

South Indian River Ranking Using Fuzzy Analytic Hierarchy Process

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Abstract

The river ranking problem is a strategic issue and has significant impact on the efficiency of a river system. On the other hand, the river ranking among many alternatives presents a multi criteria decision making (MCDM) problem. Hence fuzzy set theory can be applied. Fuzzy Analytic Hierarchy process (FAHP) technique is used to rank alternatives to find the efficient use of the river system. Fuzzy numbers and linguistic variables are used to inherently vague data. Four criteria and 20 sub criteria are identified, tested and applied to real data. The FAHP is used to analyze the structure of the river ranking problem. A real world application is conducted to illustrate the utilization of the model using the available data pertaining to a few south Indian rivers. The application can be interpreted as demonstrating the effectiveness and feasibility of the FAHP model.

Keywords: *Fuzzy AHP, fuzzy set theory, MCDM*

1 Introduction

Nowadays, water resource management should be managed in an integrated manner including water quality, water quantity, land use and economy, especially when we want to find the highest potential river developed for efficient use of water systems. Water resource planning and management should consider various aspects of river basins. Current river ranking techniques namely, Water Quality Index (WQI) Interim National Water Quality Standard (INWQS) were found only to consider water quality aspects. Other important water related aspects were neglected. Furthermore, the more the aspects are to be considered, the more difficult to obtain exact preference value when multiple units of data are used. The difficulties are also faced by the decision maker (DM) when there exists vague data in decision making process. In this study, a special focus is given on the method that deals with vague data which the DMs accounted during data acquisition.

Currently, in South India, water quality data are used to determine the water quality status in clean, slightly polluted or polluted category and to classify the rivers into Class I, II, III, IV or V based on Water Quality Index (WQI) and Interim National Water Quality Standards for South India (INWQS) respectively. However, these classification schemes do not consider other aspects such as water quantity, land use and economy which directly influence the final result in finding the most appropriate use of water system. Therefore, this study includes water quantity, land use and economy aspect in decision

making.

Previous studies on river ranking ([1], [30]) had used point value to represent the subjective data. This approach is found to be adequate when the absolute point value can exactly represent the DMs preferences. However, this point value cannot represent the degree of preference of the DMs and also the degree of risk tolerance that the DMs are ready to take. Also, in real situation, the absolute point value is not always adequate to represent the DMs preference naturally. Decision makers usually find it more convenient to express interval judgments than fixed value judgments due to the fuzzy nature of the comparison process [2]. Therefore, this paper proposes fuzzy set defuzzification technique to address vague data using triangular fuzzy number (TFN) and to represent DMs degree of confidence and degree of risk that the DMs are ready to take. This paper also proposes the linguistic variables that can be used to represent the TFN.

The purpose of this study are threefold: 1. To construct structural hierarchy that considers various aspects of river basins, 2. To rank the rivers in South India to find the most appropriate use of water system emphasizing on the present vague data and 3. To compare the result with the previous work using water quality Index (WQI) and HIPRE 3+.

2 Related Works

There are numerous multi criteria decision making (MCDM) techniques developed till date. One of the most common MCDM

techniques is AHP, ([3]-[8]). The use of AHP will keep increasing because of the AHP's advantages such as ease of use, great flexibility, and wide applicability [3]. Numerous authors have presented different ranking methods to rank alternatives under fuzzy environment during the last two decades [8]. Bottani and Rizzi [9] used fuzzy logic to deal with vagueness of human thought and AHP to make a selection the most suitable dyad supplier/purchased item. Buyukozkan et al. [10] had proposed fuzzy AHP method to evaluate e-logistics-based strategic alliance partners. Efendigil et al. [2] proposed two-phase model based on artificial neural networks and fuzzy AHP to select a third-party reverse logistics provider. Cascales and Lamata [11], proposed fuzzy AHP for management maintenance processes where only linguistic information was available. Pan [12] used fuzzy AHP for selecting the suitable bridge construction method. Sheu [13], proposed a hybrid neuro-fuzzy methodology to identify appropriate global logistics operational modes used for global supply chain management. Tsai et al. [14] used fuzzy AHP for market positioning and developing strategy in order to improve service quality in department stores. Wu et al. [15], proposed fuzzy AHP for measurement of non-profit organizational performance. Huang et al. [16] applied fuzzy AHP to represent subjective expert judgements in government-sponsored R&D project selection. Lee et al. [17] constructed fuzzy AHP to evaluate performance of IT department in the manufacturing industry in Taiwan. Chang C W et al. [18, 19], used fuzzy AHP to evaluate and control silicon wafer slicing quality. Chang and Wang

flexibility, and wide applicability [3]. In this study, AHP will be used together with fuzzy set to solve river ranking problem.

