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Fuzzy AHP and Fuzzy VIKOR Approach modelling for flood control project selection

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Abstract

This paper presents a fuzzy multi criteria analysis approach for selecting of flood control project alternatives which takes economics, social and environment into account. The multi criteria nature and the presence of both qualitative and quantitative factors make it considerably more complex. In this study, a fuzzy multi criteria decision making (MCDM) model is proposed to project evaluation. This model solves flood control project problem in fuzzy environment where both criteria and weights could be in fuzzy sets. The Fuzzy Analytic Hierarchy Process (FAHP) method is used to determine the weights of the criteria. After that, fuzzy VlseKriterijumska Optimizacija I Kompromisno Resenje (fuzzy VIKOR) is proposed to rank the alternatives. The outcome of this research is ranking and selecting best alternatives with the help of fuzzy VIKOR. A case study in the Aie River basin of Chirang district, BTAD, Assam, India has been studied consisting of four alternatives to illustrate the proposed model.

Keywords: Linguistic variable, fuzzy AHP, triangular fuzzy number, Fuzzy VIKOR.

1. INTRODUCTION:

A flood or flooding is defined as a partial or complete inundation of normally dry area by the overflow inland or the unusually rapid accumulation of surface water [1] [46]. During a flood, the overflows from river or channel banks cover the floodplain with lower velocity than in the main river, thus the floodplain can store a high quantity of water and can act as a wider waterway. Flood claims human lives, animal lives, destroy properties, roads, make the fertile land unusable and damage the environment Brahma A. K [2]. Consequences of flood that negatively impacted people, flood management reacts as a solution to the problem. According to [3] Hydrological modelling is needed for integrated watershed assessment, determining the effects of upstream watershed disturbance and flood measure on flooding.

Flood control or flood relief measure can be sorted into two groups. The first group, the structural measures, which includes common works in the flood plain as well as the catchment, and incorporates development of dams, repositories, hindering bowls and levee banks; channel changes; flood-sealing of properties; catchment alterations; and plans of seepage and flood security works. The subsequent group, the non-auxiliary measures, incorporates flood anticipating, flood cautioning and crisis arranging, arranging controls and obtaining of flood inclined territories inside the catchment, and giving flood protection to influenced individuals. [4]

A flood control which refers that, the specific process providing and operating structure designed to minimize the effects of floods by retaining, constraining or diverting flood flows [5]

Multi criteria decision making (MCDM) technique have been developed and applied to various flood control planning and studies in river basin [6, 7, 8, 9]. Raju and Pillai in 1999[14] have made a comparison of five MCDM methods, namely, ELECTRE-2, PROMETHEE-2, AHP, CP and EXPROM-2 to select the best reservoir configuration for the case study of Chaliyar river basin, Kerala, India. [10] Established a multi criteria fuzzy recognition model for flood operations. A subjective preference and iterative weight method is proposed for weight assessment. Carlos A et al. [11] Proposed MCDM method, The MACBETH approach – Measuring Attractiveness by a Categorical Based Evaluation Technique – was then used to study Livramento creek in the peninsula of Setúbal, in Portugal. Ahmad S.,et al [12] presented System dynamics, a feedback-based object-oriented simulation approach is presented for modeling reservoir operations. The proposed approach is applied to the Shellmouth reservoir on the Assiniboine River in Canada

Opricovic, S in (1998) [36, 40] devolved the VIKOR method to solve multi criteria decision making problem with conflicting and non-commensurable criteria. This method is based on an aggregating function representing “closeness to the idea” which originated in compromising programming method [37,39] The VIKOR method of compromise ranking determines a compromise set providing maximum group utility for the “majority” and minimum of an individual regrets for the “opponent” [38] On the other hand some researchers have evaluated VIKOR method under Fuzzy environment. For example, Fuzzy VIKOR in water resources planning [35]. Fuzzy VIKOR for environmental assessment [32, 33]. Author [29, 30] employed modified VIKOR method to assess the Tseng-Wen reservoir watershed in southern Taiwan to classify land use according to its environmental characteristics. An improved Group decision making (GDM) with modified Fuzzy VIKOR method was developed by [31] to identify flood vulnerability in the south Han River, Korea. The result indicated that the proposed fuzzy GDM approach can reduce the uncertainty in the data confidence and weight deviation technique. Thus the combination of the GDM approach with fuzzy VIKOR method can provide robust prioritization because its activity reflects the opinion of various groups and consider uncertainty input data [31]

Reviewing different studies on flood control operation the MCDM method in the selection process have the great applicability. According to Akter T. et al. (2002) [16] flood management decision making problem often involve multiple objectives and multiple stakeholders. To enable more effective and acceptable decision outcomes uncertainty plays an important role in flood management decision making process. In 1975 [47], Zadeh and [45]has introduced a fuzzy set concept that are more reliable to handle all the uncertainty. Most of the earlier paper [10,11,12] of flood control project used only the qualitative and quantitative data in fuzzy number form, in this paper we proposed flood control project that data are measured based on data collected via questionnaires from the experts in triangular fuzzy number form. In this proposed methodology, the decision- makers' opinions on the weighting of criteria are determined by a fuzzy AHP procedure. The ranking value at the aggregating part is determined by Fuzzy VIKOR method.

