Chapter -4

IDENTIFICATION OF THE FLOOD VULNERABILITY REGION

Fuzzy VIKOR approach to identify the flood vulnerability river basin region

Some content of this chapter is published in UGC Listed Journal "Journal **of Computer and Mathematical Sciences",** *Vol.9 (11),1768-1785 November 2018* (An International Research Journal), *www.compmath-journal.org, ISSN 0976-5727 (Print) ISSN 2319-8133 (Online)*

Some part of this chapter is presented in the seminar "International Conference on New Frontiers in Engineering, Science, Law, Management, Humanities and Social Science 2019" **INFES-2019**, IST-GAUHATI UNIVERSITY, GUWAHATI, INDIA, 23rd & 24th FEBRUARY 2019

4.1. INTRODUCTION:

In this chapter, we are interested to investigate the flood vulnerability region in BTAD of Kokrajhar, Assam, India by applying Fuzzy VIKOR Method, which was developed for multi- criteria optimization for complex system, to find a compromise priority alternative from selected criteria for flood vulnerability assessment.

Flood management can be considered as a multi criteria analysis problem of the world which includes the selection of resources, project proposal, strategies and policies (Scheuer et al., 2011) used the spatial vulnerability multi criteria analysis and probabilistic inundated risk analysis. Introduction of Fuzzy set theory (Zadeh, 1965) which deal with uncertainty and sources of vagueness has been utilized for incorporating imprecise data into decision framework. The multi criteria decision making (MCDM) technique is one of the primary pieces of present day choice Science that contains multi choice criteria and various choice alternatives. The targets of the MCDM are to locate the most appropriate alternatives from the distinctive set up criteria relying upon the problem. (Opricovic, 2007; Ju et al., 2013) For a flood management decision making problem by taking objective and multi stake holder was discussed in fuzzy environment (Aketer et al., 2004) A multi criteria genetic algorithm was proposed for compromise ranking method (Opricovic et al., 2004)

A multi criteria decision group decision making model was considered for watershed ecological risk management on three gorges Reservoir in China. (Fanghua et al., 2010; Chitsaz et al., 2015) presented a method that compares the multi criteria decision making (MCDM) methods to prioritize the flood risk management alternatives for Gorganrood River in Iran. (Sabzi, 2012)presented a comparison of multi criteria decision making technique a simulation of flood management multi criteria using six technique TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), VIKOR (in Serbian: VIseKriterijumska Optimizacija I Kompromisno Resenje), SAW (Simple Additive Weights), AHP (Analytic Hierarchy Process), ELECTRE (Elimination et Choice Translating Reality), and Compromise Programming (CP) to study Sunland Park area in southern New Mexico. “The Analytical Hierarchy Process (AHP) was most popular method, followed by TOPSIS and SAW” was stated by (M.M. de Brito et al., 2016) in his state of art survey. A new procedure called integrated multi criteria flood vulnerability was proposed by (Lee, 2013) for flood vulnerability analysis in south Han River in South Korea. Delphi technique and pressure-State- impact response frame work is introduced to objectively selected criteria and fuzzy TOPSIS technique is proposed to address the uncertainty of weights to all criteria and crisp input data. (Chang, 2013) presented Multi Criteria Analysis (MCA) method to evaluate basin environmental vulnerability in five river basins in Taiwan.

The VIKOR method which was devolved by (Opricovic, 1998; 2007) was 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 (Opricovic, 2004 & 2009) 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” (Opricovic et al., 2000) On the other hand some researchers have evaluated VIKOR method under Fuzzy environment. For example, Fuzzy VIKOR in water resources planning (Opricovic, 2011) Fuzzy VIKOR for environmental assessment (Kim Y et al.2015). In supply selection entropy based fuzzy VIKOR (Samantra, 2012; Shemshadi et al., 2011) Insurance company selection (Yucenur et al. 2012) and Health care Waste (HCW) disposal alternative MCDM technique based on Fuzzy VIKOR method (Liu, 2013). Author (Chang et al., 2009 & 2011) 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 (Lee, 2015) 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 (Lee, 2015)

In this chapter group decision making process linguistic variables are used by expert's opinion to assess, the rating and weighted criteria. The Ordered Weighted Averaging (OWA) operator is utilized to aggregate all individual experts' opinion into a group assessment. As a result, a MCDM model based on trapezoidal fuzzy number and fuzzy VIKOR method is proposed to determine the most vulnerable region of the area. The proposed methodology for group decision can effectively deal with characteristic of this problem under fuzzy environment.

The rest of this chapter has been organized as follows, in section 4.2. OWA operator. In section 4.3, we propose the fuzzy VIKOR based MCDM method for group decision making to investigate flood vulnerability under fuzzy environment. A case study is provided in section 4.4 to demonstrate the proposed method, section 4.5 result and discussion and some conclusions are made is section 4.6 finally.

4.2 THE OWA OPERATOR

4.2.1 The Ordered Weighted Averaging (OWA)

(Yager, 1988) first introduced the OWA Ordered Weighted aggregation for aggregating multi criteria to form over all decision function. The advantage of OWA is that the input data is rearranged in descending order and the loads related with the OWA administrator are the loads of the arranged places of the info information instead of the loads of the info information the weights associated with the OWA operator are the weights of the ordered positions of the input data rather than the weights of the input data (Lui, 2013).

Definition: An OWA operator of dimension n is a mapping OWA: $R^n \longrightarrow R$ that has an associated weighting vector ω=$(\omega_1, \omega_2, \ldots, \omega_n)^T, with\ \omega_j =$ $[0,1] and\ \sum_{j=1}^{n} \omega_j = 1$, such that:

$$\text{OWA}(a_1, a_2, \ldots a_n) = \sum_{j}^{n} \omega_j\, b_j \tag{4.1}$$

Where b_j is the jth largest of the a_i .

