International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 8 (2019), pp. 1341-1349

Simulation Coupled Fuzzy-AHP Approach for Decision of Water Shortage Mitigation Strategies

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Abstract:

Proactive integrated water resources management (IWRM) requires prediction of future water resources situations and formulation of multisectoral and participatory long-term strategic development plans to cope up with the emerging situations. One of the challenges associated with the strategic planning is the establishment of priorities among competing water resources development options that takes into account social, environmental and economic decision parameters. Some of the decision parameters are difficult to quantify and hence they require incorporation of expert judgments. However, the imprecise nature of experts' judgments leads to the consideration of fuzzy set theory in solving water resources management decision problems. In this study, a simulation using Water Evaluation and Planning system (WEAP) coupled with Fuzzy Analytic Hierarchy Process (Fuzzy-AHP) multi-criteria decision analysis (MCDA) approach is proposed to prioritize and select the optimal water shortage mitigation strategies. WEAP simulation model is used to predict future water availability using feasible basin development scenarios. Then, Fuzzy-AHP multi-criteria decision analysis is conducted based on the simulation output and experts' opinion data obtained through questionnaires. The proposed methodology is applied to Awash river basin in Ethiopia to facilitate the decision-making process and to suggest the optimal water shortage mitigation measure.

Keywords: *Awash Basin, Fuzzy-AHP, IWRM, MCDA, Simulation, WEAP*

1. INTRODUCTION

1.1 Background

Simulation models are extensively used for water policy analysis. WATERWARE, AQUATOOL, RiverWare, WEAP -21 and MODSIM [1-5] are of the most extensively used simulation models through which decision makers can anticipate the performance of water resource systems under various management strategies [6]. However, simulation models demonstrate the impact of various strategies for multiple scenarios in an open-ended manner and they are not able to identify optimal policy. In order to determine the optimal decision variable, simulation outputs should be integrated with some form of optimization technique or multi-criteria decision analysis (MCDA) tools. Water Evaluation And Planning system (WEAP) is one of the most extensively used simulation models [6]. Recently, some global efforts have been made to link the WEAP model with MCDA tools in order to facilitate water resources management decision-making process. Integrated methodologies comprised of WEAP, SWAT and 'DEFINITE' (decisions on a finite set of alternatives) software package [7], indicator-based decisions using WEAP and MCDM methods including simple additive weighting (SAW), compromise programming (CP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [8], and the use of K-WEAP (Korea Water Evaluation and Planning System) in conjunction with the swing weight and SAW methods [9] are some of the previous relevant studies. Despite the efforts made by the various researches mentioned here and others, the search for standardized methodologies still continues.

One of the challenges associated with water management is the establishment of priorities among competing water resources development options in social, economic and environmental sectors. Some of the decision parameters especially in the social and environmental sectors are difficult to quantify and hence they require incorporation of expert knowledge and judgments. However, the imprecise nature of expert's judgments leads to the consideration of fuzzy set theory in solving water resources management decision problems. As a practical popular methodology for dealing with fuzziness and uncertainty in Multiple Criteria Decision-Making (MCDM), Fuzzy Analytic Hierarchy Process (Fuzzy-AHP) has been applied to a wide range of applications [10]. Even though very limited in number, some attempts have also been made to apply Fuzzy-AHP in the field of water resources management [11-13].

The objective of this study is to develop an approach to prioritize and select the optimal water shortage mitigation strategies by the coupling of WEAP simulation with Fuzzy-AHP MCDA tool. The study takes into account environmental, social and economic decision variables to define the optimal solution. The proposed methodology is applied to Awash River basin in Ethiopia as a case study.

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 8 (2019), pp. 1341-1349

1.2 Study Area

The study area is Awash River basin which is the fourth largest river basin in Ethiopia. The watershed area and the total length of the river are 114,000 km^2 and 1200 km respectively. Awash river basin is located in east-central Ethiopia. Its location map is shown in Fig. 1below.

