Water Level Evaluation at Southern Malaysia Reservoir using Fuzzy Composite Programming

Supiah Shamsudin, Azmi Ab Rahman' Zaiton Binti Haron, Lat Da A/P Ai Nam

Abstract: Ranking and evaluation of properreservoir water level outflowing into downstream river system under multi-criterion environment was presented using multi-criteria decision approach specifically Fuzzy Composite Programming (FCP). The optimum water level evaluation is vital to take into consideration the various environmental, water quantity and economical aspects of the overall systems. This multicriteria analysis will optimize water release, ensuring water quality, providing economical benefits and maintaining high quality of the natural landscape. The study mainly focuses on optimizing outflowing water level by identifying and grouping the basic indicators into its particular composite structure. The basic indicators include various water quality parameters, flowrates, rainfall, scenery etc. The composite structure of the overall reservoir water use system was presented. Five(5) alternatives based on reservoir water level was adopted which include 20.6m (Alternative 1), 22.2m(Alternative 2), 23.8m(Alternative 3), 25.4m (Alternative 4) and 27.0m(Alternative 5) respectively. Sensitivity analysis using three (3) set of different weights was performed for analyzing the robustness of the optimum water level obtained. The FCP structure consists of 15 first level indicators, 5 second level indicators, 2 third level indicators and the final indicators. The optimum value was determined based on the shortest distance between the fuzzy box and an ideal point. The optimum answer was also obtained from the highest ordered sequence value. The highest ranking order indicated by highest ordered sequence value obtained was Alternative 3 (0.660), followed by Alternative 4 (0.596), Alternative 2 (0.555), Alternative 5 (0.515) and lastly Alternative 1(0.500). The highest ranking order indicated the most optimum, advisable and appropriate water level for Layang reservoir.

Keywords: Fuzzy Composite Programming, MCDM, Optimum water level, Reservoir

I. INTRODUCTION

Water is main component for lives on the earth; for without water no lives will survive. The problem related to water shortage is very crucial due to improper water management and continuous increasing human contamination activities. Even though there are countries which are blessed with abundant rainfall and stream, water shortage is still a problem due to improper management of water resources (Supiah et. al., 2010, Salisu et. al., 2010). The proper management such as proper reservoir outlet water level is very important in order to sustain the water resources with high water quality and to reduce the problem on water shortage.

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The primary aims for this study was to estimate an optimum allowed reservoir level. The optimum allowed level was taken for this study due to its simple notion, easy to incorporate into regulations and implementation. In water management studies, where decisions must simultaneously satisfy several conflicting objectives, method based on benefit –cost analysis or multicriteria decision analysis are frequently used to help identify the "optimal"decision (Christofides A. et al, 2005; Raj, P.A., 2002; Stanbury, J.S., Bogardi, I., Lee,Y.W.,Wayna E.W.,1991; Zeleny, M., 1982). Thus multi-criteria decision making specifically Fuzzy Composite Programming was introduced in order to obtain the optimum reservoir water level allowed so that the water use would be more efficient. The multicriteria namely maximizing water release, ensuring water quality is adequate and to maintain a high worth of the natural landscape.

Fuzzy Composite Programming (FCP) was chosen as it is easy to use and understand compared with other methods. Furthermore, the addition of fuzzy set theory (Zadeh 1965) to compromise programming would represent the uncertainties of the indicators. These FCP was selected based on their easiness to apply, inexpensive, and easily obtained data. The complexities of the first-level indicators were reduced by limiting the labor required to collect and analyze data. The fuzziness of the analysis includes imprecision of the first-level indicators throughout the analysis. The indicator values are assigned with most likely and largest likely ranges.

There are three main research objectives that have been carried out for this research:

i. To obtain an optimum water level allowed for best management of Layang Reservoir using Fuzzy Composite Programming.
ii. To identify and to group the basic indicator into composite structure for evaluation.
iii. To perform sensitivity analysis for analyzing the robustness of the results obtained.

II. METHODOLOGY

A. Site description

This study was conducted at Layang Reservoir. The Layang watershed in Masai consists of two main reservoirs, the Upper Reservoir and the Lower Layang Reservoir. The upper Layang Reservoir is located at 40 km north east of Johor Bahru. The Layang River is the main river that drains into the Upper Layang Reservoir. Discharge from both watersheds is about 40 MGD. The outflow rate at the intake lower to the water treatment plant is 28.5 MGD. The drainage basin for the Lower Layang Reservoir is 20.5 km^2. The total drainage basin for both reservoirs is 50 km^2 (Supiah S. 2003).