The OWA operator is commutative, monotonic, bounded and idempotent. (Lui, 2015)

4.2.2 Determination of OWA Weights

(Yager , 1988; Xu, 2005) suggested a normal distribution based method for generating the OWA weights operator (Lui, 2013) by this method, the associated weighting vector is obtained by

$$\omega_i = \frac{\frac{1}{\sqrt{2\pi\sigma_n}}e^{-[(i-\mu_n)^2/2\sigma_n{}^2]}}{\sum_{j=1}^{n}\frac{1}{\sqrt{2\pi\sigma_n}}e^{-[(j-\mu_n)^2/2\sigma_n{}^2]}} = \frac{e^{-[(i-\mu_n)^2/2\sigma_n{}^2]}}{\sum_{j=1}^{n} e^{-[(j-\mu_n)^2/2\sigma_n{}^2]}}, i = 1,2,\dots,n, \tag{4.2}$$

Where ω=$(\omega_1, \omega_2, \dots, \omega_n)^T$ is the weight vector of the OWA operator, μ_n is the mean of the collection 1, 2, ..., n , σ_n $(\sigma_n > 0)$ is the standard deviation of 1,2, ... n. μ_n and σ_n can be obtained by the following formulas, respectively:

$$\mu_n = \frac{1}{n}\frac{n(1+n)}{2} = \frac{1+n}{2} \tag{4.3}$$

$$\sigma_n = \left(\frac{1}{n}\sum_{i=1}^{n}(i-\mu_n)^2\right)^{1/2} \tag{4.4}$$

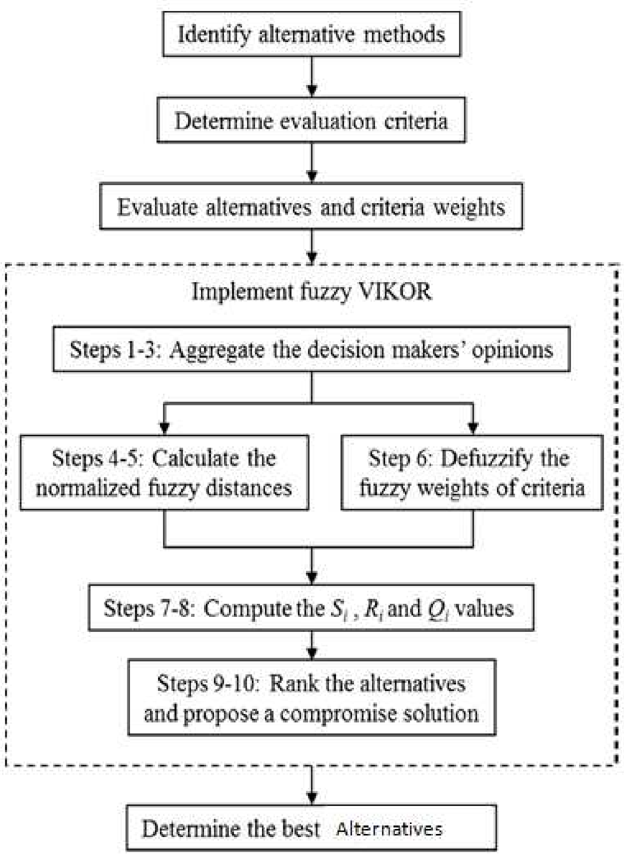

Figure. 4.1 Flowchart of the best alternative selection process

4.3 **THE PROPOSED VIKOR METHOD**:

In this section we are going to use extended version of Fuzzy VIKOR Method suggested by (Opricovic, 2011) It is focused on finding the best alternatives and a compromise solution of conflict criterion problems are determined. Let A_i (i=1,2, ...,n) be finite set of n alternatives which to be evaluated by L experts E_k (k=1,2, ...,L) with respect to a set of m evaluated criteria C_j (j=1,2, ...,m). The Fuzzy VIKOR procedure consists of the following steps as stated by (Lui, 2013; Yucenur et al., 2012)

Step-1: Construct the judgment matrix and weight vector that denote the fuzzy assessments matching to qualitative criteria for each decision-maker, and the importance weights of criteria.

Step-2: The OWA weights for the decisions makers are computed as suggested by (Xu.,2005) The normal distribution based method is employed (Lui, 2015) to calculate the weight of the OWA operator. By this method, the associated vector weight can be obtained by Eq^{n}s. 4.9- Eq^n-4.12. For example, if n=6 the we get μ_6 =3.5 and σ_6 =$\sqrt{2.92}$ we get OWA weight values as w = $(0.0865, 0.1716, 0.2419, 0.2419, 0.1716, 0.0865)^T$

Step-3: Aggregate the decisions makers' (experts') opinion to construct a fuzzy decision matrix and get the aggregated fuzzy weights of criteria.