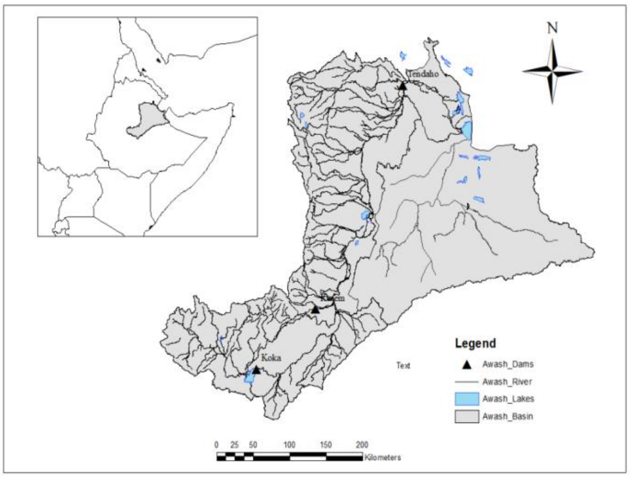

Fig.1. Map of the Awash River Basin, Ethiopia

2. MATERIALS AND METHODS

In this study WEAP model is used to simulate the water resources system in the basin and Fuzzy-AHP multi-criteria decision analysis is conducted to prioritize and select the optimal water shortage mitigation strategies. Accordingly, the simulation process and the multi-criteria decision analysis procedures are briefly presented below.

2.1 WEAP Simulation of the Water Resources System:

Water Evaluation And Planning system (WEAP) model is developed by the Stockholm Environment Institute (SEI). It integrates a range of physical hydrologic processes with the management of demands and installed infrastructure to construct simulations as a set of scenarios. Further details of WEAP model are provided in [4].

The simulation of the water resources system is conducted in two steps. First, the hydrologic processes of the basin are simulated to check the suitability of the model. Then, the basin's water resources management is modeled by setting different scenarios. The two stage simulation processes are described as follows:

2.1.1 Simulation of the Hydrologic Processes**:** The physical hydrology module of WEAP called the soil moisture method is used for simulation of Awash River basin water resources system at five selected flow gauge locations. Standard methods are used to prepare the hydro-metrological and land use input data for each sub-catchment. The water demand, reservoir data, loss rate, etc. are estimated using the data provided through various kinds of research and survey in Ethiopia [14-17]. Based on data availability, the time period (1986-2005) is selected for model calibration and validation. Initially, the model was set up using the default model parameters. Then, manual calibration is performed to reproduce the observed stream flow. The model-simulated values are compared with those obtained from observations using standard statistical tests on monthly and monthly average basis. A summary of the monthly simulation data and the corresponding results is presented in Table 1. From the Table, it is observed that the coefficient of determination (R^2) and the Index of Agreement (IA) show a good fit. Furthermore, the Nash-Sutcliffe efficiency (E) calibration and validation results are in the ranges of (0.54-0.86) and (0.55-0.93) respectively. This indicates that the model can be used to reasonably simulate the water resources system of the river basin.

2.1.2 Simulation of the Water Resources Management: In WEAP model, water resources management simulations are constructed as a set of scenarios. The year 2005 is used as a base year and the corresponding reference scenario is created using a 25-year time horizon (2006-2030) deterministically (i.e. using meteorological data of (1986-2005)).

Table 1. Summary of calibration and validation results

Nr.	Gauge Station	Melka Kuntre	Hombole	Kesem	Awash Station	Tendaho
1	Calibration (Validation) Duration	1986 -1995 (1996-2005)	1986 - 1993 (1994-2000)	1989 - 1995 (1996-2002)	1986 -1994 (1995-2003)	1988 - 1994 (1995-2001)
2	Nr. of Years	10 (10)*	8(7)	7 (7)	9 (9)	7(7)
3	Nr. of Months	120 (120)	96 (84)	84(84)	108(108)	84(84)
4	Statistical Parameter					
4.1	Coefficient of Determination (R^2)	0.88 (0.93)	0.86(0.91)	0.72 (0.93)	0.63(0.63)	0.59 (0.60)
4.2	Nash-Sutcliffe Efficiency E)	0.82 (0.93)	0.86 (0.80)	0.71(0.92)	0.54 (0.62)	0.56 (0.55)
4.3	Index of Agreement (IA)	0.96 (0.98)	0.96 (0.96)	0.92 (0.98)	0.88 (0.88)	0.83(0.86)