The rest of the paper is organized as follows: in section 2, we study about the flood control alternatives and selection of criteria in flood management control project. In section 3, the basic of fuzzy set and fuzzy number. In section 4, Fuzzy AHP is presented. In section 5, Fuzzy VIKOR method has been discussed. In section 6. We applied the proposed framework for the case of Aie river basin of Chirang District, BTAD, Assam, India, and finally conclusion have been drawn in section 7.

2. FLOOD CONTROL PROJECT ALTERNATIVES:

The main objective of flood control planning is to reduce the flood damage in a minimum constant with the cost involved. The flood control alternatives can be classified into two groups: structural and non structural. Structural alternatives represent traditional flood damage reduction by physical means [44]. In other words, the construction of flood control facilities can be referred as structural alternatives.

2.1 The structural alternatives of flood damages measure are as [43, 44]

Table 1

Alternatives	Description
A1–Dams and Reservoirs	Flood control dams/reservoirs may be constructed across the upper stream of the river to store flood water s and the magnitude of the flood water can be reduced the downstream stage of the flood. The store water can be used to generate the electricity and agricultural purposes.
A2 – Embankment and side Bands	It is the oldest commonly used methods of protection against the floods. Embankments are constructed parallel to the rivers to prevent overflows of flood water to the flood plain.
A3 –De-silting and dredging	De-silting and dredging of river is also useful method that improves the hydraulic capacity of channel can lower the water stage and increase the carrying capacity of water.
A4 – Channel diversion	An artificial channel can be used to divert the flood water that can increase the flood discharge and can reduce the damage.

2.2 Identification of decision making criterion:

The project selection process is usually difficult and it involves huge investment for implementation. The impact on environment and social also very high and may be as high as the cost of implementation of project [44]. So considering different angles the selection of flood control project must be considered in most favorable solution.

In order to evaluate the alternatives, four criteria and 15 sub-criteria are developed [44], is shown in table 2

Table 2

Main Criteria	Sub-criteria	Related literature source
Ec: Economic	Ec1: Cost of Project	[7], [44]
	Ec2: Implementation and maintenance	[44]
	Ec3: Benefit of Project	[7], [44]
Sc: Social	Sc1: Effect on social fabric	[11],[44]
	Sc2: Perception of flood	[11]
	Sc3: Recreation	[44]
Ev: Environmental	Ev1: Ecological Restoration	[11],[44]
	Ev2: Land Erosion	[11], [44]
	Ev3: Water Quality	
Tc: Technical	Tc1: Complexity of implementation	[44]
	Tc2: Level of protection	[44]
	Tc3: Complexity of maintenances	[44]

3. FUZZY SET

Zadeh (1965) proposed fuzzy set theory which handles the vagueness and uncertainty. Modeling using fuzzy sets has been proven to be effective way for multi criteria decision making problems, where the information available is subjective and imprecise ((Zimmermann, 1992)[17] A fuzzy set is defined by a membership function that maps elements to degrees of membership within a certain interval, which is usually [0, 1]. If the value assigned is zero, the element does not belong to the set (it has no membership). If the value assigned is one, the element belongs completely to the set (it has total membership). Finally, if the value lies within the interval, the element has a certain degree of membership.

Definition 3.1 A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}$ which associates with each element x in X a real number in the interval [0, 1]. The function value $\mu_{\tilde{A}}$ is termed the grade of membership of x in$\tilde{A}$.

Definition 3.2: A fuzzy set $\tilde{A}$ on the set of real number R is defined to fuzzy number if the membership functions

$\tilde{A}$:R $\longrightarrow$ [0, 1] satisfy the following properties:

(i) $\tilde{A}$ Must be a normal set.

(ii) There exists at least one $x \in$ R with $\mu_{\tilde{A}}(x) = 1$

(iii) $\mu_{\tilde{A}}(x)$ Is piecewise continuous.

Definition 3.3: Triangular Fuzzy Number

(iv) Triangular Fuzzy Number is defined as $\tilde{A} = (a', b', c')$, where a', b', c' are all real numbers and its membership function is given by

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < a' \\ \dfrac{(x - a')}{(b' - a')}, & a' \le x \le b' \\ \dfrac{(c' - x)}{(c' - b')}, & b' \le x \le c' \\ 0, & x > c' \end{cases} \qquad (1)$$