Let the Fuzzy rating for ith alternative regarding jth criterion of lth experts be $\tilde{g}_{ij} = (g_{ij1}^l, g_{ij2}^l, g_{ij3}^l, g_{ij4}^l)$ And $\tilde{w}_j^l = (w_{j1}^l, w_{j2}^l, w_{j3}^l, w_{j4}^l)$ (i=1,2,...m) and (j=1,2,...n) restively Hence the aggregated fuzzy rating of alternatives with respect to each criteria can be calculated by using Eq^n-4.9

$$\tilde{g}_{ij} = (g_{ij1}, g_{ij2}, g_{ij3}, g_{ij4}) \qquad (4.5)$$

Similarly the aggregated fuzzy weights $\tilde{w}_j$ of each criterion can be calculated as $\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4})$

Thus the matrix $\hat{I}$ and the weight $\tilde{w}$ could be expressed as

$$\tilde{K}=\begin{bmatrix} \tilde{g}_{11} & \tilde{g}_{12} & \cdots & \tilde{g}_{1n} \\ \tilde{g}_{21} & \tilde{g}_{22} & \cdots & \tilde{g}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{g}_{m1} & \tilde{g}_{m2} & \cdots & \tilde{g}_{mn} \end{bmatrix} \quad \tilde{W}=(\tilde{w}_1,\tilde{w}_2,\tilde{w}_3,\tilde{w}_4)^T \tag{4.6}$$

Step-4: Determine the best G_j^* and worst G_j^- value of all criterion rating

$$G_j^* = \max_i \{\tilde{g}_{ij}\} \tag{4.7}$$

$$G_j^- = \min_i \{\tilde{g}_{ij}\} \tag{4.8}$$

Step-5: Calculate the normalized fuzzy distance $\tilde{d}_{ij}$, i=1,2, ...m, j=1,2,...n

$$\tilde{d}_{ij} = \frac{d(G_j^*,\tilde{g}_{ij})}{d(G_j^*,G_j^-)} \tag{4.9}$$

Step -6: Defuzzify the fuzzy weight of each criterion into crisp values

The aggregated trapezoidal fuzzy number $\tilde{w}_j=(w_{j1},w_{j2},w_{j3},w_{j4})$ where the defuzzified to the best non fuzzy performance value W_j° on the centroid of TFN ($\tilde{w}_j$) is calculated by using following equation

$$w_j^\circ = \frac{\int x\mu_w(x)}{\int \mu_w(x)}$$

$$= \frac{\int_{w_{j1}}^{w_{j2}} \left(\frac{x-w_{j1}}{w_{j2}-w_{j1}}\right).xdx + \int_{w_{j2}}^{w_{j3}} xdx + \int_{w_{j3}}^{w_{j4}} \left(\frac{w_{j4}-x}{w_{j4}-w_{j3}}\right).xdx}{\int_{w_{j1}}^{w_{j2}} \left(\frac{x-w_{j1}}{w_{j2}-w_{j1}}\right)dx + \int_{w_{j2}}^{w_{j3}} dx + \int_{w_{j3}}^{w_{j4}} \left(\frac{w_{j4}-x}{w_{j4}-w_{j3}}\right)dx}$$

$$= \frac{w^2{}_{j3}+w^2{}_{j4}+w_{j3}.w_{j4}-w^2{}_{j1}-w^2{}_{j2}-w_{j1}.w_{j2}}{3(w_{j3}+w_{j4}-w_{j1}-w_{j2})} \tag{4.10}$$

Step-7: Calculate the value of S_i and R_i as follows i-1,2,.....m

$$S_i = \sum_{j}^{n} \frac{w_j^{\circ} . \tilde{d}_{ij}}{\sum_{j=1}^{n} w_j^{\circ}} \tag{4.11}$$

$$R_i = \max_j \left(\frac{w_j^{\circ}}{\sum_{j}^{n} w_j^{\circ}} \right) \tag{4.12}$$

Where $w^{\circ}{}_j$ are the weights of the criteria, S_i and R_i represents the utility measure and regret measure.

Step-8: Calculate the value of $\tilde{S}^*, \tilde{S}^-, \tilde{R}^*, \tilde{R}^-$ and $\tilde{Q}_i$

$\tilde{S}^* = \max_i \{S_i\}$ $\tilde{S}^- = \min_i \{S_i\}$

$\tilde{R}^* = \max_i \{S_i\}$ $\tilde{R}^- = \min_i \{S_i\}$

$$Q = \frac{v(S_i - \tilde{S}^-)}{(\tilde{S}^* - \tilde{S}^-)} + \frac{(1-v)(R_i - \tilde{R}^-)}{(\tilde{R}^* - \tilde{R}^-)} \tag{4.13}$$

v is introduced as a weight for the strategy for maximum group utility, where (1-v) is the weight of individual regret. The value of v is set to 0.5 in this study (1-v) is the weight of the individual regret.

Step-9 Rank the alternative by sorting the value of S, R, and Q ascending order.

Step-10: 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 2nd 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 <0.5

Hence 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")

The VIKOR method is an effective tool in multi criteria decision making. The obtained compromise solution could be accepted by the decision makers because it provides a maximum group utility of the ''majority'' (represented by min S, Eq. (4.20), and a minimum individual regret of the ''opponent'' (represented by min R, Eq. (4.19). The VIKOR algorithm can be performed without interactive participation of DM, but the DM is in charge of approving the final solution and his/her preference must be included. The compromise solutions could be the base for negotiation, involving the decision makers' preference by criteria weights.

4.4 THE CASE STUDY OF PROPOSED METHOD

4.4.1 Study Area

A case study was conducted in the river basin areas of Kokrajhar district of BTAD, Assam, India to illustrate the application of proposed Fuzzy VIKOR Method. The Kokrajhar district lies roughly between $89^{o}46'$ to $90^{o}38'$ east longitudes and between $26^{o}19'$ to $26^{o}54'$ north latitudes. The district is bounded on the north by the Himalayan Kingdom of Bhutan, by Dhubri district on the south, Chirang district on the east and the interstate boundary of West Bengal on the west. The major rivers in this district are Champamati, Gaurang (Sharalbhanga), Hell (Gongia), Guruphella, Tipkai and Sankosh. These major rivers mostly originate from the Bhutan hills which is the source and flows towards south through the district and act as tributaries of the mighty Brahmaputra that flows east to west far from the southern boundary of Kokrajhar district. The basin area is about 3,169 km^2 and consists of three administrative sub-divisions, Kokrajhar, Gossaigaon and Parbathjhara, 9 no. of Circles, 11 no. of Blocks and around 941 villages. The area covers 51.63% forest land, 47.10% Agriculture land, .25% Build area and 0.48% water bodies [38] the region receives rainfall due to the influence of south west tropical monsoon during the period May to October. The average rainfall is between 2100-3600 mm annually. The area has a rapid population growth and some development plans can also be considered. For the last ten years there has been frequent damages caused flood. The flood left 29 people death and thousands homeless.