*Numbers in the brackets show the validation values

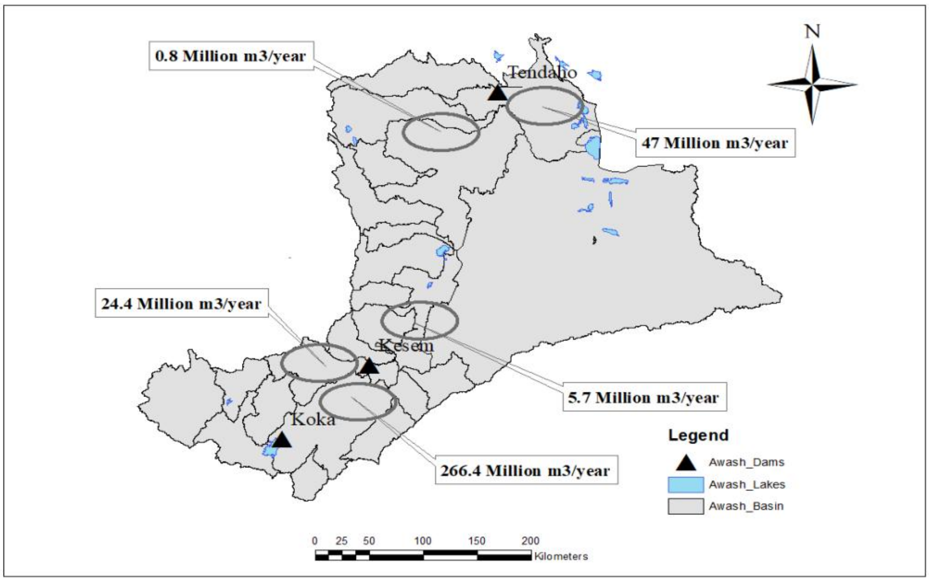

Fig. 2. Anticipated water shortage for each irrigation zone in the future (2028)

Water availability in the evaluation period (2006-2030) was assessed using future development scenarios. The irrigation area is estimated to grow from 49,695 ha at the base year 2005 to 144,980 ha at the year 2025. Domestic water demands of Nazareth, Metehara and Awash towns are projected using annual activity level growth rate of 4.2%. Mean annual environmental flows of 16.4 and 24.2 m^3/sec are also allocated at the reaches of Awash station and terminal Lake Abe respectively. The effect of the future scenarios on the hydrology of the basin is analyzed with respect to the monthly unmet demands at the irrigation zones. As a result, a total of 344.3 Mm^3 of water shortage is identified in the year 2028. The anticipated water shortage at each irrigation zone is shown in Fig. 2

2.2 Fuzzy-AHP Multi-Criteria Decision Analysis

Fuzzy-AHP methods are systematic approaches to the alternative selection and justification problem by using the concepts of fuzzy set theory and hierarchical structure analysis [18, 19]. The fuzzy-AHP analysis is conducted using a seven-step procedure. A brief description of the methodology is presented below.

2.2.1 Development of the Hierarchical Structure: An AHP model structure is configured into four levels comprised of criteria, sub-criteria and the alternatives which lead to the ultimate goal as shown in Fig. 3.

2.2.2 Identification of Alternatives: Ten (10) Long-term measures which mitigate the water shortage in the Awash River basin are defined mainly based on the recommendation of Awash River basin master plan study [14]. Seven (7) Alternatives are established from the combination of the long-term measures. Descriptions of the mitigation measures and the corresponding alternatives are presented in Table 2.

2.2.3 Definition of Criteria: The criteria used to assess each alternative are chosen in order to take into account the different economic, environmental, and social consequences of water shortage mitigation measures adopted in each alternative and they are presented as follows:

I. Economic Criteria:

a) Construction cost is the present worth in Billions of Ethiopian Birr (B.ETB).

b) Estimated damage is computed by multiplying the unmet agricultural water demand (Mm^3) by the cost of water in the Awash basin, 0.003 ETB/m^3 [20].