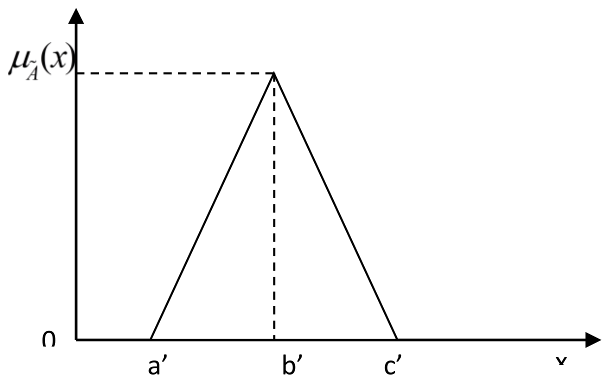

Fig. 1 Triangular fuzzy number

Let $A'_1 = (a'_1, b'_1, c'_1)$ and $A'_2 = (a'_2, b'_2, c'_2)$ be two triangular fuzzy numbers respectively, then the operational laws of these two fuzzy triangular fuzzy numbers are as follws:

$$A'_1(+)A'_2 = (a'_1, b'_1, c'_1)(+)(a'_2, b'_2, c'_2) = (a'_1 + a'_2, b'_1 + b'_2, c'_1 + c'_2) \qquad (2)$$

$$A'_1(-)A'_2 = (a'_1, b'_1, c'_1)(-)(a'_2, b'_2, c'_2) = (a'_1 - a'_2, b'_1 - b'_2, c'_1 - c'_2) \qquad (3)$$

$$A'_1(x)A'_2 = (a'_1, b'_1, c'_1)(x)(a'_2, b'_2, c'_2) = (a'_1 x a'_2,\ b'_1 x b'_2,\ c'_1 x c'_2) \qquad (4)$$

$$A'_1(/)A'_2 = (a'_1, b'_1, c'_1)(/)(a'_2, b'_2, c'_2) = (a'_1/c'_2, b'_1/b'_2, c'_1/a'_2) \qquad (5)$$

$$kA'_1 = (ka'_1, kb'_1, kc'_1) \qquad (6)$$

Definition 3.4: (distance) Let $A'_1 = (a'_1, b'_1, c'_1)$ and $A'_2 = (a'_2, b'_2, c'_2)$ be two triangular fuzzy numbers, and then the vertex method is defined to calculate the distance between them.

$$d(A'_1, A'_2) = \sqrt{\tfrac{1}{3}\left[(a'_1 - a'_2)^2 + (b'_1 - b'_2)^2 + (c'_1 - c'_2)^2\right]} \qquad (7)$$

4. FUZZY ANALYTIC HIERARCHY PROCESS (FAHP)

Thomas L. Saaty [18], first proposed the analytic hierarchy process (AHP) which is widely used as multi- criteria decision making technique. Since its invention AHP technique become one of the most widely used multi criteria decision making method for the decision makers and researchers [19]. The tradition AHP has some limitations as it is mainly used in nearly crisp decision application [20]. And AHP method is often criticized, as it deals with the very unbalanced scale of judgment and its incapability to handle the uncertainty and imprecision in the pair wise comparison process [21] to overcome these AHP limitations, [22] proposed Fuzzy AHP which is the combination of Analytical Hierarchy Process and Fuzzy theory. Fuzzy AHP makes it possible to use linguistic variables in the calculations by giving it a certain range. It is observed that decision-makers are more positive to give interval judgments than fixed-value judgments [23]. [24] Presented trapezoidal fuzzy numbers to express the decisions maker's evaluations on alternatives with respect to criterion. [25] Introduced a Fuzzy AHP approach with the use of Triangular Fuzzy Number for pair wise comparison scale of Fuzzy AHP, and the use of the extent analysis method for determining synthetic extent value of the pair-wise comparisons. Recently Fuzzy AHP is widely used to solve multi-criteria decision problems in many areas e. g. in supplier selection [26-30], selection of thermal power plant [31], selection of planning and design public office building [32], facility location selection [33], [41] established a hybrid evaluation model based on fuzzy analytic hierarchy process (AHP) and triangular number for flood risk evaluation, prediction, control and disaster mitigation. In this research work the extent fuzzy AHP proposed by Chang (1996) [25] is used to obtain crisp weights from a fuzzy comparison matrix. In this method, every criteria or alternatives are evaluated by linguistic variables and then the extent analysis is performed. The algorithm of the extent analysis method can be explained as follows:

4.1 Extent Analysis Method Chang (1996)

Let X = {x_1, x_2, x_3, …, x_n} an object set and G = {g_1, g_2, g_3, …, g_n} be a goal set. According to the method of Chang's (1992) [25] extent analysis, each criterion is taken and extent analysis for each goal g_i; is performed, respectively. Therefore, m extent analysis values for each criterion can be obtained using following notation (R. K Shukla et al., Kahraman et al., 2004)[29,42]

$M^1_{gi}, M^2_{gi}, M^3_{gi}, M^4_{gi}, M^5_{gi}, \ldots M^m_{gi}$, where gi is the goal set (i=1,2,3,4, …, n) and M^j_{gi}) (j=1,2,3,4,…, m), All are triangular fuzzy number(TFNs) The steps of Chang's [25] extent analysis can be given as in the following:

Step-1: The value of Fuzzy synthetic extent value (S_i) with respect to the ith criteria is defined as

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} * \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad (8)$$

To obtain equation $\sum_{j=1}^{m} M_{gi}^{j}$, the fuzzy addition operation of m extent analysis values for a particular matrix is performed such as:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \quad (9)$$