B. Data Collection

There are two types of data collection conducted for this study namely primary and secondary data. Primary data are obtained through site visit while secondary data were obtained from literature review. The selection of real value between intake elevation and above sea level (spillway crest elevation) was limited to five values. They were 20.6m (Alternative 1), 22.2m (Alternative 2), 23.8m (Alternative 3), 25.4m (Alternative 4) and 27.0m (Alternative 5). There were 15 basic indicators for first level indicators, 5 second level indicators, 2 third level indicators and the final indicators as constructed in Fig. 2. The optimum water level allowed was determined by considering three final criterias; maximizing water release, ensuring adequate water quality, and improving social economy.

Two visits were made; 10th January 2010 and 3rd March 2010. The purpose was to collect the water samples for water quality laboratory testing including phosphorus, nitrates as well as in-situ testing; velocity, DO and PH value. Velocity was used to calculate the flow rate using Mid-Section method. The swoffer current meter was used to obtain the velocity at the river.Data were randomly taken at nine (9) stations at Layang Reservoir. Two samples were taken at each station. Thus a total of thirty six (36) samples were collected in this study. These data were analyzed for their uncertainties using fuzzy approach.

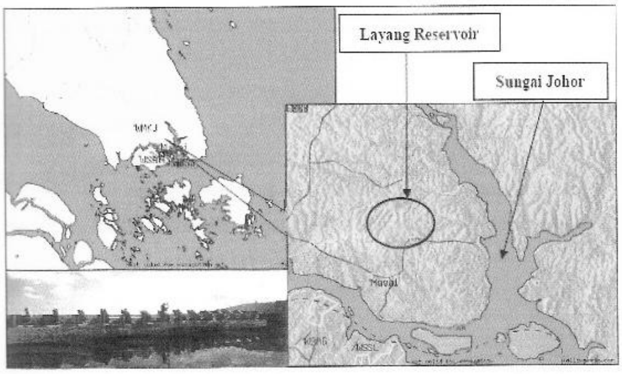

Fig.1: Site Location for Layang Reservoir (Faradilah, 2006)

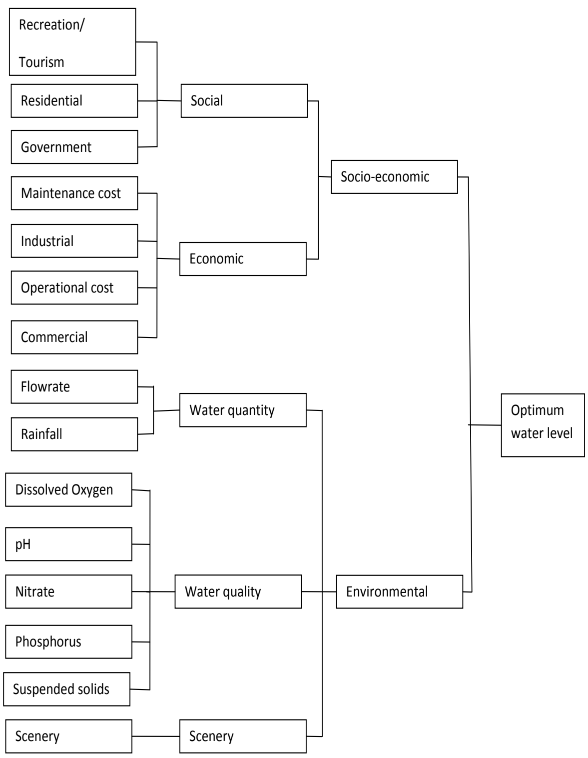

Fig 2**:** Fuzzy Composite Structures

The secondary data were also used for the analysis in addition to the primary data. Secondary data were obtained from related previous thesis as well as from Department of Drainage and Irrigation and Badan Kawalselia Air Johor (BAKAJ). Ranking numbers was used to substitute the data that was strenuous to obtain such as basic indicator data value for social as well as economy. Ranking numbers were indicated by (5), (4), (3), (2) and (1) where (5) if good and (1) if bad in descending order.

