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Technical note:

Water conservation in Kuwait: A fuzzy analysis approach

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Abstract

In an arid country like Kuwait with harsh and hot climate conditions, the scarcity of fresh water supplies presents a serious threat to sustainable socio-economic development and growth. Kuwait is an oil rich country with capital abundance and coastal locations enabled it to build desalination plants for fresh water production that is sold to the customers at highly subsidized prices. However, due to the sharp increase in population, and misuse of fresh water, there are shortages in water supply. Therefore, Kuwait should take appropriate measures to tackle this problem. This study examines the different course of actions required for water conservations by soliciting water experts' opinion. The problem is complex in nature, it constitutes a multi-criteria decision making problem since it comprises several criteria. The Fuzzy Analytical Hierarchy Process (FAHP) is utilized as a decision tool for finding the best course of actions to bring about water conservation. In this work, three factors are considered along with six water conservation policies.

Keywords: Water conservation; Fresh water production; Multi-criteria decision making; Fuzzy numbers

1. Introduction

Kuwait is situated at the northern edge of Arabian Peninsula at the head of the Arabian Gulf, a shallow semi-enclosed marginal sea with less than 100 m in depth. The climate in Kuwait is among the harshest in the world; where the temperature surpasses 50 degrees Celsius in the summer. The total area of Kuwait is around 17,818 km^3 of extremely arid zones.

Kuwait has a small, relatively open economy dominated by an oil industry and government sector. The proved crude oil reserves of the country is about 10 of the world reserves accounting for nearly half of the GDP, and 95% of export revenues. Over the last three decades, Kuwait has witnessed an unprecedented economic and social transformation, since a large portion of the oil revenues has been used to modernize the infrastructure and improve the living standards of the population. Water supply and sanitation services have been made accessible to a large percentage of the population where life expectancy has increased by 10 years, and illiteracy rate has declined significantly. In addition, all services are provided at highly subsidized prices, in economics where direct and indirect taxes play a marginal role as sources of government revenues.

Kuwait suffers from an acute shortage of potable water resources, where the average annual rainfall ranges from 70 to 130 mm. This scarcity problem if not solved, could eventually lead to a severe shortage in water supply. Compared to international standards, where the required sustainable amount of water per person is restricted to be around 1000 cubic meters (m^3), Kuwaiti national would get far less.

The existing reserves of water resources are gradually dwindling with consumption rates increasingly surpassing replenishment rates. The ground water recharge is around 160 million cubic meters per year. Hence, the search for more water resources presents Kuwait with real challenges. Developing and maintaining a continuous and secure supply of water in Kuwait is a vital pre-requisite for

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the country's socioeconomic development plans.

Water demand has increased dramatically due to the increase in population, improvements in the standard of living, industrial development, and food-self sufficiency.

Water production has increased from 43,341 million imperial gallons to 105,708 million imperial gallons (MIG) during the period 1992-2004 while water consumption increased from 42,341 MIG to 104, 680 MIG during the same period as shown in Figure 1 [14].

On the other hand, the daily average consumption has increased from around 116 MIG to 286 MIG during 1992-2004; details are shown in Figure 2 [14].

The residential sector consumes the highest amount of water (69%), followed by the governmental sector (public services and buildings), and the industrial sectors. Figure 3 [14] presents the water consumption distribution by sector in percentage (others stands for water distributed by tankers to houses and building that are not in pipe network).

The daily fresh water consumption by individuals (per capita) in Kuwait is one of the highest in the world. Table 1 lists the daily per capita consumptions in liters for several countries of the world [22]. Kuwait comes in fourth in daily per capita consumption after Qatar, United Arab Emirates (UAE), and Bahrain, while its consumption is higher than most advanced countries, this might be attributed to wastage and improper water consumption.

Moreover, the demand for fresh water is projected to increase substantially from 119,680 MIG to 459,360 MIG during 2005-2025 as shown in Figure 4 [14]. Meanwhile, the daily per capita consumption in liters (l/c/d) will rise from 542 to 785 during the same period. In order to compensate for the shortages in natural water resources and the increasing in water demand, Kuwait has resorted to building water desalination plants and wastewater treatment plants.

The cost of producing was around 1.98 $/m^3$ while the average revenue was around 0.19 in 2002. In Kuwait, water is highly subsidized; in 2002 it constituted 2.4% of the GDP, and 5.9% of the oil export revenue [15]. The total amount of subsidy during 2004-2005 was around $ 868 (Table 2).

2. Ground water

The principle ground water resource in Kuwait is contained with Dammam aquifer, a non renewable resource, which is recharged through underflow from Saudi Arabia and Iraq. However, this resource is relatively saline and not suitable for potable use, but can be used for agricultural purposes. As for fresh underground water, limited quantities were discovered at both Rawadatain and Um-Al-Aish fields. Pumping operations commenced in 1962, the estimated natural reserve of both fields is about 40,000 imperial gallons.

3. Desalination

Due to the increasing shortages in non-renewable water resources, Kuwait has an established policy of providing the principal municipal/ industrial supply of water from desalination of water diverted from the sea for the past 20-30 years, an activity that will increase as population grows. Financial costs from desalination plants (not including distribution cost) is $0.7 per cubic meter in USA, while in Kuwait, it is around $ 1-$ 2 per cubic meter. Table 3 shows the installed and planned desalination capacity during 1980-2009, it also presents the total distilled water and fresh water produced in the same period [14].

Multi-Stage-Flash (MSF) is the desalination process primarily used in Kuwait. It is an established technology and is combined with cogeneration of electricity which greatly improves the economics of desalination. However, Reverse Osmosis (RO) technologies have also been gradually adopted with some very large plants now in operation in the region.

The primary fuels used for desalination are petroleum and natural gas, reserves that are abundant in Kuwait. The consumption of desalinated water in Kuwait accounts for over 60% of the total water produced.