[20] proposed consistent fuzzy preference relation in a comparison matrix. Chen et al. [21], proposed a combination of fuzzy AHP with multi dimensional scaling in identifying the preference similarity of alternatives.

Chen and Qu [22], proposed fuzzy AHP to evaluate the selection of logistics centre location. Dagdeviren and Yuksel [23], developed fuzzy AHP for behavior-based safety management. Nagahanumaiah et al. [24], used fuzzy AHP to identify problem features for injection mould development. Duran and Aguilo [25], used fuzzy AHP for machine-tool selection. Onut et al. [26], proposed a combined fuzzy AHP and fuzzy TOPSIS approach for machine tool selection problem. Yang et al. [27], proposed fuzzy AHP for Vendor selection by integrated fuzzy MCDM techniques with independence and interdependence.

A significant finding from all the researchers is that they have used triangular fuzzy number (TFN) to represent vague data or linguistic information. It is important to note that the extent analysis method has been used by them [23] and [26] found that it cannot estimate the true weights from a fuzzy comparison matrix [28].

3 The Proposed Method

The proposed method consists of 3 stages: Data gathering, FAHP calculation and Decision making. Steps taken at each stage are described as follows:

3.1 Data gathering

Step 1: Determining objectives & choosing alternatives.

During this step, we do the following:

- Define the problem clearly with specifications on its multi-criteria aspects.
- Determine the overall goal and sub-goals, identifying the evaluation criteria.

Step 2: Determining criteria to be used in the ranking process.

In this step, we identify the candidate's alternatives. This is done in confirmation with the knowledge experts. 4 criteria namely water quality, water quantity, land use and economy have been identified. 20 sub-criteria namely biochemical oxygen demand (BOD), suspended solid (SS), PH, dissolved oxygen (DO), chemical oxygen demand (COD), ammonia nitrogen (AN), temperature, iron, flow rate, length of river, width of river, residence, industry(1), agriculture(1), forest, fishery, industry(2), recreation, agriculture(2) and reservoir have been chosen.

Step 3: Structuring decision hierarchy.

In this step, the decision problem is structured into a hierarchical model, in which the overall goal (usually the selection of the best alternative) is

This is done through literature survey and discussion with knowledgeable experts.

situated at the highest level; elements with similar features (usually evaluation criteria) are grouped at the same interim level and the decision variables (usually alternatives) are situated at the lowest level.

Step 4: Approved decision hierarchy.

Decision hierarchy is analysed in detail. This study defines the evaluation criteria and sub-criteria using water quality index, quantity of water, land use and economical activity. The 4 criteria and 20 sub-criteria proposed are structured in a hierarchy and the final decision is made. The top level in the hierarchy is our goal to find the highest rank river for efficient use of water system. Second level in the hierarchy is the four criteria which are identified as water quality, water quantity, land use and economy. Third level in the hierarchy is the 20 sub-criteria identified in step 2. At the lowest level in the hierarchy are alternatives which present the six rivers in the comparison namely the Godavari, the Krishna, the Cauvery, the Tungabhadra, the Bharathapuzha and the Bhavani. The structured hierarchy used in this study is presented in Fig. 3.1.