C. Composite Programming Algorithm (Bogardi I., 1992)

The algorithms for FCP are as shown below. The first step was normalization of the basic indicator values (Z_i) by placing into the 0-1 interval. This is necessary since the units of the various basic indicators can be quite different and difficult to compare directly. Using the maximum (Z_{i+}) and the minimum (Z_{i-}), the normalized value (S_i) of Z_i can be computed as:

$$S_i = \frac{Z_i - Z_{i-}}{Z_{i+} - Z_{i-}} \qquad (1)$$

Next, the computation of distance within the assigned group was calculated using the following equation:

$$L_j = \left[\sum_{i=1}^{nj} a_{ij} S_{ij}^{pj} \right]^{\frac{1}{pj}} \qquad (2)$$

S_{ij}= the normalized value of basic indicator *i* in the first level group *j* of basic indicators

L_j= the composite distance for first level group *j* of basic indicator

n_j= the number of basic indicator in group j

a_{ij} = the weight expressing the relative importance og basic indicators in group *j* such that their sum equal one

p_j= the balancing factor among indicator for group *j*

Finally, computation of distance (from ideal point) associated with the assigned group is calculated, L, was obtained using the following equation:

$$L = (a_1 L_1^2 + a_2 L_2^2 + \ ... a_n L_n^2)^{\frac{1}{2}} \quad (3)$$

Where:

a_1=theweight expressing the relative importance of the group 1 such that their sum equals to 1

a_2=the weight expressing the relative importance of the group 2 such that their sum equals to 1

L_1 =the composite distance for group 1

L_2 =the composite distance for group 2

n =the n^{th} of group

The tentative weight used in Equation. 2 range between 0 and 1.0. The preferences were identified from the highest ordered sequence value, *N* which was computed from:

$$N_j = \frac{\beta_j - \alpha_j}{2} + \alpha_j \qquad (4)$$

Where β and α were obtained from the interaction line of maximizing and minimizing membership functions (Chen, 1985).

The fuzzy membership function was developed before the data were input into the FCP software (Chameau, J.L. and Santamaria, J.C. (1987)). The collected data were grouped into relevant interval. The frequency for the data value within the interval was calculated .Then the relative frequency was calculated by dividing the frequency in each interval with the highest frequency. Next, the histogram was developed and the range for maximum possible range and most likely range was selected based on best approximation. The example of membership function was shown in Figure3.

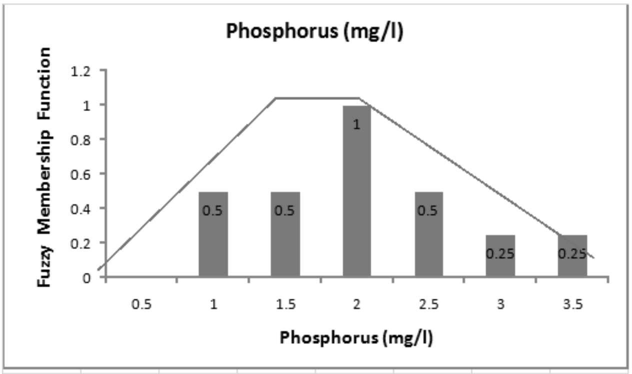

Fig. 3: Membership Function for Phosphorus (mg/l)

Table 1: Data Inputs for Alternative 1

Basic Indicators	Maximum Possible Range		Most likely range	
	low	high	low	high
Recreation/tourism value	1	5	1	2
Residential	1	5	2	3
Government	1	5	2	3
Desedimentation cost	1	5	3	4
Industrial	1	5	2	3
Pumping cost	1	5	1	2
Commercial	1	5	1	2
Flow rate	0.025	0.35	0.07	0.14
Rainfall	0	45	2.5	20
Dissolved oxygen	3.4	7.8	6.5	7.5
PH	5.5	12.1	7.8	9.8
Nitrate	0	1.24	0.1	0.25
Phosphorus	0.53	2	0.8	1.8
Suspended solid	3.8	16	8	15
Scenery	1	1	1	1

Next the sensitivity analysis was performed by varying the set of weight and balancing factors. Weights represent the relative importance between indicators in a group. The greater the importance of an indicator, the greater the weights should be assigned to it. The balancing factors were assigned for each group of indicators. The balancing factors refer to the importance of maximal deviation of indicators. Maximal deviation was the maximum difference between an indicator value and the best value for that indicator. As for this study, three trials of different set of sensitivity analysis were conducted where first trial is from expert judgment while the other two were from the analyst himself. The purpose of the sensitivity analysis was to get the robust result. All data, weight and balancing factor were input into Fuzzy Composite Programming software as shown in Table 1. The output obtained will be in the form of Numerical and Graphical form.