Higher seawater salinity will reduce the desalination plant's recovery ratio, and hence increase the cost of desalinated water.

The cost of desalinated water is high; it varies with the technology used, scale, and age of the plant. The capital cost is around $1.4 - 2.0/m^3$ for smaller desalination plants that produce 10,000m^3/day or less, while it falls to around $ 0.7-1.3/ m^3 for larger desalination plants having a capacity of 20,000m^3/day. Salinity level of seawater in Kuwait is around 45,000 mg/l of total dissolved solids (TDS).

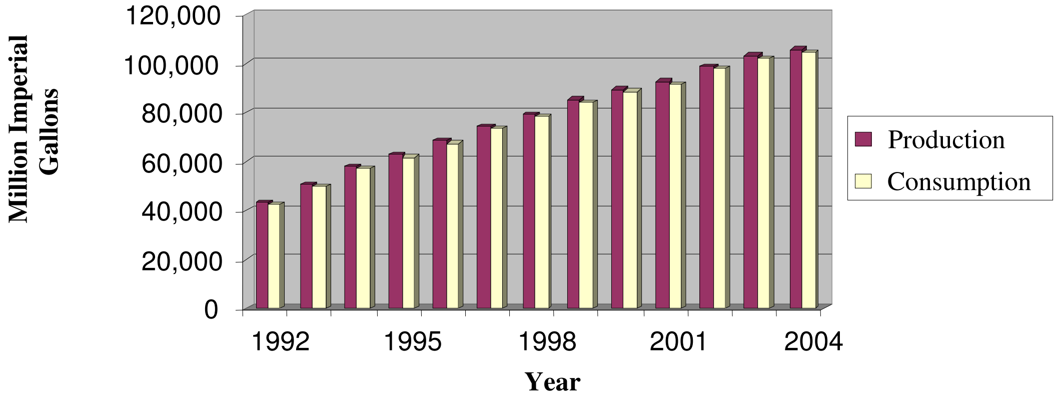

Figure 1. Water production and consumption in million imperial gallons.

Source: Ministry of Energy Statistical Yearbook, Water 2005.

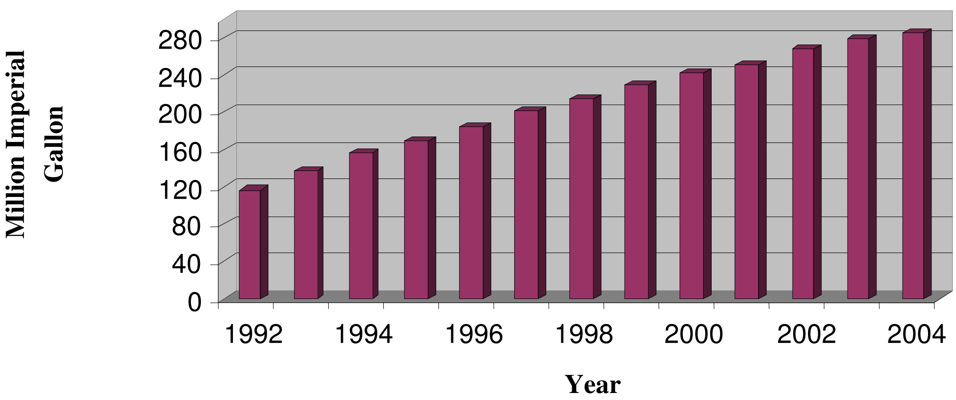

Figure 2. Daily average consumption in million imperial gallons.

Source: Ministry of Energy Statistical Yearbook, Water 2005.

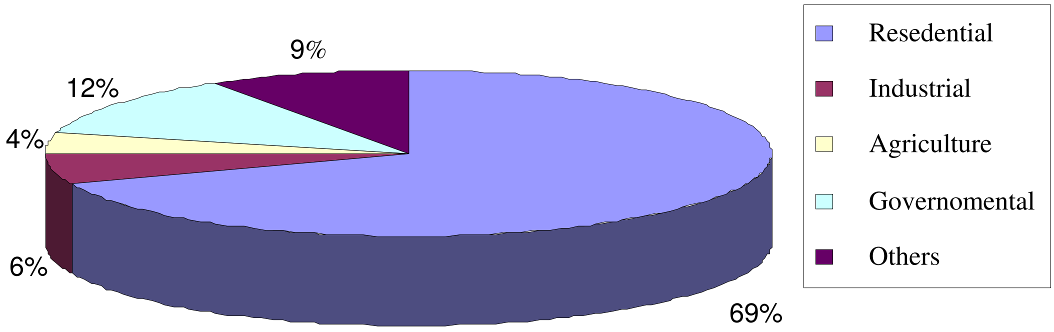

Figure 3. Water consumption per sector in percentage.

Source: Ministry of Energy Statistical Yearbook, Water 2005.

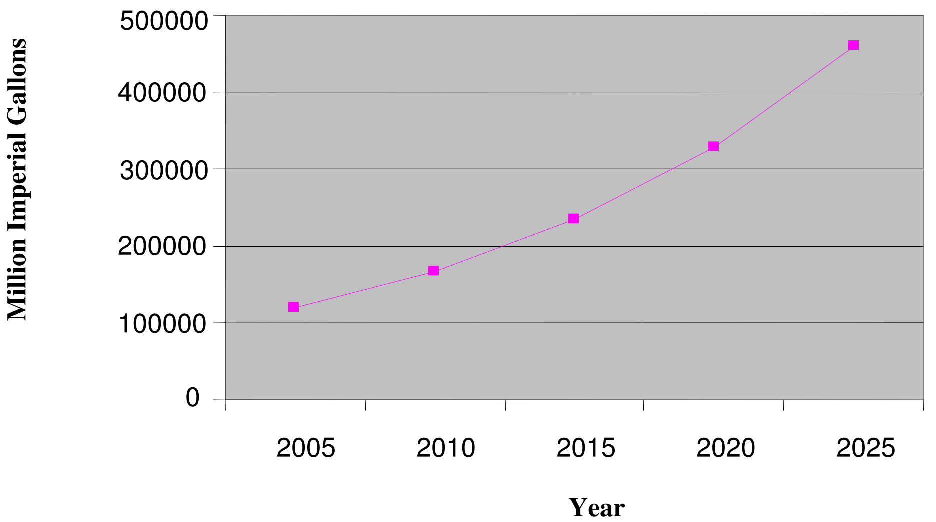

Figure 4. Projected water demand in million imperial gallon.