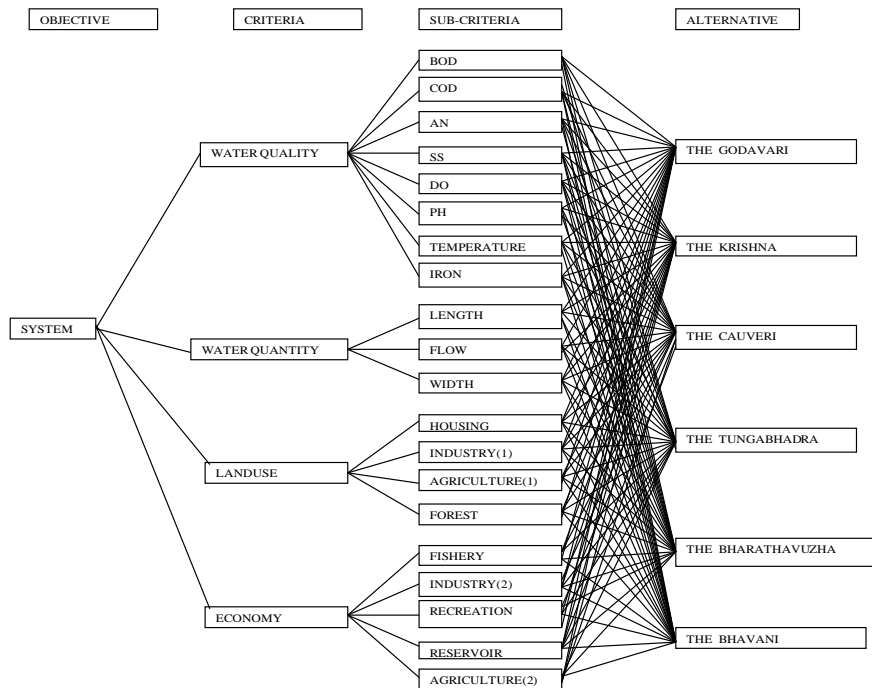


Fig. 3.1: The structured hierarchy used in this study

3.2 FAHP calculation

Step 5: Assigning weights to criteria and alternatives via FAHP.

In this study, all criteria in the judgment matrix are given equal important weights and all sub criteria (alternatives) weight vectors are represented using objective value, which were obtained from field data collection. These data cannot be used directly into AHP since they are in different units and therefore data normalization must be done in advance. Some bigger values might be preferred and therefore they have higher priority in AHP but for certain sub-criteria, smaller values are preferred than bigger values. For water quality, the lowest value for BOD, COD, AN, SS, temperature and iron, the highest value of DO and the nearest value for pH are the highest priority in AHP. For are water quantity, the highest value for flow rate, the longest and the widest rivers have the highest priority value in AHP. For land use, the highest percentage of forest and the lowest percentage of residence, industry and agriculture are the highest

priority value in AHP. For economy, the highest value is the highest priority value in AHP. In the case where smaller values are preferred, for normalized values a_j , the values of $1/a_j$ will be used and therefore higher values can be obtained and hence higher priority in AHP.

Vague data are presented by triangular fuzzy numbers (TFN). Each membership function is defined by three parameters (L, M, U), where L is the lowest possible value, M is the middle possible value and U is the upper possible value in the DMs interval judgements. The value of L, M and U can also be determined by the DMs themselves. In this study, we propose the three fuzzy parameters to represent conventional Saaty's AHP 1 – 9 relative importance scale [29], given by means of the following equations $\bar{1} \equiv (1, 1, 1)$, $\bar{x} \equiv (x-1, x, x+1)$ $\forall x = 2, 3, \dots, 8$ and $\bar{9} \equiv (9, 9, 9)$.

The TFN can express subjective pairwise comparison or presents certain degree of vagueness. We also

propose linguistic variables that can vague data should they feel uncomfortable with the triangular numbers. The proposed TFN and

be used by DMs to represent linguistic variables related to Saaty's scale of preference values are shown in Table 3.1.

Table 3.1: Proposed TFN and linguistic variables.

Saaty's scale of relative importance	Definition	TFN	Linguistic variables
1	Equal importance	(1,1,1)	Least importance
3	Moderate importance of one over another	(2,3,4)	Moderate importance
5	Essential or strong importance	(4,5,6)	Essential importance
7	Demonstrated importance	(6,7,8)	Demonstrate importance
9	Extreme importance	(9,9,9)	Extreme importance
2,4,6,8	Intermediate values between two adjacent judgements	(1,2,3), (3,4,5), (5,6,7) and (7,8,9)	Intermediate values between two adjacent judgements

In a previous work, a difficulty arose in acquiring fishery activity data, since it could not be quantified. Point value was used to represent the value of relative importance between alternatives. However, these point values are not

suitable for the DMs to give their preference judgements naturally. The proposed TFN or linguistic variables to represent vague data from previous work ([1], [30]) used in this study is shown in Table 3.2.

Table 3.2: Triangular fuzzy numbers and linguistic variables for fishery

	Point value([1],[30])	TFN	Linguistic variables
The Godavari	4	(3,4,5)	Intermediate between 3 and 5
The Krishna	4	(3,4,5)	Intermediate between 3 and 5
The Cauvery	3	(2,3,4)	Moderate importance
The Tungabhadra	3	(2,3,4)	Moderate importance
The Bharathapuzha	2	(1,2,3)	Intermediate between 1 and 3
The Bhavani	1	(1,1,1)	Least importance

Step 6: Approving weights used.

