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Using Fuzzy Analytic Hierarchy Process for Southern Johor River Ranking

Mohamad Ashari Alias, Siti Zaiton Mohd Hashim, Supiah Samsudin

Faculty of Computer Science and Information Systems,
University Teknologi Malaysia. Malaysia
ashari@utm.my:
Faculty of Computer Science and Information Systems,
University Teknologi Malaysia. Malaysia
e mail: sitizaiton@utm.my:
Faculty of Civil Engineering,
University Teknologi Malaysia, Malaysia
e mail: supiah@utm.my:

Abstract

This paper presents the application of fuzzy set theory in multi criteria decision making (MCDM). Fuzzy Analytic Hierarchy Process (FAHP) technique will be used to rank alternatives to find the most reasonable and efficient use of river system. The overall aspects of river system including both qualitative and quantitative are emphasized. Four criteria and 20 sub-criteria have been identified and compared. Fuzzy numbers and linguistic variables are presented to address inherently uncertain or imprecise data. The technique is tested to real rivers data. A comparison between the proposed technique and the previous results obtained using conventional techniques is presented.

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

1 Introduction

Nowadays, water resource management should be managed in integrated manner including water quality, water quantity, land use and economy, especially when we wanted to find the highest potential river to be developed for efficient use of water systems. Water resources planning and management should consider various aspects of river basins. Current river ranking techniques namely, Water Quality Index (WQI) and National Water Quality Standard (INWQS) were found to only 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 also faced by the decision maker (DM) when there exist vague data in the 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 Malaysia, water quality data were used to determine the water quality status weather 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 Malaysia (INWQS) respectively. However, these classification schemes did 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 included water quantity, land use and economy aspect in the decision making.

Previous study 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 proposed 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 proposed 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 rivers for Southern Johor of Peninsular Malaysia to find the most appropriate used of water system emphasizing on the present of vague data and 3. To compare the result with the previous work using water quality Index (WQI) and HIPRE 3+.

2 Related Works

There a numerous multi criteria decision making (MCDM) techniques had been developed to 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]. In this study, AHP will be used together with fuzzy set to solve river ranking problem.

Numerous authors have presented different ranking methods to rank alternatives under fuzzy environment during the last two decades [8]. Bottani and Rizzi [9] had 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 non-profit organizational performance. Huang et al. [16] had applied fuzzy AHP to represent subjective expert judgements in government-sponsored R&D project selection. Lee et al. [17] had 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 controlling silicon wafer slicing quality. Chang and Wang [20] had proposed consistent fuzzy preference relation in a comparison matrix. Chen et al. [21], proposed combination of fuzzy AHP with multi dimensional scaling in identifying the preference similarity of alternatives.

Chen and Qu [22], had 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], using fuzzy AHP to identify problem features for injection mold 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 they used triangular fuzzy number (TFN) to represent vague data or linguistic information. It is important to note that the extent analysis method used by [23] and [26] was found cannot estimate the true weights from a fuzzy comparison matrix [28].

3 The Proposed Method

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

3.1 Data gathering

Step 1: Determine objective and choosing alternatives.
This is done through literature survey and discussion with knowledgeable experts. 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: Determines criteria to be used in the ranking process.
In this step, we identified the candidate alternatives. This is also done with the confirmation from 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, dissolve oxygen (DO), chemical oxygen demand (COD), ammonia nitrogen (AN), temperature, iron, flow rate, length of river, width of river, residential, 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 situated at the highest level; elements with similar features (usually evaluation criteria) are grouped at the same interim level and decision variables (usually alternatives) are situated at the lowest level

Step 4: Approved decision hierarchy.
Decision hierarchy is analysed in detail. This study defined 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 were structured in a hierarchy and 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 Layang River, Segget River, Tebrau River, Tukang Batu River, Kempas River and Buloh River. The structured hierarchy used in this study is presented in Fig. 3.1.