The most common hydrologic vulnerability is watershed approach, the study a reach-based areal approach based on river reach is used. The basin area is divided as per the main river basin including its stream. The district watershed basin is divided into five sub- basin region as follows:

A_1: Sub basin1 (Champamati River basin)

A_2; Sub basin2 (Gourang-Sharalbhanga River basin)

A_3: Sub basin3 (Hel- Gongia River basin)

A_4: Sub basin4 (Modati-Joyma-Tipkai River Basin

A_5: Sub basin5 (Songkosh-Gadadhar River basin)

As the flood vulnerability is inherent in various circumstances, including the possibility of disaster, the influences of the disaster on society and society's ability to respond to a disaster (Lee, 2013) To assess flood vulnerability, we consider various parts of the region such as (a) Environmental factor, (b) Social Factor, (d) Economic factors as criteria and their relevant sub criteria are identified as vulnerability criteria in a hierarchical structure as shown in fig 4. In order to find the most vulnerability region, an expert committee of six decision makers, E_1, E_2, E_3, E_4, E_5 and E_6 has been formed. These experts are from different departments one

Sub Divisional Circle Officer (SDCO), one from District Disaster Management Authority (DDMA), two are executive Engineers under the water resource department one from relief and rehabilitation office and one Assistant Professors.

Based on the literature, regarding the evaluation of flood vulnerability on the criteria and sub-criteria things were discussed with the experts.

The watershed basin is presented in the fig 4.2.