Source: Ministry of Energy Statistical Yearbook, Water 2005.

Table 1. Comparison of freshwater consumption in liters per capita per day (l/c/d) between Kuwait and some selected countries.

Country	l/c/d
Tunisia (2002)	106
Western Australia (2003)	411
Ontario, Canada (2003)	215
England (1997)	141
Germany (1997)	129
Fukuoka, Japan (2000)	307
Bahrain (2002)	511
Kuwait (2002)	503
Oman (2002)	203
Qatar (2002)	744
Saudi Arabia (2002)	300
UAE (2002)	630
U.S.A (2002)	333
France (2003)	130

Source: Working party on Economic and Environment integration, "Household Water, Pricing in OCED Countries", OCED, 1999.

Table 2. Water subsidy in Kuwaiti Dinars (KD) by sector during 2004-2005.

Sector	Subsidy (Million KD***)
Residential	166.6
Industrial	26.1
Agriculture	12.9
Government*	38.8
Others**	18.9
Total	**263.2**

*Government, Public Utilities, and Water Production Stations).

**Water Supply Stations (Tankers).

*** KD= Kuwait Dinar = $ 3.3.

Source: Ministry of Planning, Kuwait Five Years Development Plan (2002/2003- 2005/2006).

Table 3. Installed and planned capacity of desalination plants in Kuwait during 1980-2009.

Year	Installed Capacity MIGD	Mm^3	Gross Production Distilled Water MIG	Mm^3	Gross Production Of Fresh Water MIG	Mm^3
1980	100	0.45	21298	98.8	23480	98.8
1985	215	0.98	34398	156.4	37241	169.3
1990	252	1.15	44454	202.1	47548	202.1
1995	286.8	1.15	57367	260.8	61546	260.8
2000	315.6	1.30	82455	374.8	88475	374.8
2001	315.6	1.43	84815	385.5	91535	385.5
2002	315.6	1.43	90668	412.1	97640	412.1
2003	315.6	1.43	94785	430.8	102057	463.9
2004	315.6	1.43	97469	443.0	104675	475.8
2005	317.1	1.44				
2006	355.6	1.62				
2007	447.5	2.03				
2008	462.5	2.10				
2009	462.5	2.10				

Source: Ministry of Energy Statistical Yearbook, Water 2005.

Table 4. Capacity and expansion of major wastewater treatment plants, $1000m^3$/day.

Plant	2003 Capacity $1000m^3$/day	2005	2010	2015	2020
Aridya/Suaybia	399	425	445	470	500
Rikka	126	146	177	202	220
Jahra	95	105	113	123	125
Um al Hayman	87	87	87	87	87
Total	**707**	**763**	**822**	**822**	**932**

Table 5. AHP scale of preferences in the pair-wise comparison process.

Numerical Ratings	Verbal Judgments of Preferences between Alternative *i* and Alternative *j*
1	*i* is equally preferred to *j*
3	*i* is slightly more preferred than *j*
5	*i* is strongly more preferred than *j*
7	*i* is very strongly more preferred than *j*
9	*i* is extremely more preferred than *j*
2,4,6,8	Intermediate values

4. Wastewater treatment and reuse

In order to meet the rapid expansion of urban areas and increasing population growth, Kuwait has build wastewater treatment plants, rigorously and safely to treat sewage after collection for reuse. Huge investments are made in order to expand the coverage of sewage treatment systems. On the basis of the amount of treated seawater compared to the total produced drinking water, the coverage rate of sewage collection and treatment system is in the range of 20-40%, lagging far behind water supply services by 80-90%. Kuwait covers 60% of its water supply through this system and plans to increase its supply from 260 MCM to 340 MCM by 2020. Table 4 gives the quantity of treated wastewater produced and reused in Kuwait.

5. The Analytic Hierarchy Process (AHP)

The analytic hierarchy process (AHP) was developed by Thomas Saaty in 1970's. It is widely used for multi-criteria decision making and has been successfully applied to many practical decision making problems. Mustafa and Ryan (1990) used AHP for as a decision support system for bid evaluation. Tiwari and Banerjee (2001) proposed the use of the AHP process as a decision support system for the selection of a casting process, and Kamal (2001) used AHP to select the most suitable contractor in the pre-qualification of process of a project. Chandra and Schall (1988) used AHP for economic evaluation of flexible manufacturing system using the Leontif input-output model. Hajeeh and Al-Othman (2005) applied AHP for desalination plant selection.

In the AHP, the decision problem is structured hierarchically at different levels, each the level consisting of finite number of elements. The relative importance of the decision elements (the weights of the criteria and the scores of the alternatives) is assessed directly from the comparison judgements. Pair-wise comparisons in AHP assume that the decision maker can compare any two elements $E_{i,} E_j$ at the same level of the hierarchy and provide a numerical value a_{ij} for the ratio of their preference (importance), if E_i is preferred to E_j then $a_{ij}> 1$. Correspondingly, $a_{ji} = 1/ a_{ij}$ and $a_{ii} =1$ for $i,j =1,2,\ldots,n$.