III. RESULT AND DISCUSSION

The results of the optimum water level evaluation during this study were presented graphically and numerically. The best alternatives using Fuzzy Composite Programming after three trials using 3 different set of weights were presented in Fig. 4-6. The sensitivity analysis based on the three trials would ensure the robustness of the results or best alternative obtained. The best alternative was obtained from the shortest distance from the centre of the smaller box to the ideal point.The big boxes represent the maximum possible range while the small boxes represent most likely range of the basic indicators.

Fig. 4 showed that the Alternative 3 was the optimum water level allowed as it had the shortest distance from the ideal point followed by Alternative 4, Alternative 2, Alternative 5 and Alternative 1. Fig. 5 also showed that the Alternative 3 as best alternative. Alternative 4 was the second choice followed by Alternative 2, Alternative 5 and lastly Alternative 1. Figure 6 also showed that Alternative 3 was the best alternative followed by Alternative 4, Alternative 5, Alternative 1 and Alternative 2.The results from the graphical output were obtained from three trials by varying the set of weights and balancing factors. The results revealed that the Alternative 3 was the chosen Alternative i.e. as a optimum allowed water level.

The numerical output was produced based on the highest ordering sequence value. The ideal point has the value of 1, therefore the ranking was higher when it was nearer to the value of 1.The analyzed results were grouped under each alternative for each trial as shown in Table 2.The sensitivity analysis based on the tree trials would produce more reliable and confident results. The three trials in the numerical results showed that the Alternative 3 was the selected alternative as it had the highest ordered sequence value of 0.660, followed by Alternative 4 with the value 0.596, Alternative 2 with the value 0.555, Alternative 5 with the value of 0.515 and lastly Alternative 1 with the value of 0.500. The ordered sequent value also indicated a robust results. Alternative 3 was selected as the optimum water level allowed as it had the ordering value of 0.660 which was closest to value of 1, compared with other alternatives.

The FCP developed for optimum water level evaluation at Layang Reservoir contained 15 first level indicators, 5 second level indicators, 2 third level indicators and the final indicators. The structure were developed using socio-economy and environmental as third level indicators. Water quality, water quantity and scenery are the major criteria in the environmental water released evaluation. The basics indicators are associated with the water quantity, water quality such as DO, PH, Nitrate, phosphorus, Suspended solid, flow rate, rainfall and scenery.

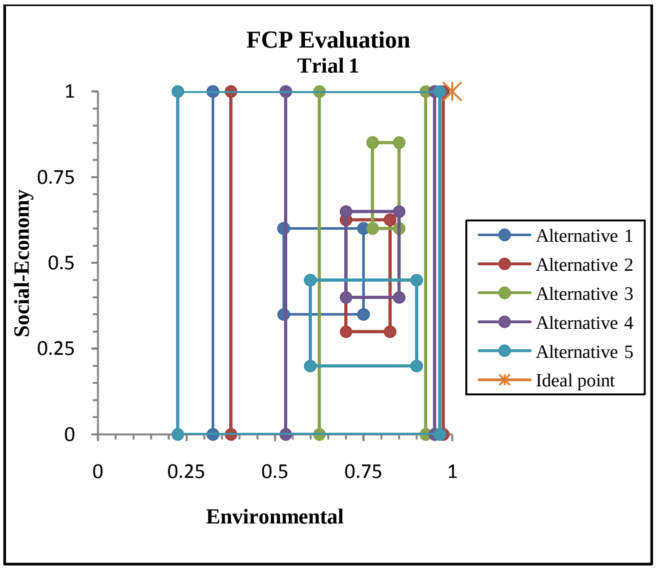

Fig. 4: Fuzzy Composite Analysis for Trial 1 (Weight Set 1)