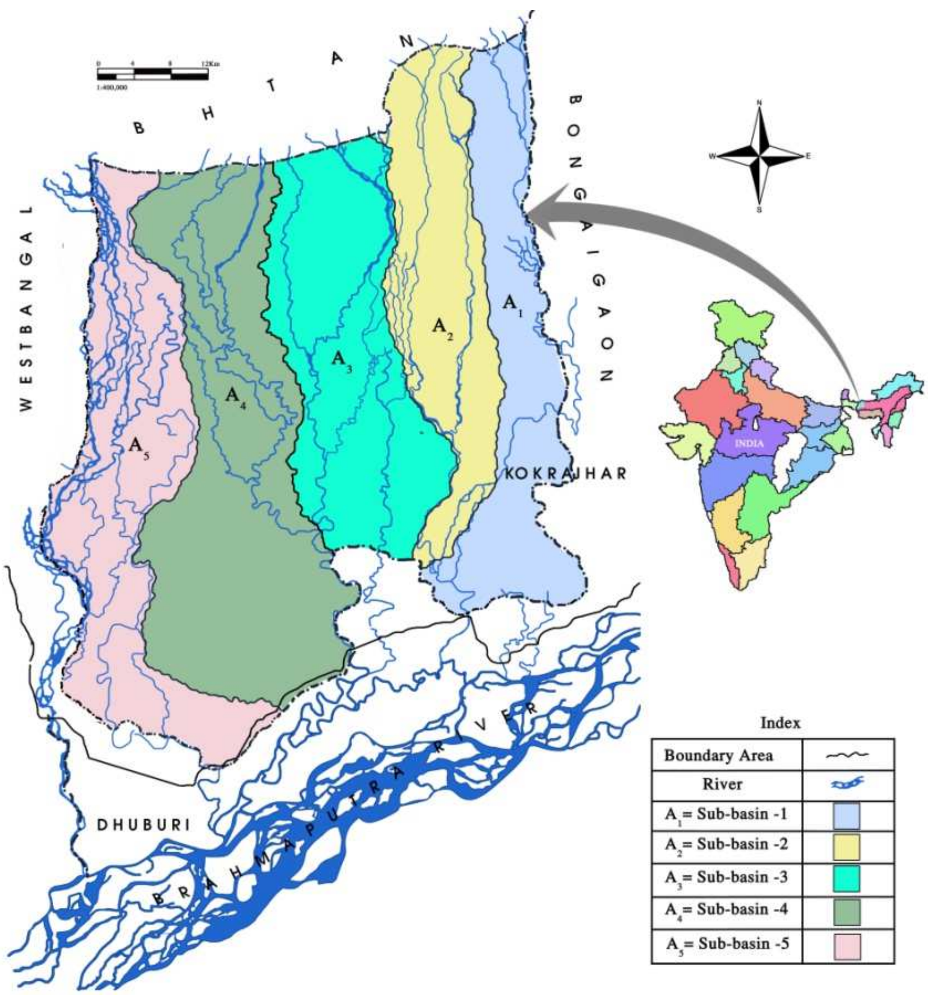

Figure 4.2 Study area map

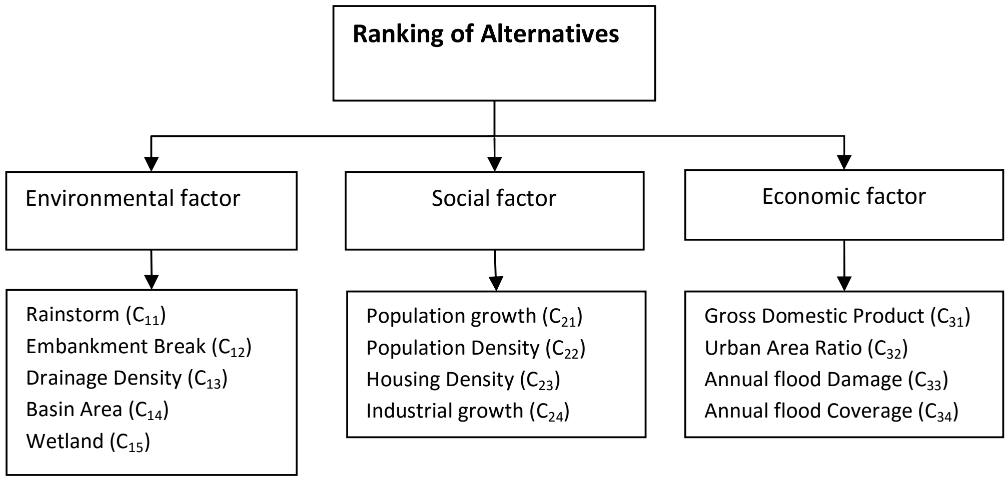

Figure 4.3 Hierarchical structure of the problem

Several interviews were arranged with the experts to acquire the judgments on the five alternatives on the weights of the 13 criteria. The objective of the first meeting is to introduce proposed framework and to provide the objective data obtained already. The experts were asked to provide their opinions on the rating of alternatives by using the linguistic variables with respect to each criterion and the importance weights of the criteria.

4.4.2 The steps of rating of flood vulnerability region can be defined as follows:

Step-1: Six decision makers (Experts) use the linguistic weighting variable shown in fig. 4.4 to evaluate the ratings of alternatives with respect to each criterion as shown in Table 4.3. Also the decision maker uses the linguistic variable shown in Fig. 4.5 to assess the important of the criteria. The important weights of the criteria determined by these six decision makers are shown in table 4.4.

Step-2: The OWA weights are determined using the normal distribution based-method suggested by (Xu, 2005) and Eq^{n} –(4.1) to Eq^{n}-(4.3), As a result, the OWA weight vector for six decision makers is computed as

$$\omega = (0.0865, 0.1716, 0.2419, 0.2419, 0.1717, 0.0865)^{T}$$

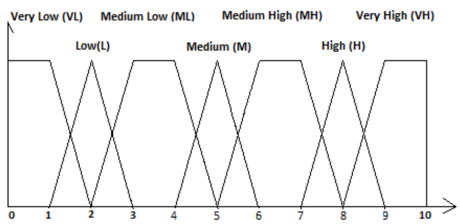

Figure4.4. Linguistic variables for rating of alternatives (Yucenur, 2012)

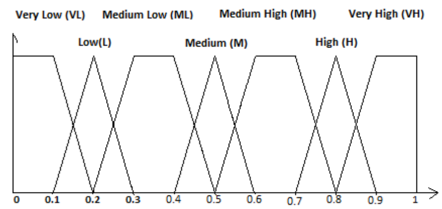

Figure4.5. Linguistic variables for rating the criteria (Yucenur , 2012)

Step-3: The evaluation shown in Table 4.3 and 4.4 are converted into trapezoidal fuzzy numbers and the aggregated fuzzy rating of alternatives and the aggregated weights of criteria are calculated to construct the fuzzy decision matrix and determine the fuzzy weights of each criterion, by using table 4.1 and table 4.2 are shown in table 4.5

TABLE 4.1:

Linguistic variable scales for rating of alternatives (Shemshadi, 2011)

Linguistic variable	Fuzzy Number
Very High(VH)	(8,9,10,10)
High(H)	(7, 8, 8, 9)
Medium High(MH)	(5, 6, 7, 8)
Medium(M)	(4, 5, 5, 6)
Medium Low(ML)	(2, 3, 4, 5)
Low(L)	(1, 2, 2, 3)
Very Low(VL)	(0, 0, 1, 2)

TABLE 4.2:

Linguistic variable scales for rating the criteria weights (Shemshadi, 2011)

Linguistic variable	Fuzzy Number
Very High(VH)	(0.8,0.9,1.0,1.0)
High(H)	(0.7,0.8,0.8,.09)
Medium High(MH)	(0.5,0.6,0.7,0.8)
Medium(M)	(0.4,0.5,0.5,0.6)
Medium Low(ML)	(0.2,0.3,0.4,0.5)
Low(L)	(0.1,0.2,0.2,0.3)
Very Low(VL)	(0.0,0.0,0.1,0.2)