Where l is the lower limit value, m is the most promising value, and u is the upper limit value and to obtain $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$. Perform the 'Fuzzy addition operation' of M_{gi}^{j}(j=1, 2, 3, 4, m) values given below $\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = (\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i)$. And then the inverse of the vector is computed, such as

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (10)$$

Step-2: As $M_1=(l_1,m_1,u_1)$ and $M_2=(l_2,m_2,u_2)$ are two TFNs, the degree of possibility of $M_2=(l_2,m_2,u_2) \geq M_1=(l_1,m_1,u_1)$ is defined as

$$V(M_2 \geq M_1) = \sup_{y \geq x}\left[\min(\mu_{M_1}(x), \mu_{M_2}(y))\right] \quad (11)$$

Where x and y are the values of the axis of membership function of each criterion. This expression can be equivalently written as given in equation below:

$$V(M_2 \geq M_1) = \begin{cases} 1, & if \quad m_2 \geq m_1 \\ 0, & if \quad l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2-u_2)-(m_1-l_1)}, & otherwise \end{cases} \quad (12)$$

To compare M_1 and M_2, we need both the values of V ($M_2 \geq M_1$) and V ($M_1 \geq M_2$)

Step-3: the degree possibility for a convex Fuzzy number to be greater than k convex Fuzzy numbers Mi (i=1, 2, 3, 4, …, k) can be defined by

$V(M \geq M_1, M_2, M_3, M_3, \ldots M_k) = V[(M \geq M_1)$ and $(M \geq M_2)$ and $(M \geq M_3)$ and $(M \geq M_4)$ and … and$(M \geq M_k)$] = min V($M \geq M_i$),i=1,2,3,4, …, k 13

Assume that $d'(C_i)=\min V(S_i \geq S_k)$ for k=1, 2, 3, 4, …n: k ≠ I, then the weight vector is given by

$$W' = [d'(C_1), d'(C_2), d'(C_3), d'(C_4), \ldots, d'(C_n),]^T \quad (14)$$

Where C_i (i=1, 2, 3, 4, …, n) are n elements

Step-4: Via Normalization, the normalized weight vectors are given by

$$W = [d(C_1), d(C_2), d(C_3), d(C_4), \ldots, d(C_n)] \quad (15)$$

Where W is non- Fuzzy number and d is the coordinate of highest intersection point D between μ_{M_1} and μ_{M_2} (as shown in Fig. 2)

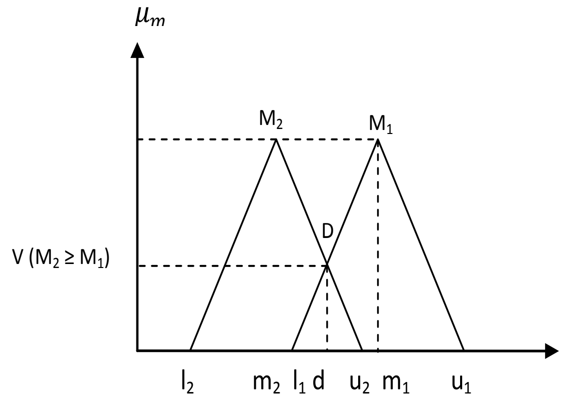

Figure 2. The intersection of two TFNs (Chang, 1996)

5. FUZZY VIKOR METHOD

In 1998 Opricovic [35] and (Opricovic and Tzeng 2004) [40], developed the Serbian name VIKOR stands for 'VlseKriterijumska Optimizacija I Kompromisno Resenje', means multi-criteria optimization and compromise solution This method applies on ranking and selecting the best from a set of alternatives, which are related with multi-conflicting criteria. Moreover, it makes it easy for the decision makers to reach the final decision by finding the compromise solution (closest to the ideal) of a problem. The basic principle of VIKOR is determining the positive-ideal solution as well as the negative-ideal solution in the first place [40]The positive ideal solution is the best value of alternatives under the measurement criteria, and the negative -ideal solution is the worst value of alternatives under measurement criteria. In the end, arrange the precedence of the schemes based on the closeness of the alternatives assessed value to the ideal scheme. Therefore, the VIKOR method is popularly known as a multi-criteria decision making method based on the ideal point technique ([40]

For compromise ranking of multi-criteria measurement, VIKOR adopted a following form of LP- metric aggregate function (Yu, 1973)

$$L_{P_i} = \left\{\sum_{j=1}^{n}[w_j(f_j^* - f_{ij})/(f_j^* - f_j^-)^P]\right\}^{1/P} \quad (16)$$

Here 1≤P≤∞; j=1, …,n, with respect to criteria and the variable i=1, …, m, represent the number of alternatives

The fuzzy VIKOR method is briefly review as steps follows:

Step 1: Forming matrix evaluation alternatives in term of criteria as follows:

$$\widetilde{D} = \|\tilde{x}_{ijl}\| \quad (17)$$

Where $\tilde{x}_{ij}$ is the fuzzy performance rating of alternatives (A_i, i=1,2,..,n) with respect to criteria C_j (j=12, ..m) Evaluated by k decision maker DM_l (l=1,.., k) $\tilde{x}_{ij} = (a_{ij}, b_{ij}. c_{ij})$ is a linguistic variable denoted by TFNS