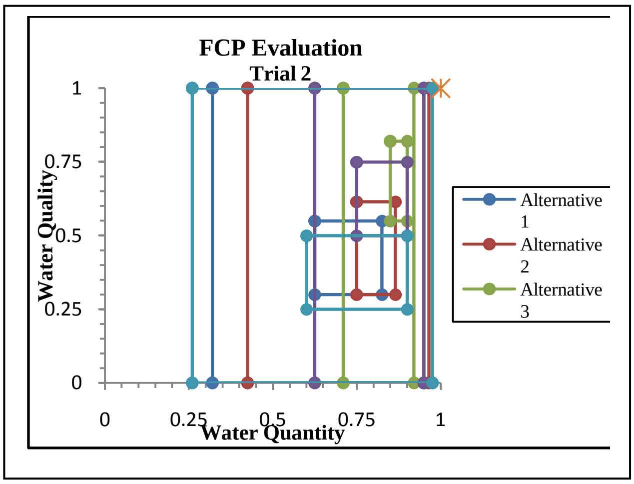

Fig. 5: Fuzzy Composite Analysis for Trial 2 (Weight Set 2)

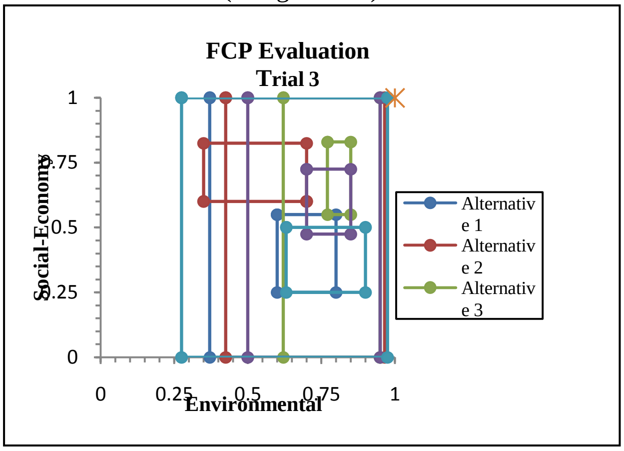

Fig. 6: Fuzzy Composite Analysis for Trial 3 (Weight Set 3)

Table 2: Ordered sequence for each trial

Option	Trial 1	Trial 2	Trial 3	Average
Alternative 3	0.652	0.659	0.668	0.660
Alternative 4	0.574	0.609	0.604	0.596
Alternative 2	0.545	0.544	0.577	0.555
Alternative 5	0.496	0.490	0.559	0.515
Alternative 1	0.495	0.484	0.522	0.500

The results for the optimum water level evaluation were presented graphically and numerically (Fig. 4 to 6). The boxes were produced as a result of trade-off between the objectives. Width of the boxes represents the uncertainty and fuzziness in the trade off. The optimum water level allowed was identified based on the shortest distance between the fuzzy box and ideal point. It was also evaluated by selecting the highest ordering sequence.

The best alternative obtained by considering the overall system was Alternative 3. This could be seen in the graphical output results as it had the closest distance from the centre of the small boxes among the other alternative. The results in the numerical output also showed that Alternative 3 had the highest ordering sequence value of 0.660 which was closest to the value of 1 as compared to the other alternatives.

This seems reasonable as we could observed that the Alternative 3 of 23.8m would be able to provide adequate water quantity to the residential especially due to its water level which was not too low or too deep. Too low and too deep water level would cause water shortage in drought season and occurrence of flooding during rainy season respectively. Apart of that Alternative 3 also has moderate water quality as well as moderate scenery value. Thus Alternative 3 would compromise all the criteria obtained in this Fuzzy Composite evaluation.

IV. CONCLUSION

The FCP composite structure had been developed whereby it consist of 15 first level indicators, 5 second level indicators, 2 third level indicators and the final indicators. Sensitivity analysis using 3 different set of weights revealed that Alternative 3 with water level value of 23.8m was frequently happened to be the best ranked alternative. The results from the sensitivity analysis showed that Alternative 3 was considered as the robust alternative.

The trade-off analyses using Fuzzy Composite Programming have several advantages especially in representing the uncertainties involve in solving the problems. The Fuzzy Composite structure was constructed to demonstrate the various related criteria involved. The uncertainties were incorporated using fuzzy membership function developed for each criteria. Fuzzy Composite Programming was preferred in solving problem under multicriteria environment as it allows the incorporation of uncertainty analysis for a wide variety of criteria and multi-objective related problem.

V. ACKNOWLEDGMENT

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