Table 4.3

Linguistic assessment of alternatives given by six experts

Experts	Alternatives	Criteria												
		C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}
E_1	A_1	MH	H	VL	L	M	L	M	L	L	M	L	L	ML
	A_2	M	M	L	ML	L	M	ML	M	L	ML	M	ML	ML
	A_3	ML	L	M	ML	M	ML	M	L	L	L	M	ML	M
	A_4	MH	ML	M	ML	MH	M	ML	L	ML	ML	L	M	ML
	A_5	ML	MH	L	M	M	ML	ML	L	L	ML	L	VL	M
E_2	A_1	MH	H	L	L	ML	L	M	L	L	M	L	L	M
	A_2	M	M	L	ML	L	M	ML	M	L	ML	M	ML	ML
	A_3	M	L	M	L	ML	M	ML	M	L	L	M	ML	L
	A_4	MH	M	ML	M	L	M	ML	ML	VL	M	L	M	ML
	A_5	ML	MH	L	M	M	ML	ML	L	L	ML	L	ML	VH
E_3	A_1	H	MH	L	M	H	M	M	M	L	MH	L	ML	ML
	A_2	H	H	M	ML	MH	H	H	H	M	L	M	ML	ML
	A_3	H	MH	ML	MH	VH	M	M	MH	VL	M	ML	ML	ML
	A_4	MH	M	ML	MH	ML	MH	M	M	L	MH	L	M	MH
	A_5	H	MH	ML	H	VH	M	M	MH	L	VH	ML	VH	H
E_4	A_1	VH	H	M	MH	L	MH	MH	MH	VL	MH	L	ML	M
	A_2	VH	H	ML	M	L	MH	M	ML	VL	MH	L	MH	H
	A_3	VH	M	ML	MH	L	MH	M	MH	ML	M	VL	MH	ML
	A_4	MH	H	ML	M	ML	M	M	L	VL	MH	M	MH	H
	A_5	VH	MH	ML	M	L	MH	M	MH	L	H	VL	MH	M
E_5	A_1	H	MH	M	MH	L	MH	ML	MH	VL	MH	L	M	MH
	A_2	VH	H	M	MH	ML	H	MH	MH	VL	H	MH	H	MH
	A_3	MH	M	ML	M	L	MH	M	M	VL	MH	VL	MH	H
	A_4	H	MH	M	ML	MH	H	MH	MH	L	H	L	MH	H
	A_5	VH	H	VL	M	MH	H	MH	H	L	MH	VL	ML	MH
E_6	A_1	H	M	M	ML	M	MH	MH	MH	L	MH	M	MH	H
	A_2	H	VH	M	ML	L	H	MH	H	VL	H	M	H	MH
	A_3	MH	H	VL	M	ML	MH	M	M	VL	MH	VL	MH	M
	A_4	H	MH	M	MH	L	MH	M	MH	L	MH	M	MH	H
	A_5	H	VH	MH	ML	M	H	MH	H	L	H	MH	ML	MH

Table 4.4

Linguistic assessment of criterion weights

Experts	**Criteria**												
	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}
E_1	H	MH	M	M	H	MH	M	ML	ML	MH	M	H	MH
E_2	VH	MH	M	M	H	MH	M	ML	ML	ML	M	H	ML
E_3	H	VH	L	M	H	MH	MH	H	H	ML	L	M	M
E_4	VH	H	M	MH	ML	H	MH	M	MH	H	M	H	MH
E_5	H	VH	M	M	VL	H	MH	M	L	H	ML	H	MH

Table 4.5

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

Criteria	Alternatives					
	A_1	A_2	A_3	A_4	A_5	Weights
C_{11}	(6.570,7.570,7.915,8.828)	(6.484,7.484,7.742,8.484)	(5.172,6.172,6.828,7.742)	(5.516,6.516,7.258,8.258)	(5.796,6.796,7.141,8.054)	(**0.726,0.826,0.852,0.926**)
C_{12}	(5.914,6.914,7.327,8.327)	(6.312,7.312,7.399,8.312)	(3.657,4.657,4.828,5.828)	(4.500,5.500,6.000,7.000)	(6.087,7.087,7.673,8.587)	(**0.698,0.798,0.874,0.924**)
C_{13}	(2.414,3.327,3.414,4.414)	(2.742,3.742,3.984,4.984)	(2.000,2.742,3.484,4.484)	(3.000,4.000,4.500,5.500)	(2.001,3.001,3.743,4.743)	(**0.383,0.483,0.491,0.591**)
C_{14}	(3.000,4.000,4.500,5.500)	(2.603,3.603,4.431,5.431)	(3.655,4.655,5.085,6.085)	(3.742,4.742,5.258,6.258)	(4.087,5.087,5.173,6.173)	(**0.426,0.526,0.552,0.652**)
C_{15}	(3.001,4.001,4.243,5.243)	(1.518,2.518,2.776,3.776)	(2.604,3.604,4.174,5.088)	(2.516,3.516,4.258,5.258)	(4.760,5.760,6.260,7.173)	(**0.433,0.524,0.574,0.674**)
C_{21}	(3.726,4.726,5.226,6.226)	(5.742,6.742,6.984,7.984)	(4.327,5.327,5.914,6.914)	(4.673,5.673,6.087,7.087)	(4.726,5.726,5.726,6.726)	(**0.552,0.652,0.726,0.826**)
C_{22}	(4.601,5.601,5.688,6.688)	(4.157,5.157,5.828,6.828)	(3.827,4.827,4.914,5.914)	(3.570,4.570,4.915,5.915)	(3.984,4.984,5.742,6.742)	(**0.450,0.550,0.650,0.750**)
C_{23}	(3.726,4.726,5.226,6.226)	4.843,5.843,6.172,7.172)	(3.999,4.999,5.257,6.257)	(3.000,4.000,4.500,5.500)	(4.968,5.968,6.210,7.210)	(**0.374,0.474,0.500,0.600**)
C_{24}	(0.742,1.484,1.742,2.742)	0.760,1.260,1.760,2.760)	(0.587,1.087,1.673,2.673)	(0.828,1.570,1.915,2.915)	(1.000,2.000,2.000,3.000)	(**0.269,0.369,0.434,0.534**)
C_{31}	(4.742,5.742,6.484,7.484)	3.930,4.930,5.585,6.585)	(3.484,4.484,4.742,5.742)	(4.742,5.742,6.484,7.484)	(4.485,5.485,6.485,7.399)	(**0.393,0.493,0.559,0.659**)
C_{32}	(1.260,2.260,2.260,3.260)	3.827,4.827,4.914,5.914)	(0.587,1.087,1.673,2.673)	(1.774,2.774,2.774,3.774)	(0.345,0.603,1.431,2.431)	(**0.340,0.440,*0*.440,0.540**)
C_{33}	(2.345,3.345,3.915,4.915)	4.016,5.016,5.758,6.758)	(3.500,4.500,5.500,6.500)	(4.500,5.500,6.000,7.000)	(3.204,4.118,4.946,5.859)	(**0.674,0.774,0.774,0.874**)
C_{34}	(3.915,4.915,5.345,6.345)	3.673,4.673,5.586,6.586)	(2.087,3.087,3.914,4.914)	(5.226,6.226,6.726,7.726)	(5.430,6.430,7.085,8.085)	(**0.483,0.583,0.657,0.748**)

Step-4: The best and the worst values of all criterion rating are determined by using eq. –(4.7) and (4.8) and shown in table 4.6.