II. Environmental Criteria:

c) Sustainability is a qualitative criterion taking into account the different sustainability degrees of each alternative.

d) Environment-friendly is a qualitative criterion taking in to account the different degree of impact upon the environment

III. Social Criteria:

e) Water shortage duration is expressed as the number of months with water shortage and it is computed from the WEAP model simulation outputs.

f) Job opportunity is a qualitative criterion taking into account the increase in employed persons during all phases of implementation of the alternatives.

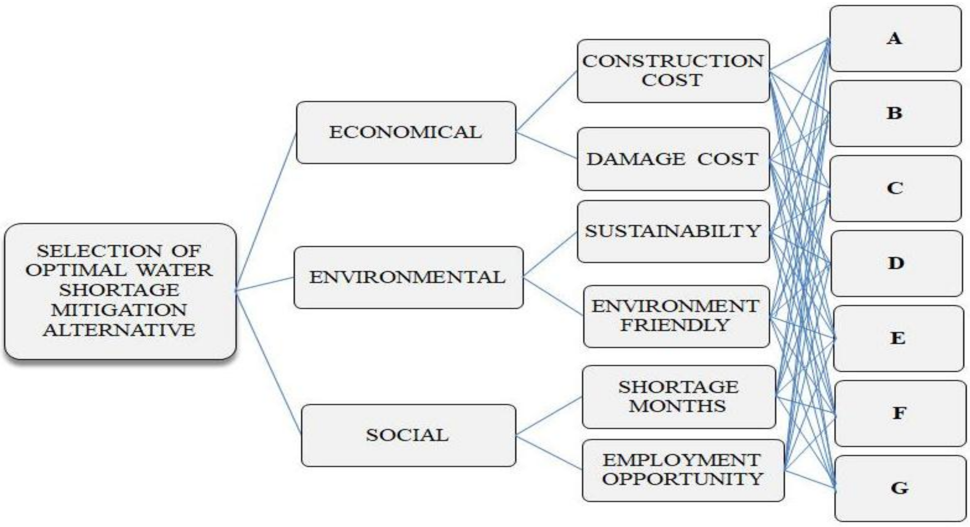

Fig. 3. Analytic Hierarchical Process (AHP) structure

Table 2. Water shortage mitigation measures and alternatives

Nr	Mitigation Measures	Target	Alternatives						
			A	B	C	D	E	F	G
1	Capacity Building in Water Resources Manag-ement	Improved irrigation practices & management awareness	x	x	x	x	x	x	x
2	Urban Water Demand Management: (water leakage detection and improved water supply distribution system)	10% loss reduction	x	x	x	x	x	x	x
3	Improvements in Agricultural Water Use Efficiencies: (through canal lining, land levelling and application of hydroflumes & siphons at the private and communal furrow irrigation schemes)	10% efficiency improvement	x	x	x	x	x	x	x
4	Conversion from Furrow to Sprinkler Irrigation: (on about 21,000 ha sugarcane plantation)	15 % irrigation efficiency improvement	x						
5	Raising the Top Water Level of Koka Dam by 1m	Adds 178 Mm^3 to the storage capacity and increase the reservoir life by about 7 years.		x					
6	Raising the Top Water Level of Koka Dam by 3m	Adds 615 Mm^3 to the storage capacity and increase the reservoir life by about 25 years.			x				
7	Construction of New Dam above Koka dam: (Melka Kuntre Dam).	To store about 310 Mm^3 of water				x			
8	Conjunctive Use of Surface and Groundwater: (through development of 120 deep wells)	To produce about 130 Mm^3 supplementary groundwater					x		
9	Water Transfer: (Muger – Awash interbasin transfer system)	To transfer 269 Mm^3 water						x	
10	Construction of New Dam below Koka dam: (Awash Compensation Dam)	To store 312 Mm^3 of water							x

2.2.4 Construction of Linguistic and Crisp Matrices: A multi-criteria decision analysis using AHP and Fuzzy-AHP methods requires construction of pair-wise comparison matrices. In this study, the input data for the matrices are comprised of qualitative and quantitative parameters. For the qualitative aspects, the weights are assessed by pair-wise comparison through questionnaires from 23 water resources experts. Each expert was asked to express the relative importance of two decision elements from the same level of the hierarchical structure using a five-point linguistic and crisp number scale using Table 3 adopted from [21,24]. Regarding the quantitative aspects, the present worth of each alternative is estimated using available data. Estimations of the number of water shortage months and the corresponding unmet demand which later converted to cost of damage are computed using the simulation outputs. The estimated quantitative parameters are summarized and presented in Table 4. After estimating the values of the three quantitative parameters for each alternative, cost and month ratios are calculated using pair wise comparisons. Each ratio is further converted to the equivalent five-point number scale using Table 3.