Each set of comparisons for a level with n elements requires n $(n-1)/2$ judgments, which are further used to construct positive reciprocal matrix of pair-wise comparisons $A = [a_{ij}]$. The priority vector $w = (w_1, w_2,.., w_n)^T$ may be obtained from the comparison matrix by applying some prioritization method. AHP has three underlying concepts: structuring the complex decision problem as a hierarchy of goal, criteria, and alternatives, pair-wise comparisons of elements at each level of the hierarchy with respect to each criterion on the preceding level, and finally vertically synthesizing the judgments over the different levels hierarchy (1980).

6. The Fuzzy Analytic Hierarchy Process (FAHP)

The AHP method cannot straightforwardly be applied to solving uncertain decision problems and imprecisely defined ones. In this case, a natural way to cope with such uncertain judgments is to the comparison ratios as fuzzy judgments as fuzzy sets or fuzzy numbers. The fuzzy set theory was proposed by Zadeh (1965), and Bellman and Zadeh (1970) described the decision making method in fuzzy environment. Laarhoven and Pedrycz (1983) proposed the first studies that applied fuzzy logic principle to AHP. Buckley (1985) initiated trapezoidal fuzzy numbers to express the decision maker's evaluation on alternatives with respect to each criterion while Laarthoven and Pedrycz were using triangular fuzzy numbers. Chang (1996) introduced a new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pair-wise comparison scale of fuzzy AHP, and with use the extent analysis method for the synthetic extend values of the pair-wise comparison (2003).

Deng (1999) presented a fuzzy approach for tackling qualitatitive multi-criteria problems in a simple and straightforward manner. Zhu *et al.* (1999) proved the basic theory of the triangular fuzzy number and improved the formulation the triangular fuzzy number's size. Enea and Piazza (2004) focused on the constraints that have to be considered within fuzzy AHP. They used constrained fuzzy AHP in project selection. Kahraman *et al.* (2004) used the fuzzy AHP for comparing catering firms in Turkey.

Tang and Beynon (2005) used fuzzy AHP for the development and application of a capital investment study. They tried to select the type of fleet car to be adopted by a car rental company. Tolga *et al.* (2005) used fuzzy replacement analysis and AHP in the selection of operating system. Chan and Kumar (2005) proposed a model for providing a framework for an organization to select the global supplier by considering risk factors. They used fuzzy extended AHP in the selection of global supplier in the current business scenario.

FAHP approach is based on fuzzy concepts with was proposed by Lofti Zadeh. Fuzzy sets and logic are powerful mathematical tools modeling uncertain systems in many scientific, economic, and social fields; and are facilitators for common-sense reasoning in decision making in the absence of complete and precise information. A fuzzy set is an extension of a crisp set; crisp sets only allow full membership or non-membership at all, whereas fuzzy sets allow partial memberships. Zadeh, proposed to use values ranging from 0 to 1 for showing the membership of the objects in a fuzzy set. Here, complete membership is represented as 1 and complete non-membership as 0. Values between 0 and 1 represent intermediate degrees of membership.

Fuzzy numbers are a special form of fuzzy sets, a fuzzy number is a fuzzy quantity $\tilde{N}$ that represents a generalization of a real number *r*, thus is used to approximate *r*. A fuzzy number $\tilde{N}$ is a convex normalized fuzzy set (Nguyen and Walker (2000). A fuzzy number is characterized by a given interval of real numbers, each grade of membership between 0 and 1.

Triangular fuzzy numbers (TFN) are used in this study; Triangular fuzzy numbers are a special case of fuzzy number (1980). A triangular fuzzy number $\tilde{N}$ is defined by three real numbers, expressed as (*l*,*m*,*u*), where *l* is the lowest possible vale, *m* indicating the most promising value, and *u* indicating the largest possible value that describe the fuzzy event. It is characterized by a linear piecewise continuous membership function $\mu_{\tilde{N}}(x)$ which is described as:

$$\mu_{\tilde{N}}(x) = \begin{cases} 0 & x < l \\ (x-l)/(m-i) & l \le x \le m \\ (u-x)/(u-m) & m \le x \le u \\ 0 & x > u \end{cases} \quad (1)$$

A triangular fuzzy number $\tilde{N}$ is represented graphically as shown in Figure 5.

The basic theory of FAHP is as follows: assume the problem under study has *n* independent alternatives $(\tilde{A}_1, \tilde{A}_2, \ldots, \tilde{A}_n)$ with the weights $(\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n)$ respectively. The decision maker does not know in advance the values of $\tilde{w}_i$, *i* = 1,2,…,*n*, but he/she is capable of making pair-wise comparisons between the different alternatives. Also, assume that the quantified judgments provided by the decision maker) on pairs of alternatives $(\tilde{A}_i, \tilde{A}_j)$ are represented in an *n*×*n* a fuzzy comparison matrix $\tilde{A} = \{\tilde{a}_{ij}\}$ is constructed as:

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} \ldots\ldots\ldots \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 \ldots\ldots\ldots . \tilde{a}_{2n} \\ \vdots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} \ldots\ldots\ldots 1 \end{bmatrix} \quad (2)$$

where a fuzzy triangular numbers $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ with the following properties:

- $\tilde{a}_{ij} \approx \tilde{w}_i / \tilde{w}_j, i, j = 1,2,\ldots\ldots,n$.
- $\tilde{a}_{ii} = 1,\ i = 1,2,\ldots..,n.$ All diagonal cells have the value 1.
- $\tilde{a}_{ji} = 1/\tilde{a}_{ij} \approx \tilde{w}_j / \tilde{w}_i, i, j = 1,2,\ldots\ldots,n$.
- $\tilde{a}_{ij} \cong (\tilde{w}_i / \tilde{w}_j) > 1, i, j = 1,2,\ldots\ldots,n$, If $\tilde{A}_i$ is more preferred than $\tilde{A}_j$.