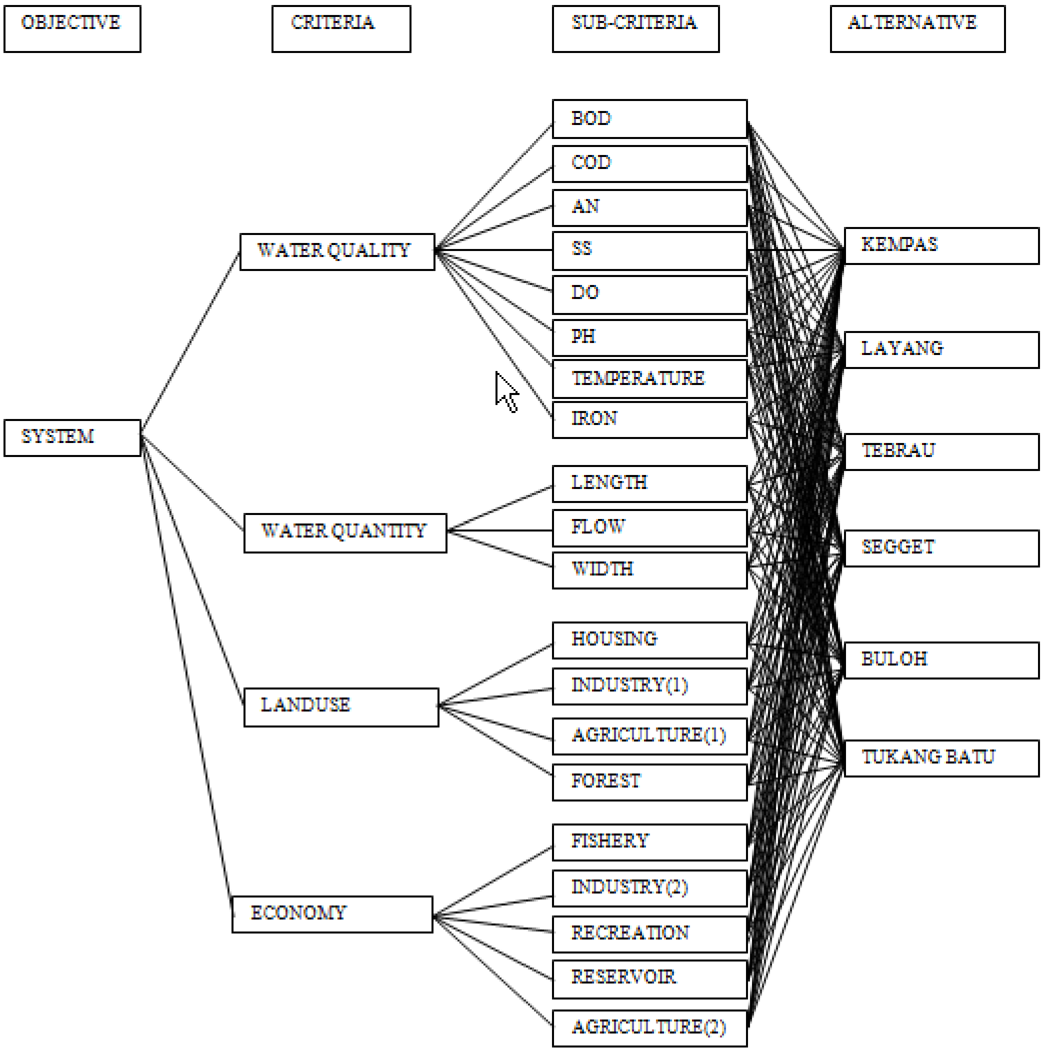

Fig. 3.1: The structured hierarchy used in this study

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 unit, therefore data normalization must be done in advanced. Some bigger values might be preferred and therefore 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 were the highest priority in AHP. For water quantity, the highest value for flow rate, the longest and the widest rivers were the highest priority value in AHP. For land use, the highest percentage of forest and the lowest percentage of resident, industry and agriculture were the highest priority value in AHP. For economy, the highest value is the highest priority value in AHP. In the case when smaller values are preferred, for normalized values a_j, the values of $1/a_j$ will be used and therefore higher value can be obtained and hence higher priority in AHP.

Vague data were 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 proposed the three fuzzy parameters to represent conventional Saaty's AHP 1 – 9 relative importance scale [29], given by means of the following equations $\tilde{1} \equiv (1,1,1)$, $\tilde{x} \equiv (x\text{-}1, x, x\text{+}1)$ $\forall$ x = 2,3,..,8 and $\tilde{9} \equiv (9, 9, 9)$.