Table 4.6

The fuzzy best and fuzzy worst values of all criteria ratings

G^*_1	(6.570,7.570,7.915,8.828)	G^-_1	(5.172,6.172,6.828,7.742)
G^*_2	(6.312,7.312,7.399,8.312)	G^-_2	(3.657,4.657,4.828,5.828)
G^*_3	(3.000,4.000,4.500,5.500)	G^-_3	(2.001,3.001,3.743,4.743)
G^*_4	(4.087,5.087,5.173,6.173)	G^-_4	(2.603,3.603,4.431,5.431)
G^*_5	(4.760,5.760,6.260,7.173)	G^-_5	(1.518,2.518,2.776,3.776)
G^*_6	(5.742,6.742,6.984,7.984)	G^-_6	(3.726,4.726,5.226,6.226)
G^*_7	(4.157,5.157,5.828,6.828)	G^-_7	(3.570,4.570,4.915,5.915)
G^*_8	(4.968,5.968,6.210,7.210)	G^-_8	(3.000,4.000,4.500,5.500)
G^*_9	(1.000,2.000,2.000,3.000)	G^-_9	(0.587,1.087,1.673,2.673)
G^*_{10}	(4.742,5.742,6.484,7.484)	G^-_{10}	(3.484,4.484,4.742,5.742)
G^*_{11}	(3.827,4.827,4.914,5.914)	G^-_{11}	(0.345,0.603,1.431,2.431)
G^*_{12}	(3.204,4.118,4.946,5.859)	G^-_{12}	(2.345,3.345,3.915,4.915)
G^*_{13}	(5.226,6.226,6.726,7.726)	G^-_{13}	(2.087,3.087,3.914,4.914)

Step-5: The normalized fuzzy distance calculated by Eq^n –(4.9) for each criterion of the alternative are shown in table 4.7

Step-6: Defuzzify the fuzzy criteria weights to get crisp values by using Eq^n –(4.10) and result shown in along in last column of table 4.7

Table 4.7

Normalized fuzzy distance for the five alternatives.

Criteria	Alternatives					
	A_1	A_2	A_3	A_4	A_5	**Weights**
C_{11}	0.000	0.134	0.831	0.572	0.514	**0.831**
C_{12}	0.090	0.000	0.822	0.507	0.080	**0.822**
C_{13}	0.488	0.259	0.593	0.000	0.487	**0.487**
C_{14}	0.415	0.539	0.143	0.115	0.000	**0.539**
C_{15}	0.308	0.552	0.350	0.348	0.000	**0.552**
C_{21}	0.689	0.000	0.457	0.359	0.416	**0.689**
C_{22}	0.258	0.000	0.538	0.600	0.107	**0.600**
C_{23}	0.296	0.024	0.254	0.487	0.000	**0.487**
C_{24}	0.248	0.309	0.402	0.174	0.000	**0.402**
C_{31}	0.000	0.296	0.526	0.000	0.065	**0.526**
C_{32}	0.312	0.000	0.403	0.250	0.440	**0.440**
C_{33}	0.774	0.731	0.416	1.045	0.000	**0.774**
C_{34}	0.279	0.282	0.617	0.000	0.061	**0.617**

Step-7 and 8: The calculated the values of S_i, R_i and Q_i, i= 1,2, ... , m are shown in table 4.8.

Table 4.8

The value of S, R, and Q for all alternatives

	Alternatives				
	A_1	A_2	A_3	A_4	A_5
S	0.536	0.403	0.818	0.574	0.279
R	0.100	0.094	0.107	0.135	0.066
Q	0.483	0.319	0.798	0.774	0.000

Step-9: The ranking of all alternatives by S, R and Q in increasing order are shown in table 4.9

Table 4.9

The ranking of alternatives ordered by S, R, and Q in increasing order

	Alternatives				
	A_1	A_2	A_3	A_4	A_5
By S	3	2	5	4	1
By R	3	2	4	5	1
By Q	3	2	5	4	1

Step-10: This step proposes the group of alternatives as the best compromise solution with utilizing both the scores and rankings of fuzzy VIKOR. In this context of flood vulnerability, it suggests that the river basin region needs to implement adaption plan with the highest priority based on the vulnerability scores and ranking.

As we see in table 4.9 the alternatives (A_5) based on Q is apparently the best (most vulnerability) compromise solution, two conditions C1 and C2 are also satisfied:

$Q(A_2)^{(2)} - Q(A_5)^{(1)} = (0.319-0) = 0.319 \geq \frac{1}{5-1}$

And **A_5** is the best ranked (best compromise solution) by R and S Graph of S, R and Q are shown in Figure 4.6

Table 4.10

Criteria wise ranking of five alternatives.

