(x_n)$) }, where $\mu_A(x)$ is the grade of membership of element *x* in set A. The greater value of $\mu_A(x)$ will indicate the greater truthness of the statement that element *x* belongs to set A. The membership function of a fuzzy set can take any value form the closed interval [0,1] instead of either 0 or 1 like crisp set [4-5].

Fuzzy Logic

Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to deals with the concept of partial truth and partially false that means the truth value of any object is in between "completely true" and "completely false". Fuzzy logic is a concept of approximate reasoning that express with matter of degree and belongings.

It is most suitable for evaluation of uncertainty or vagueness data, which can't be derived precisely with the help of mathematical model. According to the concept of fuzzy set theory, when a statement is completely true then the membership value is 1 and when a statement is completely false the membership value is 0 and when the statement is partially true and partially false then the membership value will be in between 0 and 1 [3,14]. Experts rely on common sense and his perception when he able to solve problems more precisely. Fuzzy system represents expert's knowledge and perception when the data or information are involved with vague and ambiguous terms.

Membership function

The central concept of fuzzy set theory is the membership function, which represents the relationship of an element to a set. The membership function of a fuzzy set is expressed on a continuous scale from 0-1 representing full membership to full non-membership. In particular, by setting the membership function to one, we symbolize a maximum value of the factor of the investigated process, and setting membership function to zero, we represent a minimum of value of the membership function [5,15]. The choice of a membership function is somewhat arbitrary and should mirror the subjective expert opinion. Thus membership function of any object of a set is represent the gradual transition from regions completely outside periphery boundary of the set to regions completely inside boundary of the set. There are numerous types of membership functions, but triangles and trapezoid membership functions are most commonly used in practice. The membership function of any event can be designed in three process that are (a) by interviewed method among the people those are very familiar with existing system / environmental / issues / problems / strategy, (b) generate from the available local data or information, (c) record from the feedback result of existing performances. But the first process can give better result in question of solution of fuzzy logic based problems thus has been used in large scale in practically [9-10].

METHODOLOGY

The job for the selection of most suitable location for a dam out of n-alternatives using fuzzy model is at aim to minimse the uncertainty in the individual decisions of different experts. The methodology leads on the concept of fuzzy logic and fuzzy decision and outcome results also found more precise. In this section few definitions are discussed below for better understanding the methodology for field application.

Definition: Fuzzy Attributes

Fuzzy attributes are the fuzzy data collected for evaluation the degree of membership value of each within the closed interval [0,1] by obtaining individual expert's perception independently. Suppose for a job "Assessment of water quality of a river", the some relevant fuzzy attributes could be 'high BOD', 'low pH', 'high turbidity', 'low discharge', etc. few examples out of many [3-5].

Definition: Universe of the Assessment

Collection of all attributes considered for assessment of overall study of a project is called the universe of the assessment. Suppose that x_1, x_2 ,x_3, x_4 ,x_5, ……...., x_n are the fuzzy attributes are considered for the overall evaluation of a project then the U = {x_1, $_{x,2}$……...., x_n} be a finite discrete universe set of attributes x_i, where i = 1, 2,…. , n.

Definition: Mean Fuzzy Set (MFS)

Suppose aim of assessment is to evaluate the degree of constraint of the project. Let U be an universal set and X_1= [Set of all non-favourable fuzzy attributes] and X_2 = [Set of all favourable fuzzy attributes] are the two fuzzy sets of U. If the membership function of fuzzy subset X_1 is $\mu_1(x)$ and X_2 is $\mu_2(x)$, then the mean membership value (for non-favourable condition) of the fuzzy subset

X_1 and X_2 is also a fuzzy set X of U whose membership function $\mu_{MFS}(x)$ is given by

$$\mu_{MFS}(x) = \frac{\mu_1(x) + [1 - \mu_2(x)]}{2}$$

Definition: Environmental Weighted Averages Value EWAV)

Let X be an union fuzzy set with membership function $\mu(x)$ of universe U. Suppose that to each element $x \in U$, there is an associated weight $W_x \in R+$ (set of all non-negative real numbers). Then the environmental weighted averages value (EWAV) of the fuzzy set X is the non-negative number a(X) given by

$$a(X) = \frac{\sum \mu_{MFS}(x).W_x}{\sum W_x}$$

Definition :Fuzzy Decision (FD)

Any evaluation is one kind of prediction process which itself involved uncertainty. Thus accuracy of the decision is also fluctuates widely from one decision maker to other due to limitation of knowledge or working capability of their intellectual functionaries. To control the working capability of intellectual functionaries of an expert, the tool of fuzzy decision (FD) has a vital role to achieve the targeted goal where many constraints are clubbed with all possible decisions of the expert. To understand the functional logic of FD, an algorithm is presented below [4,16].