2.2.5 Consistency Test: The experts' judgement matrices are analyzed for consistency. The Consistency Index (CI) and the Consistency Ratio (CR) are calculated as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (1)$$

$$CR = \frac{CI}{RI} \quad (2)$$

Where: λ_{max} is the largest eigenvalue of the matrix, n is the matrix size and RI is a random index which can be obtained from Table 5 for different n values. For a judgement matrix to be consistent, CR should not exceed 0.10. If it is more, the judgement is inconsistent and hence it should be reviewed and improved [21]. However, practically as the matrix size increases the degree of inconsistency also increases. Some studies also indicated that a CR of less than 0.20 is considered tolerable [22]. For our study, the responses being taken over from a wide range of experts from various fields, a consistency ratio up to 0.23 is tolerated in some cases.

2.2.6 Formulation of Aggregated Fuzzy Matrices: consistent crisp matrices from section 2.2.5 are transformed into the corresponding triangular fuzzy scale using Table 3. And then, the aggregated experts' opinions matrices are determined using the aggregation of individual judgments (AIJ) procedure [23]. In this method, each decision maker conducts the pairwise comparisons by himself. Afterwards the (weighted) geometric mean method could be used to obtain the group judgment for each entry of the comparison matrices.

Table 3. Description of AHP scale

Linguistic Scale	**Saaty Scale**	**Triangular Fuzzy Scale**	**Triangular fuzzy reciprocal**
Just equal	1	(1,1,1)	(1,1,1)
Weakly Important	3	(1, 3/2, 2)	(1/2, 2/3, 1)
Strongly more Important	5	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very Strongly more Important	7	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Absolutely more important	9	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

Note: the AHP scale is adopted from Saaty (1987) and the Fuzzy AHP conversion is from Chang (1992)

Table 4. Summary of quantitative input data for pair-wise comparison matrix

Alternative	Parameter Values Before and After Mitigation Measures						
	Construction cost (B.ETB)	Unmet Demand (Mm^3)		Damage Cost (M.ETB)		Nr. of Shortage Months	
		Before	After	Before	After	Before	After
A	6.636	344.3	104.1	1.033	0.31	6	2
B	0.871	344.3	118.8	1.033	0.36	6	3
C	0.965	344.3	76.3	1.033	0.23	6	2
D	2.223	344.3	96.7	1.033	0.29	6	3
E	1.628	344.3	51.15	1.033	0.15	6	2
F	17.067	344.3	134.7	1.033	0.40	6	4
G	2.878	344.3	53.24	1.033	0.16	6	1

Table 5. Random Index (RI)

N	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.96	1.12	1.24	1.32	1.41	1.45	1.49	1.51

2.2.7 Calculation of Fuzzy Priority Weights: The fuzzy priority weights of the decision elements are calculated based on the Chang's extent analysis method [19, 24]. Let X = {x_1, x_2,... , x_n} be an object set and U = {U_1, U_2,... , U_m} be a goal set. According to this method, each object is taken and extent analysis for each goal, g_i is performed, respectively. Therefore, *m* extent analysis values for each object can be obtained, with the following signs:

$M^1_{gi}, M^2_{gi} \ldots M^m_{gi}$, $i=1, 2, \ldots, n$ Where all M^j_{gi} (j= i=1, 2,.., m) are Triangular Fuzzy Numbers (TFNs).