This implies that matrix $\tilde{A}$ is a positive and reciprocal matrix with 1's in the main diagonal and hence the decision maker should only provide value judgments in the upper triangle of the matrix. The values assigned to $\tilde{a}_{ij}$ according to Saaty (AHP) scale are usually in the interval of 1–9 or their reciprocals. Table 5 presents Saaty's scale of preferences in the pair-wise comparison process. The following are the main steps of FAHP:

1. State the overall objective of the problem and identify the criteria that influence the overall objective.
2. Structure the problem as a hierarchy of goal, criteria, sub-criteria, and alternatives.
3. Start by the second level of the hierarchy:
   - Do pair-wise comparison of all elements in the second level and enter the judgments in an *n*x*n* matrix. The values assigned to $\tilde{a}_{ij}$ according to Saaty (AHP) scale are usually in the interval of 1–9 or their reciprocals (Table 7).

- Calculate the fuzzy priorities by first finding the fuzzy geometric mean geometric for the different rows of the pair-wise comparison of the matrix. Next, the resulting vectors are normalized by dividing each entry by the sum of entries in the vector. The fuzzy geometric mean (*FGM*) is calculated as follows:

$$FGM = \prod_{j=1}^{n} (\tilde{a}_{ij})^{1/n} \quad ,i = 1,2,......,n \quad (3)$$

- Compute the consistency ratio of the matrix of judgments to make sure that the judgments are consistent.

4. Repeat step 3 for all elements in a succeeding level but with respect to each criterion in the preceding level.
5. Synthesize the local priorities (fuzzy local weights) over the hierarchy to get a priority (fuzzy composite weight) for each alternative.
6. Defuzzifying the resulted fuzzy values of the fuzzy composite weight in order to obtain a crisp value using the Center of Area method which calculate using the relationship in 5:

$$CN_{ij} = \frac{[(u_{ij} - l_{ij}) + (m_{ij} - l_{ij})]}{3} + l_{ij} \quad \forall i, j \quad (4)$$

7. Application of FAHP for policy prioritization for water conservation in Kuwait

There are several challenges facing water resource management in Kuwait, the main ones being:

1. Unsustainable use of groundwater resources.
2. Lack of urban water demand management.
3. Institutional and legal constraints.
4. Limited private sector participation.

The main focus in Kuwait has been on addressing various water problems and developing water supplies, no substantial efforts have been invested in improving demand management of water supplies. More specifically effective policies need to tackle the following issues:

- Improving demand management of urban water supplies through metering, pricing, and other efficiency improving measurers.
- The common characteristics Kuwait are the very high level of water consumption per capita.
- Consumption is very high by international standards.
- Addressing the tariff, metering, and billing major issues, which led to the excessive use and its rapid increase of municipal water in Kuwait
- The lower cost recovery has also created problems of heavy reliance on government subsidies and inadequate operation and management budget, leading to occurrence of deferred maintenance of desalination systems with a concomitant decrease in service overtime in countries like Kuwait.
- The extended usage of fresh water for home garden irrigation may account for as much as half of the total domestic usage.

Kuwait uses different water policies to encourage water conservation. These policies should be implemented with the usage of proper instruments and identify the best course of actions to better utilize the available water resources with the objective of conserving water usage. AHP is used to support the decision makers and planners in prioritization of policy instruments for efficient, effective, and reliable water conservation in Kuwait. The outline structure is as follows:

- Modeling the water conservation problem as a hierarchy showing the different decision making levels.
- Conducting pair-wise comparison of attributes at the different levels with respect to each criterion (policy) at the proceeding level and computing the local priority vector for each matrix of judgments.
- Synthesizing local priorities over the different levels of the hierarchy to get composite priorities of the alternatives (factors).

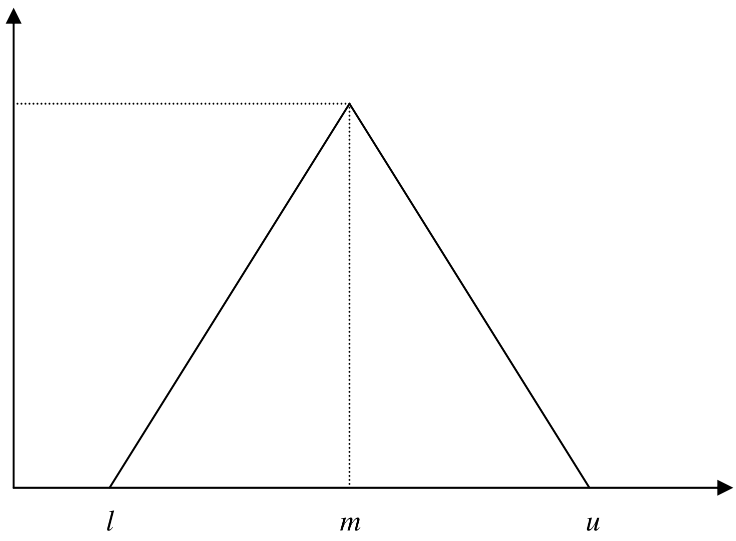

Figure 5. A triangular fuzzy number $\tilde{N}$.