Criteria	Ordering of Alternatives (decreasing) High to low				
C_{11}	A_1	A_2	A_5	A_4	A_3
C_{12}	A_2	A_5	A_1	A_4	A_3
C_{13}	A_4	A_2	A_5	A_1	A_3
C_{14}	A_5	A_4	A_3	A_1	A_2
C_{15}	A_5	A_1	A_4	A_3	A_2
C_{21}	A_2	A_4	A_5	A_3	A_1
C_{22}	A_2	A_5	A_1	A_3	A_4
C_{23}	A_5	A_2	A_3	A_1	A_3
C_{24}	A_5	A_4	A_1	A_2	A_3
C_{31}	A_2	A_1	A_5	A_2	A_3
C_{32}	A_2	A_4	A_1	A_3	A_5
C_{33}	A_5	A_4	A_3	A_2	A_1
C_{34}	A_4	A_5	A_1	A_2	A_3

Table 4.11

Ranking of criteria weights. Ordering (High to low)

1	2	3	4	5	**6**	7
C_{11}	C_{12}	C_{33}	C_{21}	C_{34}	C_{22}	C_{15}

Ordering

8	9	10	11	12	13
C_{14}	C_{31}	C_{13}	C_{23}	C_{32}	C_{24}

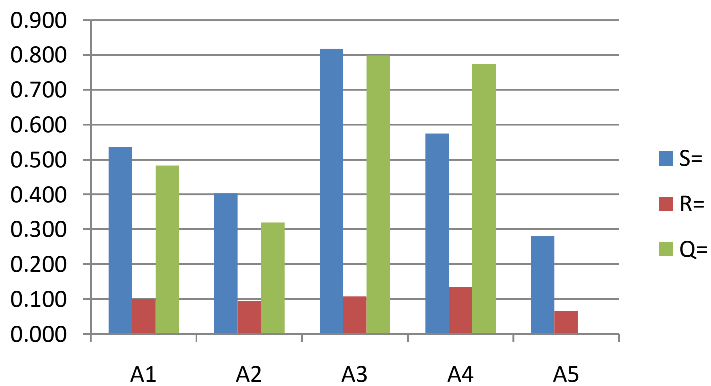

Figure 4.6 Ranking of Alternatives by S R and Q

4.5 RESULT AND DISCUSION:

Table 4.10 shows criteria wise ranking of the vulnerability of five alternatives (sub basin) discus in this study. The result shows that the alternative A_1 -Sub basin1 (Champamati River basin) is the highest vulnerability in the criteria C_{11}, alternative A_2 -Sub basin2 (Gourang-Sharalbhanga River basin) is the highest vulnerability in the criteria C_{12}, $C_{21,}$ $C_{22,}$ C_{31}, $C_{32,}$ alternative A_4 -Sub basin4 (Modati-Joyma-Tipkai

River Basin) is the highest vulnerability in the criteria C_{13}, C_{34}, alternative A_5 -Sub basin5 (Songkosh-Gadadhar River basin) is the highest vulnerability in the criteria C_{14}, C_{15}, C_{23}, C_{24}, C_{33} respectively and alternatives A_1 basin1 (Champamati River basin) is the lowest vulnerability in the criteria C_{21} and C_{33}, alternatives A_2 basin2 (Gourang-Sharalbhanga River basin) is the lowest vulnerability in the criteria C_{14} and C_{15}, and alternative A_3 -Sub basin3 Sub basin3 (Hel- Gongia River basin) is the lowest vulnerability in the criteria C_{11}, C_{12}, C_{13}, C_{23}, C_{24}, C_{31}, C_{32}, C_{34}

Table 4.11 shows ranking criteria weights, criteria C_{11} (Rainstorm) is the highest weights as per the experts followed by C_{12} (Embankment Break) and C_{33} (Annual flood Damage) respectively while criteria C_{24} (Industrial growth) has the least criteria weights. Ranking of Criterion weights are shown in Figure 4.7

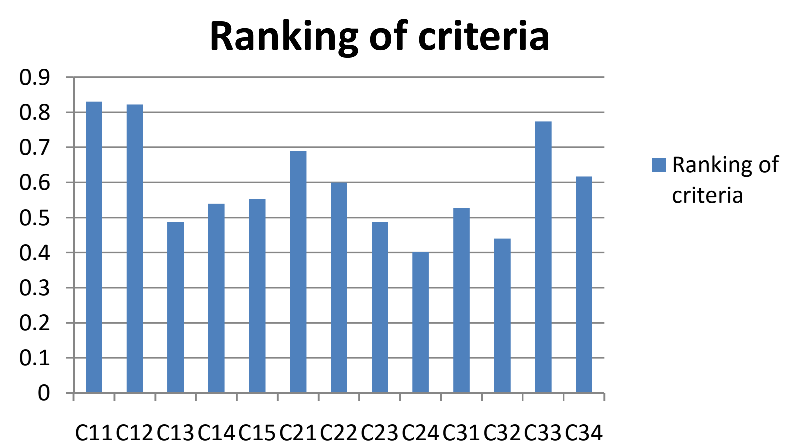

Figure 4.7 Ranking of Criterion weights

4.6 CONCLUSION:

In this study, we assessed the flood vulnerability in Kokrajhar region with Fuzzy VIKOR. We defined the flood vulnerability as a function of Environmental factor, social factor and economic factors, and we profiled the key indicators for vulnerability with the expert's opinions. Fuzzy VIKOR method is a helpful tool in multi criteria decision making compromised solution which obtained, could be accepted by the decision makers because it provides a maximum group utility (represented by min S) of the majority, and a minimum of the individual regret (represented by min R) of the opponent. In this chapter we proposed a modified Fuzzy VIKOR that was supported by OWA operator and determined the weights of criteria. According to the final score, the alternative A_5 (minimum of Q) that the Songkosh-Gadadhar river sub-basin is the most vulnerable region while A_2 and A_1 alternatives are second and third most vulnerability river basin region.