Step 2: Construct the aggregated fuzzy performance decision matrix as follows:

$$\tilde{F} = \begin{bmatrix} \tilde{f}_{11} & \tilde{f}_{12} & \vdots & \tilde{f}_{1n} \\ \tilde{f}_{21} & \tilde{f}_{22} & \vdots & \tilde{f}_{2n} \\ \cdots & \cdots & \ddots & \vdots \\ \tilde{f}_{m1} & \tilde{f}_{m2} & \cdots & \tilde{f}_{mn} \end{bmatrix} \quad (18)$$

Where
$\tilde{f}_{ij} = \frac{1}{k}\sum_{l=1}^{k} x_{ijl} \quad \forall\, i, j$

Step 3: Determine the fuzzy best value (FBV) and fuzzy worst value (FWV)

$$\tilde{f}_j^* = max\tilde{f}_{ij}, \forall\, i \qquad \tilde{f}_j^- = min\tilde{f}_{ij}, \forall\, i \quad (19)$$

Step 4: Calculate the normalized fuzzy distance d_{ij} , i=1,2,m, j=1,2,...n

$$d_{ij} = \frac{d(\tilde{f}_j^* - \tilde{f}_{ij})}{d(\tilde{f}_j^* - \tilde{f}_j^-)} \quad (20)$$

Step 5: Compute the value of S_i and R_i (i=1,…, m) by using the relations:

$$S_i = \sum_{j=1}^{n} w_j * d_{ij} \quad (21)$$

$$R_i = \max_j (w_j * d_{ij}) \quad (22)$$

S_i is the aggregate value of i^{th} alternatives with a maximum group utility and R_i is the aggregated value of i^{th} alternatives with a minimum individual regret of 'opponent'. Where w_j are the important weights of criteria obtained by using Fuzzy AHP.

Step 5: Compute the value of Q_i for i = 1, ..., m with the relation,

$$Q_i = \frac{V(S_i - S^*)}{(S^- - C)} + \frac{(1-v)(R_i - R^*)}{(R^- - R^*)} \quad (23)$$

Here, $S^* = minS_i$, $S^- = maxS_i$, $R^* = minR_i$, $R^- = maxR_i$ and $v \in [0,1]$ is a weight for the strategy of maximum group utility, and v = 0.5 whereas (1-v) is the weight of individual regret. The compromise can be selected with 'voting by majority' (v> 0.5), with 'consensus' (v = 0.5) with 'veto' (v<0.5)

Step 6: Rank the alternative by sorting the value of S, R, and Q ascending order.

Step 7: Propose a compromise solution the alternative $A^{(1)}$, which is the best ranked solution by the measure Q (minimum) if the following two conditions are satisfied.

C1. "Acceptance advantage: $Q(A^{(2)}) - Q(A^{(1)}) \geq DQ$ Where $A^{(2)}$ with 2^{nd} position in the ranking list by Q and DQ=1/m-1

C2. Acceptable stability in decision making The alternative $A^{(1)}$ must also be the best rank by S or R. This compromise solution is stable within a decision making process which could be strategy of maximum group utility (when v > 0.5 is needed) or "by consensus" $v \approx 0.5$ or "with veto v <0.5Hence v is the weight of decision making strategy of maximum group utility

If one of the conditions is not satisfied then the compromise solution is proposed which consist of –

CS1. Alternatives $A^{(1)}$ and $A^{(2)}$ if only the condition C2 is not satisfied

Or

CS2. Alternatives $A^{(1)}$, $A^{(2)}$, ... $A^{(m)}$ if the condition C1 is not satisfied: $A^{(m)}$ is determined by the relation $Q(A^{(2)}) - Q(A^{(1)}) \geq DQ$ for maximum M (The position of these alternatives are "in closeness")

6 APPLICATION OF PROPOSED FRAMWORK:

CASE STUDY

Aie Manas River which is originates in the Black Mountains of Bhutan at the altitude about 4,915 meters near the village of Bangpari, is about 110km in length passes through Chirang District, BTAD (Bodoland Territorial Area District), (in Fig.3) Assam. These river falls under the Manas-Beki-Aie sub basin. It is one of the biggest and important sub basin of Brahmaputra river basins. The sub basin lies between altitude 26° 15N and 28° 40N and longitude 90° 13'E and 92° 18'E. The entire course of Aie has been experiencing the natural process of self adjustment of its section of parameters. The maximum average rain fall is about 2448.8mm annually [48]. The highest temperature recorded in the area is 35.30° c and minimum is 8.20° c. For the last ten years about 1270 numbers of houses has been damaged due to the erosion and some parts of village has been displaced (2013-14) as per the report from District Disaster Management Report.

This historical flash floods alarming Aie river have shown that structural flood control measure are required to protect natural resources, agriculture land and villages from flood risk and land erosion.