Algorithm of FD

Logically in fuzzy decision, the membership value (μ) is treated as 1 for the maximum favourable condition of a given goal or constraint and it is 0 for minimum favourable condition of a given goal or constraint. Let us consider a group of locations as L

Where, $L = \{ L_1, L_2, L_3, \ldots\ldots, L_L\}$
$= \{ L_i \}$, for $i = 1, 2, 3, \ldots, L$

Let a fuzzy set G describing goals associated with each option (L_i) such that

$G = \{ \mu(g_1/L_1), \mu(g_2/L_2), \mu(g_3/L_3), \ldots\ldots, \mu(g_L/L_L)\}$
$= \{ \boldsymbol{\mu(g_i/L_i)}\}$, for $i = 1, 2, 3, \ldots, L$

Now if the two fuzzy sets C_1 and C_2 describing two constraints associated with each option (L_i) such that
$C_1 = \{ \mu_1(c_1/L_1), \mu_1(c_2/L_2), \mu_1(c_3/L_3), \ldots\ldots, \mu_1(c_L/L_L) \}$
$= \{ \boldsymbol{\mu_1(c_i/L_i)}\}$, for $i = 1, 2, 3, \ldots, L$

And $C_2 = \{ \mu_2(c_1/L_1), \mu_2(c_2/L_2), \mu_2(c_3/L_3), \ldots, \mu_2(c_L/L_L) \}$
$= \{ \boldsymbol{\mu_2(c_i/L_i)}\}$, for $i = 1, 2, 3, \ldots, L$

Then the Fuzzy Decision (FD) will be given by
$FD = Max \{D(L_i)\}$,

where $D(L_i) = Min \{\mu(g_i/L_i), \mu_1(c_i/L_i), \mu_2(c_i/L_i) \}$
In the next section we will present a hypothetical case study to understand the fuzzy model.

Case Study

Suppose a project "Selection of Most Suitable Location for a Dam out of Ten Locations". For selection of a dam, it is very essential to carry out a detailed study on important factors like topography of area, width of river, foundation conditions, water quality, soil erosion, sedimentation, environmental issues, social impacts, economic development etc. For simplicity in presenting the methodology we considered here ten locations of the river and ten factors for fuzzy assessment.

The study has split-up into two phases and in the first phase we assessed the EWAV of each location of river individually. Thereafter in the second phase, we used individual EWAV, cost of projects and river discharge of each location in FD-model and finally come into conclusion which location is actual most suitable out of them.

We considered 20 experts out of which 10 experts for the assessment of favourable attributes and rest 10 experts for the assessment of non-favourable attributes of each location of the river. In the study of EWAV, we formed initially twenty fuzzy attributes x_i (where, i = 1,2,3,.....,20) (Table-1) where ten are non-favourable attributes (negative for decision) and rest ten are favourable attributes (positive for decision) for assessment of membership value of each. Suppose weight of each factor is prefixed by the twenty experts like as for $x_1 = 5$, for $x_2 = 5$, for $x_3 = 5$, for $x_4 = 5$, for $x_5 = 5$, for $x_6 = 10$, for $x_7 = 15$, for $x_8 = 20$, for $x_9 = 20$, and for $x_{10} = 10$ respectively so that total weight is 100.

In this case study we evaluate the expert's perception in two stage: first considered the attribute as non-favorable **(i.e negative for decision)** and in second considered the attribute as favorable **(i.e positive for decision)** in the range of 0 to 1.

Table1

Non-Favourable attributes (negative for decision)	Favourable attributes (positive for decision)
x_1= high turbidity	x_{11}= low turbidity
x_2= high Ph	x_{12}= low Ph
x_3= high BOD	x_{13}= low BOD
x_4= high COD	x_{14}= low COD
x_5= high toxic metal	x_{15}= low toxic metal
x_6= high Soil erosion	x_{16}= low Soil erosion
x_7= bad foundation conditions	x_1 = good foundation conditions
x_8= broad cross sectional area	x_{18}= narrow cross sectional area
x_9 = low capacity spillway area	x_{19} = high capacity spillway area
x_{10}= high Rehabilitation	x_{20}= low Rehabilitation

Now the job is to calculate the EWAV of all locations. In table-2, calculation of EWAV for the location-1 is given and in similar process of calculation, EWAVs of others nine locations are given in table-3.