The four steps of Chang's extent analysis method are as follows:

Step 1. The value of fuzzy synthetic extent with respect to i^{th} object is defined as

$$S_i = \sum_{j=1}^{m} M^j_{gi} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M^j_{gi} \right]^{-1} \quad (3)$$

To obtain $\sum_{j=1}^{m} M^j_{gi}$, perform the fuzzy addition operation of *m* extent analysis values for a particular matrix such that

$$\sum_{j=1}^{m} M^j_{gi} = \left[\sum_{j=1}^{m} l_i \,,\ \sum_{j=1}^{m} m_i \,,\ \sum_{j=1}^{m} u_i\right] \quad (4)$$

And to obtain $\left[\sum_{j=1}^{n} \sum_{j=1}^{m} M^j_{gi}\right]^{-1}$,

perform the fuzzy addition operation of M^j_{gi} ($j= i=1, 2, \ldots, m$) values such that

$$\sum_{i=1}^{n} \sum_{j=1}^{m} = \left[\sum_{i=1}^{n} l_i \,,\ \sum_{i=1}^{n} m_i \,,\ \sum_{i=1}^{n} u_i\right] \quad (5)$$

and then compute the inverse of the vector in Eqn. 5 such that

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M^j_{gi} \right]^{-1} = \left[\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right] \quad (6)$$

Step 2. The degree of possibility of

$M_2 = (l_2 \ , m_2 \ u_2 \ ) \ \geq \ M_1 = \ (l_1 \ , m_1 \ u_1 \ )$ is defined as

$$V(M_2 \geq M_1) = \sup_{y \geq x} \left[\min\left(\mu_{M1}(x), \mu_{M2}(y)\right)\right] \quad (7)$$

And can be equivalently expressed as follows:

$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) =$

$$\mu_{M2}(d) = \begin{cases} 1, & \text{if } m_2 \geq m_1 \\ 0, & \text{if } l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{otherwise} \end{cases} \quad (8)$$

Where d is the ordinate of highest intersection point D between μ_{M1} and μ_{M2} (Fig. 4)

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

Step 3. The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i = (i = 1,2,….,k) can be defined by $V(M \geq M_1, M_2, \ldots \ldots, M_k)$

$$= [(M \geq M_1) and\ (M \geq M_2) and \ldots and\ (M \geq M_k)] \quad (9)$$

= min $V(M \geq M_i)$, i = 1, 2,…,k

Assume that $d'(A_i) = \min V(S_i \geq S_k)$ (10)

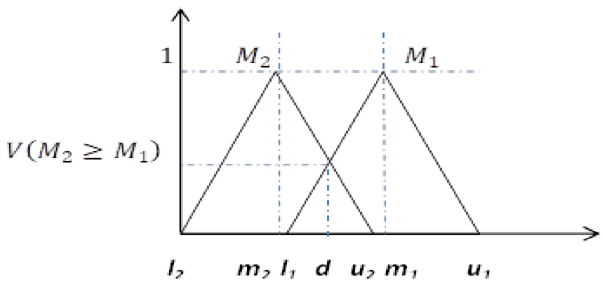

Fig. 4. The intersection between M_1 and M_2

For k = 1,2,….,n; $k \neq i$, Then the weight vector is given by

$$W' = \left(d'(A_1), d'(A_2), \ldots, d'(A_n)\right)^T$$

Where $A_i (i = 1,2, \ldots, n)$ are n elements (11)

Step 4. Via normalization, the normalized weight vectors are

$$W = \left(d(A_1), d(A_2), \ldots, d(A_n)\right)^T$$

Where W is a nonfuzzy number (12)

The above steps are demonstrated using selected fuzzy evaluation matrices as follows:

From Table 6,

S_E = (2.74, 3.03, 3.37) ⊗ (1/10.06, 1/9.02, 1/8.13)
= (0.27, 0.34, 0.41)

S_{En} = (2.85, 3.15, 3.46) ⊗ (1/10.06, 1/9.02, 1/8.13)
= (0.28, 0.35,0.43)

S_S = (2.54, 2.83, 3.23) ⊗ (1/10.06, 1/9.02, 1/8.13)
= (0.25, 0.31, 0.40) are obtained.

Using these vectors,

V ($S_E \geq S_{En}$) =0.91, V ($S_E \geq S_S$) =1.00, min=0.91

V ($S_{En} \geq S_E$) = 1.00,V ($S_{En} \geq S_S$) =1.00, min=1.00

V ($S_S \geq S_E$) =0.85, V ($S_S \geq S_{En}$) = 0.76, min=0.76

Via normalization, the weight vector of the three main criteria with respect to the goal is is calculated as:

$W_G = (0.34, 0.37, 0.29)^T$.