The TFN can express subjective pair wise comparison or presents certain degree of vagueness. We also proposed linguistic variables that can be used by DMs to represent vague data should they feel uncomfortable with the triangular numbers. The proposed TFN and 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 judgments	(1,2,3), (3,4,5), (5,6,7) and (7,8,9)	Intermediate values between two adjacent judgments

In previous work, a difficulty was aroused when acquiring fishery activity data, since it cannot be quantified. Point value was used to represent the value of relative importance between alternatives. However, these point values is 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
Kempas	4	(3,4,5)	Intermediate between 3 and 5
Layang	4	(3,4,5)	Intermediate between 3 and 5
Tebrau	3	(2,3,4)	Moderate importance
Segget	3	(2,3,4)	Moderate importance
Buloh	2	(1,2,3)	Intermediate between 1 and 3
Tukang Batu	1	(1,1,1)	Least importance

Step 6: Approving weights used.

Weights were approved by knowledge experts through a construction of judgement matrix as well as weight vector *W* for the hierarchical structure. The comparisons are used to form a matrix of pair-wise comparisons called the judgement matrix *A*.

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

Each entry a_{ij} of the judgements matrix are governed by the 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.

After a judgement matrix has been built, any fuzzy data is then defuzzified and is performed using a method used by Chang [18, 19] as follows,

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

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.

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

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

$$L_{11} = 0.5 * (4-3) + 3 = 3.5,\ U_{11} = 5 - (5\text{-}4) * 0.5 = 4.5.$$
$$a_{11} = [0.5 * 3.5 + (1-0.5) * 4.5 = 4.$$

Eigenvalue and eigenvector were 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:

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

where, $\lambda_{\max}$ is the largest eigenvalue of the judgement matrix and n is the number of elements and R.I is the random index for consistency for different order of random 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 more than that.

For all objective data used in this study, average value method is used. Table 3.3 – Table 3.6 present normalized (average) data which were 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
Kemas	0.87	5.66	1.34	1.43	0.26	4	1.09	00
Layang	31.85	119.05	123.46	23.47	0.29	2	1.14	42
Tebrau	4.08	12.14	18.18	27.86	0.16	1	1.05	28
Segget	2.39	8.81	18.87	13.16	0.13	3	1.07	96
Buloh	11.20	8.27	21.28	15.82	0.08	6	1.06	28
Tukang Batu	13.87	2.01	11.03	12.41	0.09	5	1.00	62

Table 3.4: Data for water quantity

	Length	Flow	Width
Kempas	0.11	0.07	0.03
Layang	0.10	0.18	0.02
Tebrau	1.00	0.00	1.00
Segget	0.11	0.32	0.07
Buloh	0.09	1.00	0.05
Tukang Batu	0.06	0.26	0.01

Table 3.5: Data for land use

	Resident	Industry(1)	Agriculture(1)	Forest
Kempas	20.12	5.52	0.00	0.63
Layang	129.87	12.71	212.77	1.00
Tebrau	1.00	1.05	1.00	0.00
Segget	8.36	1.00	0.00	0.00
Buloh	36.23	1.16	0.00	0.00
Tukang Batu	0.00	2.35	0.00	0.00

Table 3.6: Data for economy

	Fishery	Recreation	Industry(2)	Agriculture(2)	Reservoir
Kempas	1.00	0.50	1.00	0.20	0.40
Layang	1.00	1.00	0.60	0.60	1.00
Tebrau	0.75	0.50	0.60	1.00	0.40
Segget	0.75	1.00	1.00	0.20	0.40
Buloh	0.50	0.50	1.00	0.20	0.20
Tukang Batu	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 $[w_i]_{nx1}$. W^T is the transpose of the weight vector W and it can be shown as $[w_i]_{nx1}$. The judgement matrix A is made up of candidate alternatives $[A_1, A_2, \ldots, A_m]$ and the evaluation criteria is given as S_i, then the final score S of alternatives can be calculated as follows:

$$A=\left[a_{ij}\right]_{mxn}=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix},\ W=\left[w_j\right]_{1xn}=\begin{bmatrix} w_1 & w_2 & \cdots & w_n \end{bmatrix},\text{ and } W^T=\begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix},$$

Then,

$$S=A\otimes W^T=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}\otimes\begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}=\begin{bmatrix} a_{11}\otimes w_1 \odot a_{12}\otimes w_2 \odot\cdots\odot a_{1n}\otimes w_n \\ a_{21}\otimes w_1 \odot a_{22}\otimes w_2 \odot\cdots\odot a_{2n}\otimes w_n \\ \vdots \\ a_{m1}\otimes w_1 \odot a_{m2}\otimes w_2 \odot\cdots\odot a_{mn}\otimes w_n \end{bmatrix}=\begin{bmatrix} s_1 \\ s_2 \\ \vdots \\ s_m \end{bmatrix},$$

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* ⊗ 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.