Table-2

Attribute	Favourable membership value [$\mu_1(x)$]	Attribute	Non-Favourable membership Value [$\mu_2(x)$]	Mean membership value [$\mu_{MFS}(x)$]	Weight of the factor (w)	EWAV a(X)
x_1	0.70	x_{11}	0.20	0.45	5	
x_2	0.50	x_{12}	0.60	0.55	5	
x_3	0.40	x_{13}	0.45	0.43	5	
x_4	0.40	x_{14}	0.55	0.48	5	
x_5	0.20	x_{15}	0.70	0.45	5	**0.490**
x_6	0.70	x_{16}	0.20	0.45	10	
x_7	0.75	x_{17}	0.20	0.48	15	
x_8	0.40	x_{18}	0.50	0.45	20	
x_9	0.60	x_{19}	0.50	0.55	20	
x_{10}	0.85	x_{20}	0.20	0.53	10	

Therefore the EWAV of location-1(L_1) = 0.490. Similarly suppose the EWAV of location-2(L_2) = 0.386, location-3(L_3) = 0.448, location-4(L_4) = 0.357, location-5(L_5) = 0.422, location-6 (L_6) = 0.435, location-7(L_7) = 0.475, location-8(L_8) = 0.365, location-9(L_9) = 0.345 and location-10(L_{10}) = 0.323.

Now the job is to follow the algorithm of Fuzzy Decision (FD) considering the data of EWAV, river discharge and cost of project and then finally come into conclusion which one is actually most suitable location out of ten. Here discharge of the river and cost of project of each location is estimated and tabulated in table-3.

Table-3

Location	EWAV	Cost of Construction (Rs. In lakhs)	River Discharge (in cusec)
L_1	0.490	22	9500
L_2	0.386	34	3000
L_3	0.448	25	6000
L_4	0.357	38	9000
L_5	0.422	39	8500
L_6	0.435	46	5500
L_7	0.475	32	8700
L_8	0.365	48	6900
L_9	0.345	45	5300
L_{10}	0.323	36	9000

For construction of a dam, 'River Discharge' is always plays as goal, i.e. **G** and the 'Environmental Weighted Average Value (EWAV) and 'Cost of Project' are the two constraints, i.e. $\mathbf{C_1}$ and $\mathbf{C_2}$. Naturally for selection of most suitable location of a dam, membership function will be 1 when the expert perception on (i) river discharge is maximum and (ii) EWAV and cost of project is minimum. Similarly the membership function will be 0 when vice versa. Therefore the fuzzy decision of the fuzzy sets for above three options will be as:

$$G = \mu(g_i/L_i) = [1.0/L_1, 0.15/L_2, 0.50/L_3, 0.95/L_4, 0.80/L_5, 0.35/L_6, 0.85/L_7, 0.65/L_8, 0.25/L_9, 0.95/L_{10}]$$

$$C_1 = \mu(C_1/L_i) = [0.10/L_1, 0.50/L_2, 0.30/L_3, 0.70/L_4, 0.45/L_5, 0.35/L_6, 0.20/L_7, 0.65/L_8, 0.80/L_9, 1.0/L_{10}]$$

$$C_2 = \mu(C_2/L_i) = [1.0/L_1, 0.65/L_2, 0.80/L_3, 0.50/L_4, 0.45/L_5, 0.20/L_6, 0.70/L_7, 0.15/L_8, 0.30/L_9, 0.60/L_{10}]$$

Therefore, $D(L_i)$

$= \mu(g/L_i) \cap \mu(C_1/L_i) \cap \mu(C_2/L_i)$

$$= [0.10/L_1, 0.15/L_2, 0.30/L_3, 0.50/L_4, 0.45/L_5, 0.20/L_6, 0.20/L_7, 0.15/L_8, 0.25/L_9, 0.60/L_{10}]$$

Then the fuzzy decision is given by

FD = $\text{Max}\{D(L_i)\} = 0.60/L_{10}$

RESULT

Most suitable location out of ten is $\mathbf{L_{10}}$

CONCLUSION

The site selection of a dam is not an easy job to an engineer due to the involvement of many constraints and uncertainty. In such job, any decision maker has to take decision infavour of good discharge of river, less adverse environmental condition and low cost of the project. But an expert always hesitates to take a precise decision on the multiple data of different locations. From the present case study it reveals that fuzzy model has the capability to ensure the expert's perception more precisely and able to give an optimisation solution for selection of most suitable location of a dam out of alternatives.

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