From Table 7,

S_{CC} = (1.68, 1.82, 1.99) ⊗ (1/4.46, 1/4.04, 1/3.69)
= (0.38, 0.45, 0.54)

S_{DC} = (2.01, 2.22, 2.46) ⊗ (1/4.46, 1/4.04, 1/3.69)
= (0.45, 0.55, 0.67) are obtained.

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 8 (2019), pp. 1341-1349

Table 6. The fuzzy evaluation matrix of the criteria with respect to the goal (Aggregated Individual Judgement (AIJ))

	Economic/E	Environmental/En	Social/S	Fuzzy sum of each row		
Economic/E	(1,1,1)	(0.84,0.94,1.05)	(0.9,1.1,1.32)	2.74	3.03	3.37
Environmental/En	(0.95,1.07,1.19)	(1,1,1)	(0.9,1.09,1.28)	2.85	3.15	3.46
Social/S	(0.76,0.91,1.12)	(0.78,0.92,1.11)	(1,1,1)	2.54	2.83	3.23
			Total	8.13	9.02	10.06

Table 7. Evaluation of the sub-attributes with respect to economic criteria (Aggregated Individual Judgement (AIJ))

	Const. Cost /CC	Damage Cost /DC	Fuzzy sum of each row		
Construction Cost /CC	(1,1,1)	(0.68,0.82,0.99)	1.68	1.82	1.99
Damage Cost /DC	(1.01,1.22,1.46)	(1,1,1)	2.01	2.22	2.46
		Total	3.69	4.04	4.46

Table 8. Evaluation of the Alternatives with respect to Sustainability (W_{SS}) (Aggregated Individual Judgement (AIJ))

	A	B	C	D	E	F	G
A	(1,1,1)	(4/5,1,5/4)	(3/4,7/8,1)	(3/5,3/4,1)	(7/8,10/9,4/3)	(4/3,5/3,2)	(3/5,3/4,1)
B	(4/5,1,5/4)	(1,1,1)	(2/5,1/2,5/7)	(1,10/9,11/8)	(2/3,5/6,1)	(3/4,1,6/5)	(1,10/9,11/8)
C	(1,8/7,4/3)	(7/5,2,17/7)	(1,1,1)	(7/8,8/7,3/2)	(5/6,1,5/4)	(7/9,1,9/7)	(7/8,8/7,3/2)
D	(1,4/3,5/3)	(3/4,1,10/9)	(2/3,7/8,8/7)	(1,1,1)	(2/3,6/7,1)	(8/9,1,5/4)	(1,1,1)
E	(3/4,1,8/7)	(1,6/5,3/2)	(4/5,1,6/5)	(1,7/6,3/2)	(1,1,1)	(1,8/7,3/2)	(1,7/6,3/2)
F	(1/2,3/5,3/4)	(5/6,1,4/3)	(7/9,1,9/7)	(4/5,1,10/9)	(2/3,7/8,10/9)	(1,1,1)	(4/5,1,10/9)
G	(1,4/3,5/3)	(3/4,1,10/9)	(2/3,7/8,8/7)	(1,1,1)	(2/3,6/7,1)	(8/9,1,5/4)	(1,1,1)

Using these vectors,

$V(S_{CC} \geq S_{DC}) = 0.47$, $V(S_{DC} \geq S_{CC}) = 1.00$ are obtained.

Thus, the weight vector of the economic sub-criteria is calculated as $W_E = (0.32, 0.68)^T$.

Similarly, the weight vector from Table 8 is calculated as $W_{SS} = (0.14, 0.12, 0.18, 0.14, 0.16, 0.12, 0.14)^T$

Generally, the process started with the calculation of the weight vector of the main criteria with respect to the goal. Then, using similar procedure, the weight vectors of the sub-criteria and the alternatives are obtained with respect to each of the main criterion and sub-criterion respectively.