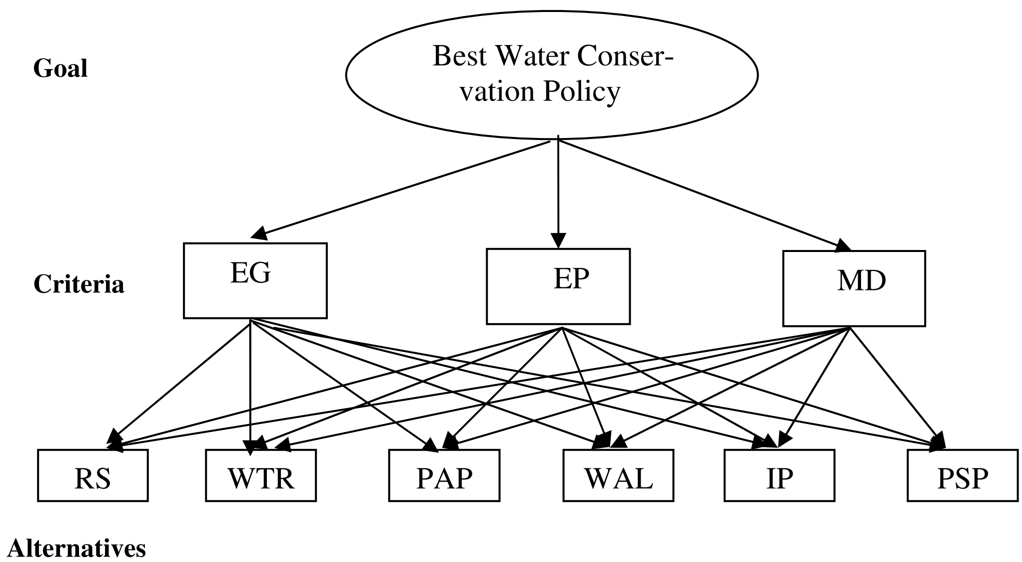

Figure 6. Hierarchical presentation of the model.

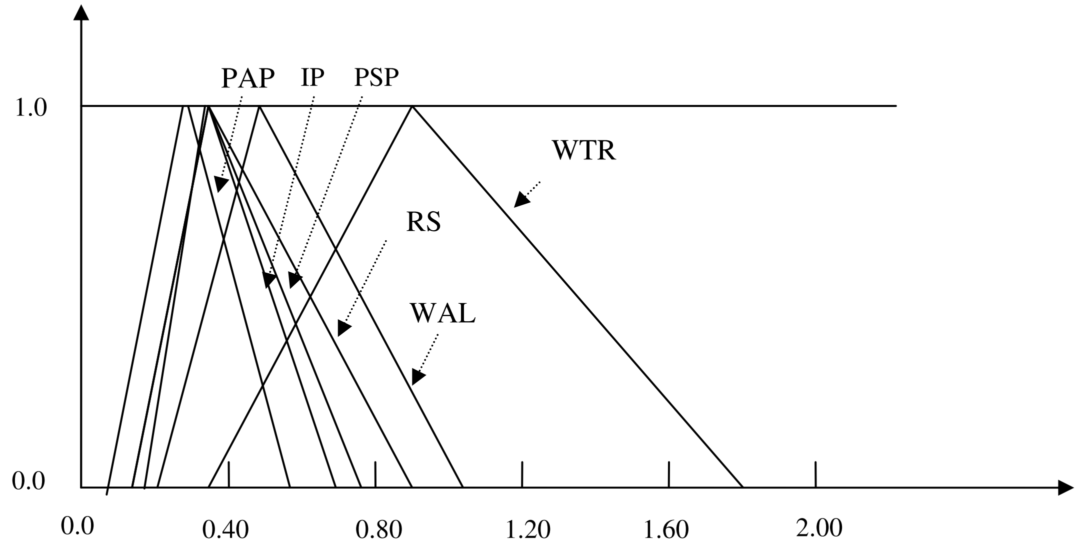

Figure 7. Membership functions of the different policies.

Table 6. Pair-wise comparison of criteria with respect to the goal.

	EG	EP	MD	Geometric Mean
EG	(1,1,1)	(1,2,3)	(1/4,1/3,1/2)	(0.630, 0.874, 1.145)
EP	(1/3, 1/2,1)	(1,1,1)	(1/6,1/5,1/4)	(0.382, 0.464, 0.630)
MD	(2,3,4)	(4,5,6)	(1,1,1)	(2.000, 2.466, 2.884)

Table 7. Pair-wise comparison of policy options with respect to the criteria EG.

	RS	WTR	PAP	WAL	IP	PSP	Geometric Mean
RS	(1,1,1)	(2,3,4)	(5,6,7)	(3,4,5)	(4/3,3/2,2)	(4/3,3/2,4/2)	(1.940,2.335,2.871)
WTR	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	(2/3,4/3,6/3)	(1/3,1/2,1/1)	(1,2,2/3,2/2)	(0.550,0.816,1.201)
PAP	(1/7,1/6,1/5)	(1/3,1/2,1)	(1,1,1)	(2/4,2/3,2/2)	(4/21,1/4,2/5)	(1/4,1/3,1/2)	(0.323,0408,0.585)
WAL	(1/5,1/4.1/3)	(3/6,3/4,3/2)	(2/2,3/2,4/2)	(1,1,1)	(4/15,3/8,2/3)	(1/3,1/2,1)	(0.445,0612,0.935)
IP	(1/2,2/3,3/4)	(1,2,3)	(5/2,4,21/4)	(3/2,8/3,15/4)	(1,1,1)	(2/3,1,3/2)	(1.038,1.557,2.013)
PSP	(1/3,1/2,1)	(2/2,3/2,4/2)	(2,3,4)	(1,2,3)	(2/3,1,3/2)	(1,1,1)	(0.874,1.285,1.817)

Table 8. Pair-wise comparison of policy options with respect to the criteria EP.