Fig. 3 (map) Satellite map of Chirang District

Source: Google earth

6.1 Priority weight for decision criteria by (FAHP)

According to proposed model, the main objective of using Fuzzy AHP is to determine important weight of the criteria that will be used in Fuzzy VIKOR method [29]. According to the proposed model the weights of the Criteria and sub criteria can be analysed (shown in Table 2). A panel of three experts (Decision Makers) were selected to find the weights of criteria. They are DM1-Project Director (District Disaster Management), DM2- Executive Engineer Irrigation Department and DM3- Assistant Project Director (District Disaster Management) The computational procedure for determining the weights is as follows.

Step-1: The experts were asked to give the rate pair wise comparisons to each criteria identified in table 2 according to the linguistic variable as per table 3 and the rating obtained are presented in the table 4.

Step-2: The linguistic variable are converted to the corresponding Triangular Fuzzy Numbers (TFNs) and aggregating the elements of synthetic pairwise comparison matrix by using Geometric mean method suggested by Lee 2009 [27] that is: shown in table 5

$$l_{ij} = \left(\prod_{p=1}^{p} l_{ijp}\right)^{1/p}, m_{ij} = \left(\prod_{p=1}^{p} m_{ijp}\right)^{1/p} ,$$

$$u_{ij} = \left(\prod_{p=1}^{p} u_{ijp}\right)^{1/p}$$

(Due to the space limitation, linguistic evaluation matrix and fuzzy evaluation matrix of main criteria only are given here.)

Step 3: Likewise, Fuzzy geometric mean of pairwise comparison matrix of sub criterion are computed and then Important weights that is priority vector crisp relative for identified criteria is obtained from the calculation based on pairwise comparison matrixes by using eq. (8) to eq. (15), the extent analysis method proposed by Chang (1996) and values are presented in the table 6. We are using this criterion weight for ranking the alternatives in fuzzy VIKOR method

Table 3

Linguistic variables for Fuzzy Pairwise Scale

Linguistic Scale	Triangular Fuzzy Scale	Triangular Fuzzy Reciprocal Scale
Equal Important(EI)	(1, 1, 1)	(1, 1, 1)
Less Important (LI)	(2/3, 1, 3/2)	(2/3, 1, 2/3)
Fairly Important (FI)	(3/2, 2, 5/2)	2/5, ½, 2/3)
Very Important (VI)	5/2, 3, 7/2)	(2/7, 1/3, 2/5)
Absolute Important(AI)	(7/2, 4, 9/2)	(2/9, ¼, 2/7)

Table 4

Pairwise comparison of Main criteria via Linguistic variables.

		Ec	Sc	Ev	Tc
Ec	DM1	EI	LI	FI	VI
	DM2	EI	FI	VI	EI
	DM3	EI	EI	EI	LI
Sc	DM1		EI	LI	LI
	DM2		EI	EI	EI
	DM3		EI	FI	FI
Ev	DM1			EI	LI
	DM2			EI	FI
	DM3			EI	VI
Tc	DM1				EI
	DM2				EI
	DM3				EI

Table 5

Fuzzy geometric mean of pairwise comparison (Main Criteria)

	Ec	Sc	Ev	Tc
Ec	(1,1,1)	(1,1.26,1.554)	(1.554,1.817,2.061)	(1.186,1.442,1.738)
Sc	0.644,0.794,1	(1,1,1)	(1,1.260,1.554)	(1,1.260,1.554)
Ev	(0.485,0.550,0.644)	(0.644,0.794,1)	(1,1,1)	(1.357,1.817,2.359)
Tc	(0.575,0.693,0.843)	(0.644,0.794,1)	(0.424,0.550,0.737)	(1,1,1)

Table 6

Final priority weights of Main criteria and Sub criteria

Main Criteria	Weights (w_i)	Sub Criteria	Weight (wij)	Final weights (W=wixwij)
Ec: Economic	0.3037	Ec1	0.4404	0.1337
		Ec2	0.3667	0.1114
		Ec3	0.1930	0.0586
Sc: Social	0.2884	Sc1	0.4783	0.1379
		Sc2	0.3108	0.0896
		Sc3	0.2109	0.0608
Ev: Environmental	0.2373	Ev1	0.4610	0.1094
		Ev2:	0.3965	0.0941
		Ev3:	0.1425	0.0338
Tc: Technical	0.1707	Tc1:	0.4165	0.0711
		Tc2:	0.4239	0.0724
		Tc3:	0.1506	0.0257

Table 7

Linguistic variables for the rating of Alternatives

Linguistic variable	Triangular Fuzzy Number
Best or Very High (B)	(8,9,10)
Good or High (G)	(6, 7, 8)
Fair or Medium (F)	(4, 5,6)
Poor or Low (P)	(2, 3, 4)
Worst or very low (W)	(1, 1, 2)

6.2 Application of Fuzzy VIKOR for ranking Alternatives

This step fuzzy VIKOR method is applied for the selection of best structural flood control project as the alternatives shown in the (table 1). The evaluations main criteria and sub-criteria shown in Table 2. There are four main criteria and twelve sub criterions are considered in this study.