Weights have been approved by knowledge experts through the

construction of a judgement matrix as well as weight vector W for the hierarchical structure. The

comparisons are used to form a matrix of pairwise comparisons

called the judgement matrix A .

$$A = [a_{ij}] = \begin{matrix} & C_1 & C_2 & \dots & C_n \\ \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} & \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \end{matrix}$$

Each entry a_{ij} of the judgement matrix is governed by three rules: $a_{ij} > 0$; $a_{ij} = 1/a_{ji}$; $a_{ii} = 1$ for all i . The resulting weights of the elements may be called the local weights.

method used by Chang [18, 19] as follows,

After a judgement matrix has been built, any fuzzy data is then defuzzified and is performed using a

$$(a_{ij}^\alpha)^\lambda = [\lambda \cdot L_{ij}^\alpha + (1 - \lambda) \cdot U_{ij}^\alpha], \quad 0 \leq \lambda \leq 1, \quad 0 \leq \alpha \leq 1,$$

where, $L_{ij} = (M_{ij} - L_{ij}) * \alpha + L_{ij}$ and $U_{ij} = U_{ij} - (U_{ij} - M_{ij}) * \alpha$ and its reciprocal

value can be calculated as below.

$$(a_{ji}^\alpha)^\lambda = 1 / (a_{ij}^\alpha)^\lambda, \quad 0 \leq \lambda \leq 1, \quad 0 \leq \alpha \leq 1, \quad i > j.$$

where, α display a decision maker's preference and λ is risk tolerance. Initial value for both α and λ is 0.5 to reflect normal preference and risk tolerance. When $\alpha = 1$, the uncertainty range is the

lowest and when $\lambda = 1$, the DMs are pessimistic. Based on Table 3.2, when α and λ is 0.5, defuzzification is performed as follows:

$$L_{11} = 0.5 * (4 - 3) + 3 = 3.5,$$

$$U_{11} = 5 - (5 - 4) * 0.5 = 4.5.$$

$$a_{11} = [0.5 * 3.5 + (1 - 0.5) * 4.5] = 4.$$

Eigenvalue and eigenvector have been calculated and a consistency check is performed using Saaty and Kearns's conventional AHP method [29]. Saaty and Kearns [29] proposed consistency index (C.I.) and consistency ratio

(C.R.) to verify the consistency of the comparison matrix. C.I. and C.R. are defined as follows:

$$C.I. = \frac{\lambda_{\max} - n}{n - 1},$$

$$C.R. = \frac{C.I.}{R.I.}$$

where, λ_{max} is the largest eigenvalue of the judgement matrix and n is the number of matrix. The value of C.R. should be around 10% or less to be accepted. According to Saaty and Kearns [29], in some cases, 20% of C.R can be tolerated but cannot be more than that.

For all objective data used in this study, average value method is used. Table 3.3 –

elements and R.I is the random index for consistency of different order of random

Table 3.6 present normalized (average) data which have been used in this method. There are other ways, such as least value method and best value method that can be used in this work but it is beyond the focus of this study.

Table 3.3: Data for water quality

	BOD	COD	AN	SS	DO	PH	Temp	Iron
The Godavari	0.87	5.66	1.34	1.43	0.26	4	1.09	00
The Krishna	31.85	119.05	123.46	23.47	0.29	2	1.14	42
The Cauvery	4.08	12.14	18.18	27.86	0.16	1	1.05	28
The Tungabhadra	2.39	8.81	18.87	13.16	0.13	3	1.07	96
The Bharathapuzha	11.20	8.27	21.28	15.82	0.08	6	1.06	28
The Bhavani	13.87	2.01	11.03	12.41	0.09	5	1.00	62

Table 3.4: Data for water quantity

	Length	Flow	Width
The Godavari	0.11	0.07	0.03
The Krishna	0.10	0.18	0.02
The Cauvery	1.00	0.00	1.00
The Tungabhadra	0.11	0.32	0.07
The Bharathapuzha	0.09	1.00	0.05
The Bhavani	0.06	0.26	0.01