	RS	WTR	PAP	WAL	IP	PSP	Geometric Mean
RS	(1,1,1)	(1/7,1/6,1/5)	(2/4,2/3,2/2)	(1/4,1/3,1/2)	(1,1,1)	(5/7,5/6,5/5)	(0.483,0.560,0.681)
WTR	(5,6,7)	(1,1,1)	(3,4,5)	(1,2,3)	(5,6,7)	(4,5,6)	(2.587,3.238,4.050)
PAP	(2/2,3/2,4/2)	(1/5,1/4,1/3)	(1,1,1)	(1/3,1/2,1/1)	(2/2,3/2,4/2)	(4/4,5/4,6/4)	(0.637,0.840,1.122)
WAL	(2,3,4)	(1/3,1/2,1/1)	(1,2,3)	(1,1,1)	(2,3,4)	(4/2,5/2,6/2)	(1.178,1.680,2.289)
IP	(1,1,1)	(1/7,1/6,1/5)	(2/4,2/3,2/2)	(1/4,1/3,1/2)	(1,11)	(5/7,5/6,5/5)	0.483,0.560,0.681)
PSP	(5/5,6/5,7/5)	(1/6,1/5,1/4)	(4/6,4/5,4/4)	(2/6,2/5,2/4)	(5/5,6/5,7/5)	(1,1,1)	(0.577,0.672,0.791)

Table 9. Pair-wise comparison of policy options with respect to the criteria MD.

	RS	WTR	PAP	WAL	IP	PSP	Geometric Mean
RS	(1,1,1)	(2/2,3/2,4/2)	(2,3,4)	(4/2,5/2,6/2)	(1,1,1)	(1/3,1/2,1/1)	(1.049,1.334,1.698)
WTR	(2/4,2/3,2/2)	(1,1,1)	(1,2,3)	(4/3,5/3,6/3)	(2/4,2/3,2/2)	(1/4,1/3,1/2)	(0.661,0.889,1.201)
PAP	(1/4,1/3,1/2)	(1/3,1/2,1/1)	(1,1,1)	(5/7,5/6,5/5)	(1/4,1/3,1/2)	(1/7,1/6,1/5)	(0.359,0.445,0.607)
WAL	(2/6,2/5,2/4)	(3/6,3/5,3/4)	(5/5,6/5,7/5)	(1,1,1)	(2/6,2/5,2/4)	(1/6,1/5,1/4)	0.458,0.533,0.635)
IP	(1,1,1)	(2/2,3/2,4/2)	(2,3,4)	(4/2,5/2,6/2)	(1,1,1)	(1/3,1/2,1/1)	(1.049,1.133,1.698)
PSP	(1,2,3)	(2,3,4)	(5,6,7)	(4,5,6)	(1,2,3)	(1,1,1)	(1.849,2.667,2.821)

Table 10. The composite weight of the different water conservation policies.

Alternative / Criteria	EG	EP	MD	Composite Weight
	(0.135,0.242,0.380)	**(0.082,0.129,0.210)**	**(0.430,0.629,0.957)**	
RS	(0.206,0.333,0.554)	(0.050,0.074,0.115)	(0.121,0.185,0.313)	(0.164,0.369,0.855)
WTR	(0.058,0.116,0.232)	(0.269,0.429,0.681)	(0.076,0.123,0.221)	(0.381,0.873,1.807)
PAP	(0.034,0.058,0.113)	(0.066,0.111,0.189)	(0.041,0.062,0.112)	(0.104,0.248,0.558)
WAL	(0.048,0.087,0.180)	(0.122,0.223,0.385)	(0.053,0.074,0.117)	(0.184,0.471,1.067)
IP	(0.110,0.222,0.389)	(0.050,0.074,0.115)	(0.121,0.185,0.313)	(0.123,0.299,0.696)
PSP	(0.093,0.183,0.351)	(0.060,0.089,0.133)	(0.214,0.370,0.520)	(0.135,0.326,0.745)

Table 11. The fuzzy, crisp and normalized composite weight of the different water conservation policies.

Conservation Policy	Fuzzy Composite Weight	Crisp Composite Weight	Normalized Composite Weight
RS	(0.164, 0.369, 0.855)	0.463	0.147
WTR	(0.381, 0.873, 1.807)	1.020	0.325
PAP	(0.104, 0.248, 0.558)	0.311	0.099
WAL	(0.184, 0.471, 1.067)	0.574	0.183
IP	(0.123, 0.299, 0.696)	0.373	0.119
PSP	(0.135, 0.326, 0.745)	0.402	0.128

7.1. Hierarchy of the water conservation problem

The structure of hierarchy of decision problem under study is presented in Figure 6. In order to find the best policies to be implemented, their impact on the different factors such as economic, financial, social, and environmental should be measured. In this study, the following factors are used:

1. *Economic Growth (EG):* The cost of water is composed of production cost (capital cost of the distillation / desalination project), conveyance and storage costs, network distribution system costs, operation, maintenance, and replacement costs. The conservation process will undoubtedly reduce the water bill. In addition, the amount of money saved can be used in other sectors and hence promote development.
2. *Environmental Protection (EP)*: There is significant concern over the disposal of brine (concentrated salt solution that is hot and contains various chemicals) which could harm coastal and marine ecosystems. All the desalination plants in Kuwait are discharging the brine waste. Chemicals added to the desalination process for scale prevention, corrosion reduction and corrosion products may be discharged to the water bodies together. Therefore, conserving the use of water will not only contribute in less desalination plants, but also reducing the pollution discharged.
3. *Meeting Water Demand (MD)*: This implies that water conservation should be implemented such that the basic water requirement is not violated. The water demand for the different sectors should be met.