First of all a committee of three experts has been identified they are E1-Project Director (District Disaster Management), E2-Executive Engineer Irrigation Department E3- Assistant Project Director (District Disaster Management

We utilized the fuzzy-VIKOR method to determine the best flood control project alternatives consists of the following steps.

Step 1: The three decision makers uses the linguistic variable defines the table 7 to evaluate the alternatives with respect to criterion are presented in table 8.

Step 2: The linguistic evaluation shown in table 7 are then converted into triangular fuzzy number and then the aggregated fuzzy rating of alternatives are calculated to construct fuzzy decision matrix, as shown in table 9.

Step 3: The fuzzy best value (FBV) and fuzzy worst value (FWV) are determined using eq. (19) are shown in table 10.

Step 4: The normalized fuzzy distance is determined by using eq. (20) are shown in the table 10 and the criterion weight determined by Fuzzy AHP is also shown in the last column of table 11.

Step 5: The values S_i, R_i and Q_i, $i = 1, 2, \ldots, m$ are calculated by Eqs. (21)– (22) And the results are shown in table 12

Step 6: The rankings of the four alternative methods by S, R and Q in increasing order are shown in table 13

Step 7: As we see in Table 14, the treatment alternative A3 is apparently the best flood control project alternatives in accordance with the values of Q. Also the conditions C1 and C2 are satisfied by

When v=0.5

Q (A1)-Q (A2) = 0.4576-0.0660=0.3916>1/ (4-1)

and A3 is best ranked by S.

Thus, **A3 –De-silting and dredging** is the most suitable structural flood control model followed by A1

The graph of Q (ranking) for different value (v=0.1, 0.5, 0.75, 0.9) are shown in figure 4

Table 8

Linguistic assessment of alternatives given by three experts

Experts openion	Alternatives	Criteria											
		Ec1	Ec2	Ec3	Sc1	Sc2	Sc3	Ev1	Ev2	Ev3	Tc1	Tc2	Tc3
E1	A1	B	F	F	G	G	B	F	F	G	B	P	F
	A2	B	F	G	F	P	G	F	F	G	G	F	F
	A3	G	P	G	B	P	P	G	F	G	F	F	P
	A4	B	G	P	G	F	F	B	F	B	B	F	P
E2	A1	B	F	F	B	P	B	P	P	G	G	W	P
	A2	B	P	P	P	B	L	P	P	F	G	F	P
	A3	B	G	G	F	G	P	F	G	F	P	P	G
	A4	P	F	P	G	F	P	F	F	F	F	B	P
E3	A1	B	G	F	F	P	B	G	F	B	P	W	P
	A2	G	F	P	G	F	F	F	G	G	F	W	P
	A3	B	P	G	F	F	P	F	P	G	F	F	B
	A4	G	F	B	F	P	G	B	P	G	F	F	F

Table 9

Aggregated fuzzy ratings of alternatives and aggregated fuzzy weights of criteria.

Criteria	Alternatives											
	A1			A2			A3			A3		
Ec1	(8.00,	9.00,	10.00)	(7.33,	8.33,	9.33)	(7.33,	8.33,	9.33)	(5.33,	6.33,	7.33)
Ec2	(4.66,	5.66,	6.66)	(3.33,	4.33,	5.33)	(3.33,	4.33,	5.33)	(4.66,	5.66,	6.66)
Ec3	(4.00,	5.00,	6.00)	(3.33,	4.33,	5.33)	(6.00,	7.00,	8.00)	(4.00,	5.00,	6.00)
Sc1	(4.66,	5.66,	6.66)	(4.00,	5.00,	6.00)	(5.33,	6.33,	7.33)	(5.33,	6.33,	7.33)
Sc2	(3.33,	4.33,	5.33)	(3.33,	4.33,	5.33)	(4.33,	5.33,	6.33)	(3.33,	4.33,	5.33)
Sc3	(8.00,	9.00,	10.00)	(4.00,	5.00,	6.00)	(2.00,	3.00,	4.00)	(4.00,	5.00,	6.00)
Ev1	(4.00,	5.00,	6.00)	(3.33,	4.33,	5.33)	(4.66,	5.66,	6.66)	(6.66,	7.66,	8.66)
Ev2	(3.33,	4.33,	5.33)	(4.00,	5.00,	6.00)	(4.00,	5.00,	6.00)	(3.33,	4.33,	5.33)
Ev3	(6.66,	7.66,	8.66)	(5.33,	6.33,	7.33)	(5.33,	6.33,	7.33)	(4.00,	5.00,	6.00)
Tc1	(3.33,	4.33,	5.33)	(5.33,	6.33,	7.33)	(3.33,	4.33,	5.33)	(5.33,	6.33,	7.33)
Tc2	(1.33,	1.66,	2.66)	(3.00,	3.66,	4.66)	(3.33,	4.33,	5.33)	(5.33,	6.33,	7.33)
Tc3	(2.66,	3.66,	4.66)	(2.66,	3.66,	4.66)	(5.33,	6.33,	7.33)	(2.66,	3.66,	4.66)

Table 13

The rankings of the four alternatives by S, R and Q in increasing order.