	Kempas	Layang	Tebrau	Segget	Buluh	Tukang Batu
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 the chosen one. Based on the overall composite value in Table 3.7, Layang River is the best-ranked river followed by Tebrau River, Buloh River, Kempas River, Segget River and Tukang Batu River. Layang River also scored the highest composite priority value on water quality, land use and economy. Therefore, Layang River will be chosen as the most efficient use of river system for South Johore.

Fig. 3.2 shows comparison result of priority index between WQI and HIPRE 3+ ([1], [30]) and FAHP methods used in this study.

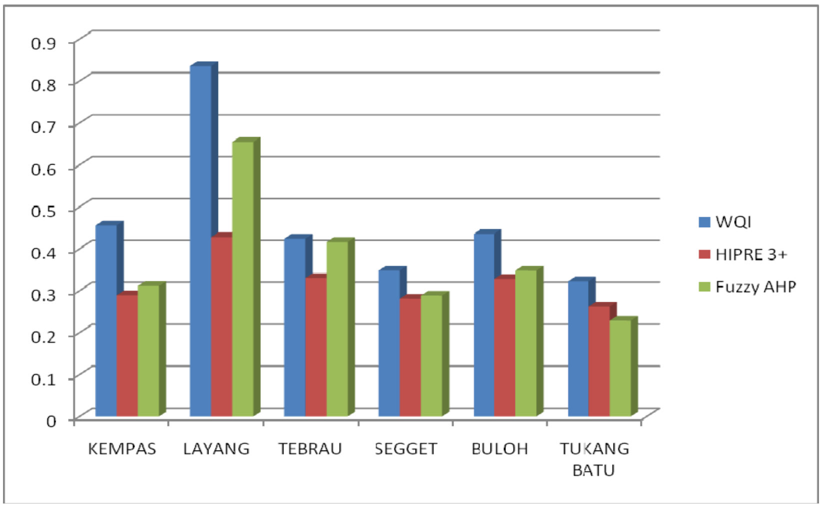

Fig. 3.2: Comparison results between WQI, HIPRE 3+ and FAHP.

Table 3.8 shows comparison result of river ranking using WQI, HIPRE 3+ and FAHP.

Table 3.8: Comparison results of river ranking

	WQI	HIPRE 3+	FAHP
KEMPAS	2	4	4
LAYANG	1	1	1
TEBRAU	4	2	2
SEGGET	5	5	5
BULOH	3	3	3
TUKANG BATU	6	6	6

Equal ranking results were found by using HIPRE 3+ and FAHP methods, but slight different when compared to WQI. All ranking techniques show similar ranking for the best, the third, fifth and the worst rank rivers.

4 Conclusion

This work has been focused on handling vague data in the decision making process. Various aspects of river basins to find the most efficient use of water system had been proposed in this study. The proposed FAHP approach is found to be able to deal with vague data using fuzzy triangular numbers. The proposed FAHP ranking result is similar to previous HIPRE 3+ technique and slight different when compared to WQI technique. It is claimed that the proposed technique not only can be used to address problem with vague data acquisition, but it can also represent the relative level of risk and level of confidence that the DMs may given. The TFN used in this study can also be used to represent linguistic variables should the DMs feel uncomfortable to use interval judgment values. Layang 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.

The result from this work is not only similar to the previous work using HIPRE 3+ but also suggest more flexible and provides information on DMs' degree of preferences.

5 Future Work

One of the most important yet difficult tasks during this work was to formulate the problem. It is important to focus effort on structuring the decision problem and the support of problem definition and design. There is little guidance available to help a decision analyst structure a MCDM problem ([33], [37]). Based on review on peer reviewed papers and also review papers by other researchers had shown that until now, there is still little efforts in building a knowledge base that stored most if not all design and definition previously used and/or published which can be used to assist DM in structuring MCDM problem. Therefore, a work to assist DMs to structure their problem is needed.

Further work will focus on assisting DMs to formulate the problem in a hierarchical structure. An internet-based knowledge-base will be developed. A 'point and click' method will be developed to make the searching faster and easier.

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