The main policy options available for Kuwait to promote water conservation as discussed with many experts in the field are as follows:

1. *Reducing Subsides (RS)*: At present, government policies in the region are to equally subsidize freshwater for all purposes. One way of rationing freshwater among activities may be achieved through devising an effective water costing scheme, and hence readjusting the policy of water subsidy.
2. *Accelerating Wastewater Treatment and Reuse (WTR)*: In Kuwait, the full utilization of treated wastewater remains in the early stages of development. The volume of reuse of treated wastewater is still far less than the volume of treated wastewater discharged. In these countries, the desalinated water supply that is collected and renovated through sewage treatment systems is 20-40% of the desalinated water supply, while the international average is in the range of 60-70%. Treated wastewater could replace fresh water in landscape irrigation, amenity purposes, irrigation of agriculture crops, etc; this will contribute substantially to fresh water conservation.
3. *Public awareness program (PAP)*: Kuwait should adopt a strong public awareness programs to create water conservation consciousness, specifically in calling for irrigation water savings for home gardens, and car washings. These programs should be designed to include educational institution, the media, the political leadership, and the public. The programs should focus on making the public aware of the actual cost of the water, its scarcity, and the need for water demand management based on regulations, to discourage inefficiency and waste in all sectors.
4. *Water Audit and Water Loss (WAL)*: The leakage from water distribution is very high. Reduction in leakage could be achieved through:
   - Rigorous leakage inspection.
   - Replacing of pipes.
   - Adopting modern plumbing codes.
   - Using high water-efficient appliances.
5. *Incentive Pricing (IP)*: As was indicated previously, water consumption is very high and is forecasted to increase due to population increase and high wastage. In addition, fresh water is highly subsidized. One primary suggestion is to increase the price of water to consumers, and simultaneously provide incentives to consumers

who effectively reduce their water consumption.

6. P*rivate Sector Participation (PSP)*: In order to satisfy the increasing water demand and improve operational efficiency. The private sector can reduce the financial burden by playing a vital role as a partner of the public sector in improving the efficiency of timidities management, providing technical and management expertise, and funds for major investment water infrastructure. In this regards, reverie of the international experience in the involvement of the private sector in water management should be assessed.

7.2. Pair-wise comparisons

The hierarchy of the decision problem as shown in Figure 6 has three levels. The first level is the goal, the second level presents the criteria and the bottom level presents the alternatives. Several water experts[1] in Kuwait were consulted in order to form the different pair-wise comparison matrices.

Table 6 presents the matrix of the fuzzy pair-wise comparisons of the different criteria in the second level with respect to the goal in the first level. The fuzzy geometric mean for the different criteria are calculated using equation 3, the results are as shown in the last column in the above table. The fuzzy priority vector is calculated by normalizing the values of the geometric means, the results are as shown in the following matrix:

$$\begin{bmatrix} 0.135 & 0.242 & 0.380 \\ 0.082 & 0.129 & 0.210 \\ 0.430 & 0.629 & 0.957 \end{bmatrix}$$

Next, the pair-wise comparison of the different alternatives (level 3) with respect to each criterion in the proceedings level (level 2), these matrices are given in Tables 7 to 10 for criteria EG, EP, and MD, respectively.

The normalized fuzzy priority weight is calculated as before, the normalized matrix is as follows:

$$\begin{bmatrix} 0.206 & 0.333 & 0.554 \\ 0.058 & 0.116 & 0.232 \\ 0.034 & 0.058 & 0.113 \\ 0.048 & 0.087 & 0.180 \\ 0.110 & 0.222 & 0.389 \\ 0.093 & 0.183 & 0.351 \end{bmatrix}$$

The fuzzy priority weight for the pair-wise comparison of the different water conservation policies with respect to EP, MD is presented in Tables 8 and 9, respectively. The normalized fuzzy priority vector is as shown below:

$$\begin{bmatrix} 0.050 & 0.074 & 0.115 \\ 0.269 & 0.429 & 0.681 \\ 0.066 & 0.111 & 0.189 \\ 0.122 & 0.223 & 0.385 \\ 0.050 & 0.074 & 0.115 \\ 0.060 & 0.089 & 0.133 \end{bmatrix}$$

The fuzzy geometric mean (priority vector) is shown in the column in Table 9. The vector of the fuzzy priority vector is normalized, the result is:

$$\begin{bmatrix} 0.121 & 0.185 & 0.313 \\ 0.076 & 0.123 & 0.221 \\ 0.041 & 0.062 & 0.112 \\ 0.053 & 0.074 & 0.117 \\ 0.121 & 0.185 & 0.313 \\ 0.214 & 0.370 & 0.520 \end{bmatrix}$$

7.3. Synthesizing judgments

The last step in the FAHP process is the synthesizing of judgments, in this step the fuzzy composite weight of the policies (alternative) are determined by combining the fuzzy priority weights of the factors (criteria) as given in Table 6 and the fuzzy priority weights for the policies (alternatives) at the different criteria as given by Tables 7 to 9.

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The membership function of the composite weights of the different policies is shown in Figure 7. Next, and in order to find the crisp composite weight of the different polices as given above, the center of area defuzzification method as given in equation 4 is used. The crisp values are next normalized. Detailed results are as shown in Table 11.

8. Conclusion and recommendation

It can be deduced from the prioritization process that the most effective instruments for water conservation the in Kuwait are Accelerating Wastewater Treatment and Reuse (WTR = 32.5%), Water Audit and Water Loss (WAL= 18.3%), Reducing Subsidies Policy (RS = 14.7%), Private Sector Participation (PSP = 20.4 %), Incentive Pricing (IP = 11.9 %), and lastly comes Public Awareness Program (PAP). Kuwait should implement sound water management policies and practices in order to enhance the proper and efficient usage of water. Based on this study, the main focus should be on:

1. Accelerating wastewater treatment and reuse.
2. Implementing water audit procedures and measures for minimizing water loss.
3. Providing a combination of tariffs, financial incentives, regulation, and improved efficiency in irrigation and municipal water use, to achieve conservation of scarce water resources and minimize wasteful water use.
4. Increasing the role of the private sector by forging a public-private cooperative relationship.
5. Providing incentive pricing for awarding customers who consume water efficiently.
6. Enhancing Public awareness programs in order to educate consumers and the public of the personal and societal benefits of adequately using water, and reducing wastage.

Other policy measures that are as important and Kuwait should pay close attention to are:

- Enforcing mandatory metering for all households with periodic inspection and certification of meter accuracy.
- Passing and enforcing water laws and regulation.
- Enhancing the mechanism of water bill payments.

Some of the above measures have been already initiated in the Kuwait countries to some extend over the past few years.

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