	Alternatives			
	A1	A2	A3	A4
S	3	4	1	2
R	1	3	2	4
Q	2	4	1	3

Table 12

The values of S, R and Q for all alternatives.

	Alternatives			
	A1	**A2**	**A3**	**A4**
S	2.4510	2.5259	1.6423	1.7262
R	0.4239	0.5000	0.5000	1.0000
Q	0.4576	0.5660	0.0660	0.5474

Table11

Normalized fuzzy distances for the four alternatives and Criterion Weight

Criteria	Alternatives				
	A1	A2	A3	A4	Weight
Ec1	0.00	0.25	0.25	1.00	0.4404
Ec2	0.00	1.00	1.00	0.00	0.3667
Ec3	0.75	1.00	0.00	0.75	0.1930
Sc1	0.50	1.00	0.00	0.00	0.4783
Sc2	1.00	1.00	0.00	1.00	0.3108
Sc3	0.00	0.67	1.00	0.67	0.2109
Ev1	0.80	1.00	0.60	0.00	0.4610
Ev2	1.00	0.00	0.00	1.00	0.3965
Ev3	0.00	0.50	0.50	1.00	0.1425
Tc1	1.00	0.00	1.00	0.00	0.4165
Tc2	1.00	0.57	0.45	0.00	0.4239
Tc3	1.00	1.00	0.00	1.00	0.1506

Table10

The fuzzy best and fuzzy worst values of all criteria ratings

f^*_1	(8.00,	9.00,	10.00)	f^-_1	(5.33,	6.33,	7.33)
f^*_2	(4.67,	5.67,	6.67)	f^-_2	(3.33,	4.33,	5.33)
f^*_3	(6.00,	7.00,	8.00)	f^-_3	(3.33,	4.33,	5.33)
f^*_4	(5.33,	6.33,	7.33)	f^-_4	(4.00,	5.00,	6.00)
f^*_5	(4.33,	5.33,	6.33)	f^-_5	(3.33,	4.33,	5.33)
f^*_6	(8.00,	9.00,	10.00)	f^-_6	(2.00,	3.00,	4.00)
f^*_7	(6.67,	7.67,	8.67)	f^-_7	(3.33,	4.33,	5.33)
f^*_8	(4.00,	5.00,	6.00)	f^-_8	(3.33,	4.33,	5.33)
f^*_9	(6.67,	7.67,	8.67)	f^-_9	(4.00,	5.00,	6.00)
f^*_{10}	(5.33,	6.33,	7.33)	f^-_{10}	(3.33,	4.33,	5.33)
f^*_{11}	(5.33,	6.33,	7.33)	f^-_{11}	(1.33,	1.67,	2.67)
f^*_{12}	(5.33,	6.33,	7.33)	f^-_{12}	(2.67,	3.67,	4.67)

Table 15

Ranking of alternatives by Q for different values of v

	Alternatives			
	A1	A2	A3	A4
v=0.10	1	3	2	4
v=0.50	2	4	1	3
v=0.75	3	4	1	2
v=0.90	3	4	1	2

Table 14

The Q for different values of v

	Alternatives			
	A1	A2	A3	A4
v=0.10	0.092	0.219	0.119	0.909
v=0.50	0.458	0.566	0.066	0.547
v=0.75	0.686	0.783	0.033	0.321
v=0.90	0.824	0.913	0.013	0.185

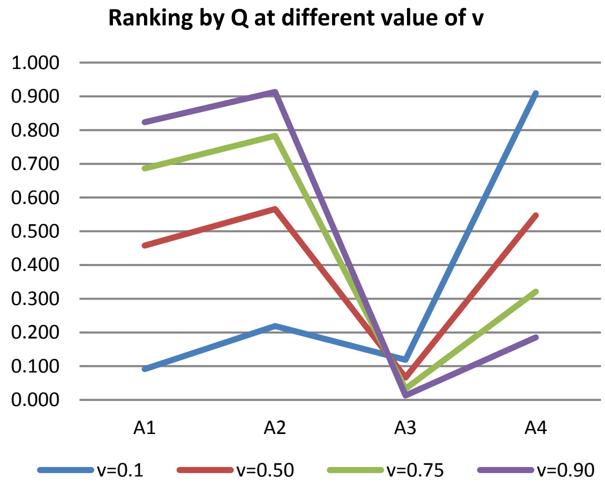

Figure 4

7. CONCLUSION

The fuzzy VIKOR method focuses on ranking and selecting from a set of alternatives in a fuzzy environment. Due to its characteristics and capabilities, the fuzzy VIKOR method has been widely studied and applied in flood risk management problems. The fuzzy VIKOR method is based on aggregating fuzzy measure Q that represents the distance of an alternative to the ideal solution. In this research, we combine fuzzy VIKOR and fuzzy AHP approach to develop a more accurate flood control project selection methodology. A numerical example illustrates an application of fuzzy VIKOR method. It is an intention to demonstrate the conceptual and operational justification of the application of the method in real world problem.

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