Table 3.5: Data for land use

	Resident	Industry(1)	Agriculture(1)	Forest
The Godavari	20.12	5.52	0.00	0.63
The Krishna	129.87	12.71	212.77	1.00
The Cauvery	1.00	1.05	1.00	0.00
The Tungabhadra	8.36	1.00	0.00	0.00
The Bharathapuzha	36.23	1.16	0.00	0.00
The Bhavani	0.00	2.35	0.00	0.00

Table 3.6: Data for economy

	Fishery	Recreation	Industry(2)	Agriculture(2)	Reservoir
The Godavari	1.00	0.50	1.00	0.20	0.40
The Krishna	1.00	1.00	0.60	0.60	1.00
The Cauvery	0.75	0.50	0.60	1.00	0.40
The Tungabhadra	0.75	1.00	1.00	0.20	0.40
The Bharathapuzha	0.50	0.50	1.00	0.20	0.20
The Bhavani	0.25	0.50	1.00	0.20	0.20

Step 7: Ranking the alternatives.

Calculate the relative weight of element for each level. The composite priorities of the alternatives will be determined by aggregating the weights throughout the hierarchy. Set the weight vector W made up of evaluation criteria as $[w_i]_{n \times 1}$. W^T is the transpose of the

weight vector W and it can be shown as $[w_i]_{n \times 1}$. The judgement matrix A is made up of candidate alternatives $[A_1, A_2, \dots, A_m]$ and the evaluation criteria is given as S_i , then the final score S of alternatives can be calculated as follows:

$$A = [a_{ij}]_{m \times n} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix}, W = [w_j]_{1 \times n} = [w_1 \ w_2 \ \dots \ w_n], \text{ and } W^T = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}$$

$$S = A \otimes W^T = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \otimes \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} a_{11} \otimes w_1 \odot a_{12} \otimes w_2 \odot \dots \odot a_{1n} \otimes w_n \\ a_{21} \otimes w_1 \odot a_{22} \otimes w_2 \odot \dots \odot a_{2n} \otimes w_n \\ \vdots \\ a_{m1} \otimes w_1 \odot a_{m2} \otimes w_2 \odot \dots \odot a_{mn} \otimes w_n \end{bmatrix} = \begin{bmatrix} S_1 \\ S_2 \\ \vdots \\ S_m \end{bmatrix}$$

Then,

where, a_{ij} is the relative importance of the j th evaluation w_j criteria. a_{ij} is the relative importance of the i th alternative A_i corresponding to the j th evaluation criterion and is the final score of candidate alternative

A_i . Operator \otimes represents multiplication and is an addition operator.

Table 3.7 shows the composite priorities for the 6 rivers using FAHP method.

Table 3.7: Composite priorities using FAHP.

	The Godavari	The Krishna	The Cauvery	The Tungabhadra	The Bharathapuzha	The Bhavani
Water quality	0.063	0.173	0.081	0.070	0.110	0.082
Water quantity	0.017	0.024	0.167	0.041	0.095	0.027
Land use	0.076	0.248	0.006	0.009	0.023	0.011
Economy	0.155	0.210	0.163	0.168	0.120	0.108
Overall	0.311	0.655	0.416	0.288	0.348	0.229
Rank	4	1	2	5	3	6

3.3 Decision making

Step 8: Choosing the highest ranking from the set of alternatives.

Alternative with the highest priority value will be chosen. Based on the overall composite value in Table 3.7, The Krishna is the best-ranked river followed by the Cauvery, the

Bharathapuzha, the Godavari, the Tungabhadra and the Bhavani. Krishna River also scored the highest composite priority value on water quality, land use and economy. Therefore, Krishna River will be chosen as the most efficient use of river system in South India.

Table 3.8: Comparison results of river ranking

	FAHP
THE GODAVARI	4
THE KRISHNA	1
THE CAUVERY	2
THE TUNGABHADRA	5
THE BHARATHAPUZHA	3
THE BHAVANI	6

4 Conclusion

This work has focused on handling vague data in the decision making process. Various aspects of river basins to find the most efficient use of water system have been proposed in this study. The proposed FAHP approach is found to be able to deal with vague data using fuzzy triangular numbers. It is claimed that the proposed technique not only can be used to address the problem with vague data acquisition, but it can also represent the relative level of risk and level of confidence that the DMs may give. The TFN used in this study can

also be used to represent linguistic variables should the DMs feel uncomfortable to use interval judgment values. Based on the available data, Krishna River is found to be the best river to be chosen should a development project is to be made which emphasize on efficient use of river system.

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