3. RESULTS & DISCUSSION

In this study, a new decision-making approach is developed by the coupling of WEAP simulation with Fuzzy-AHP using Chang's extent analysis method as the solving procedure. The input matrices, Fuzzy-AHP solutions, computation of the consistency ratio and priority weights are all done in Microsoft Excel workspace. The overall synthesized priorities of proposed strategies are presented in Table 9.

According to the synthesized priorities of the main criteria, "Environmental criterion" with a weight of 0.37 has the highest ranking. Thereafter "Economic criterion" with a weight of 0.34 comes in second place. Whereas, with a weight of 0.29 "Social criterion" has the lowest ranking. The result shows that "Environmental factors" should be considered as a priority in order to select the water shortage mitigation measures. According to the synthesized priorities of the sub-criteria, 'cost of estimated damage', took priority over 'cost of construction' with regard to economic criteria. 'Sustainability' took priority over 'Environment-friendly' with regard to environmental criteria. And 'Number of water shortage months' took priority over 'Job opportunity' with regard to social criteria. The overall evaluation of alternatives shows that "Alternative G" (an integrated activity of capacity building, urban water demand management, improvements in agricultural water use efficiency and construction of new dam below Koka dam) is selected as an optimal alternative. The water transfer alternative "Alternative F" is ranked last.

Table 9. The Overall Synthesized Priorities

	Construction Cost	Damage Cost		Priority	
Weight	0.32	0.68		Weight	
Alternatives					
A	0.00	0.03		0.020	
B	0.25	0.00		0.082	
C	0.27	0.17		0.202	
D	0.16	0.11		0.127	
E	0.21	0.34		0.302	
F	0.00	0.00		0.000	
G	0.11	0.34		0.268	
	Sustainability	Environment Friendly		Priority	
Weight	0.62	0.38		Weight	
A	0.14	0.36		0.228	
B	0.12	0.22		0.160	
C	0.18	0.00		0.112	
D	0.14	0.00		0.085	
E	0.16	0.36		0.235	
F	0.12	0.06		0.095	
G	0.14	0.00		0.085	
	Shortage Months	Employment Opportunity		Priority	
Weight	0.77	0.23		Weight	
A	0.15	0.00		0.112	
B	0.00	0.00		0.000	
C	0.15	0.12		0.139	
D	0.00	0.40		0.092	
E	0.15	0.00		0.112	
F	0.00	0.09		0.021	
G	0.56	0.40		0.522	
	Economical	Environmental	Social	Priority	Rank
Weight	0.34	0.37	0.29	Weight	
A	0.020	0.228	0.112	**0.124**	**4**
B	0.082	0.160	0.000	**0.088**	**6**
C	0.202	0.112	0.139	**0.150**	**3**
D	0.127	0.085	0.092	**0.101**	**5**
E	0.302	0.235	0.112	**0.223**	**2**
F	0.000	0.095	0.021	**0.042**	**7**
G	0.268	0.085	0.522	**0.272**	**1**

Practical consideration of the proposed alternatives shows that "Alternative G" has an advantage over the others due the location of the new dam which maximizes the water supply of the nearby irrigation schemes through storing the releases and spills from Koka dam. On the other hand, the water transfer scheme "Alternative F", is far from the irrigation schemes and it is the most expensive option. In this regard, the prioritization result is reasonable and acceptable.

4. CONCLUSION

The newly developed method presented in this paper addresses the proactive, multi-disciplinary and participatory nature of the IWRM decision making process. Moreover, the decision makers' and experts' uncertainty during subjective judgement has been dealt with a fuzzy approach. The proposed method is applied in Awash river basin as a case study and the result is found to be valid. Hence, it is suggested here that the method can be applied to facilitate decisions of strategic planning both in the case study basin and other river basins worldwide.

Acknowledgments

This paper is part of the larger PhD research program funded by the Egyptian government through the bilateral cooperation project in the field of water resources between the Ministry of Water Resources and Irrigation of the Arab Republic of Egypt and the Ministry of Water, Irrigation and Energy of the Federal Democratic Republic of Ethiopia. The authors are grateful for the assistance provided by the two Ministries, the Nile Water Sector and specially the focal person Eng. Noha Mohamed Nasralla.

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