The concept of sustainability has received much attention from urban water systems planners and decision makers during the last two decades. A variety of system analysis tools have been used to assess the performance of urban water systems in achieving sustainability goals. This paper presents the lessons learned from conducting a hypothetical case study in the context of sustainability assessment of urban water systems. A fuzzy analytic hierarchy process, a well-known multi-criteria decision-making tool, is employed in terms of a group decision-making model as the sustainability assessment method. The case study is performed for a hypothetical region in Iran; however, data and information obtained from Tehran’s urban water system are applied to simulate the real-world situation in the case study. The objective of the case study is the sustainability assessment and prioritisation of development scenarios for the region’s urban water system. The results show that group decision-making models are efficient tools to provide a framework for incorporating stakeholder participation into the decision-making processes of urban water systems development. Also, fuzzy techniques can aid decision makers in dealing with the uncertainties and ambiguities of sustainability assessment models, particularly when most data and information are non-quantitative.

1. Introduction

The concept of sustainability has received much attention from urban water systems planners and decision makers (DMs) during the last two decades. This trend was stimulated by the introduction of sustainable development in Brundtland’s report, described as ‘to fulfill basic human needs without compromising the ability of future generations to fulfill their basic needs’ (WCED, 1987). Sustainable development demands a paradigm shift in conventional planning approaches, which merely aim to maximise the economic benefits of water and sanitation services in the short term, regardless of the long-term environmental and social impacts. It is expected that urban water systems should meet the following requirements in order to promote sustainability principles (Butler and Parkinson, 1997; Hellström et al., 2000; Malmqvist and Palmquist, 2005; Marsalek et al., 2008).

- Provide sufficient, healthy and safe water for satisfying potable and non-potable uses at all times.
- Collect and treat wastewater to protect urban residents from diseases and the environment from adverse impacts.
- Collect and control the urban runoff and improve the quality of stormwater to protect urban areas from flooding.
Minimise the misuse of natural resources such as fresh-water, energy and nutrients. 

Provide sufficient access to financial resources for water organisations to continuously monitor and operate the systems and make water and sanitation costs affordable for users. 

Employ reliable and efficient technologies that are adaptable to local conditions.

A variety of system analysis tools have been used to assess the performance of urban water systems in achieving sustainability goals. Exergy analysis (Hellström and Kärman, 1997), life-cycle assessment (Lundin and Morrison, 2002), material flow analysis (Jepsson and Hellström, 2002), life-cycle costing (Rebitzer et al., 2003), microbiological risk analysis (Ashbolt et al., 2006) and multi-criteria decision-making (MCDM) methods (Lundie et al., 2008) are examples of system analysis tools applied for sustainability assessment of urban water systems. MCDM techniques offer the important advantage of combining the results of different analytic methods to produce an integrated sustainability index for urban water systems. In the following section, a brief review of the application of MCDM methods to sustainability assessment of urban water systems is provided.

1.1 Literature review

Butler et al. (2003) presented the main results of ‘Sward’ (the sustainable water industry asset resource decisions), which was a major collaborative project implemented by a team of researchers from universities in the UK. Its aim was to provide a means whereby water service providers could more efficiently incorporate the principles of sustainability into the decision-making process. In Sward, seven phases were proposed as alternatives for sustainability assessment of urban water systems, including generation of options, selection of sustainability criteria and indicators, selection of preferred options and implementation of the selected options. The researchers suggested applying multi-criteria decision-aid (MCDA) tools such as a simple multiple attribute rating technique (Smart), analytic hierarchy process (AHP) and elimination and choice expressing reality technique (Electre) to select most sustainable options. Lai et al. (2008) reviewed the application of MCDM methods for integrated sustainability assessment of urban water systems and highlighted some of their shortcomings, such as preferential independency, double counting and undercounting, as well as lack of transparency of results and methods. Kain et al. (2007) evaluated three MCDAs for sustainable water management from a process facilitation perspective. Lundie et al. (2008) suggested a framework for evaluating the overall sustainability of urban water systems and adopted a simple scoring MCDM to implement the proposed framework in a hypothetical case study. Khatri et al. (2011) proposed a framework for computing a performance index for urban infrastructure systems using a fuzzy MCDM approach. In their framework, the relative importance of performance indicators was determined using AHP and a final synthesised performance index was calculated using a simple fuzzy scoring approach. They applied the framework to demonstrate and measure the performance of civil infrastructures, including the water supply and wastewater systems in Katmandu, Nepal. Chen et al. (2012) reviewed the application of some conventional environmental assessment tools such as life-cycle assessment (LCA), material flow assessment (MFA) and environmental risk assessment (ERA) in sustainability assessment of recycled water schemes. Owing to the limitations in the individual models, they recommended adopting an integrated approach to sustainability assessment of urban water reuse schemes using a MCDM framework. Alegre et al. (2012) developed an urban water cycle services (UWCS) performance assessment framework as a part of the ‘Trust’ (transitions to the urban water services of tomorrow) project. Trust was an EU-funded research project implemented between 2007 and 2013 by collaborators from European countries with the aim of supporting water authorities and utilities in Europe in designing and implementing appropriate urban water policies to improve urban water cycle services. The performance assessment framework involves selecting a set of performance metrics and indicators with regard to a predefined set of sustainability objectives and criteria, as well as a web-based self-assessment tool. By means of the self-assessment tool, urban water service providers can assess the sustainability of their services based on scores received from performance metrics. Carden and Armitage (2013) suggested a composite index called SIUWM (the sustainability index for integrated urban water management) for sustainability assessment of urban water services, especially in developing countries such as South Africa. SIUWM comprises four components (social, economic, environmental and institutional) and a set of sustainability indicators. Using a simple scoring MCDM, SIUWM scores were calculated for ten South African cities.

MCDM techniques have received much attention in the context of sustainability assessment of urban water systems in previous studies; however, some remaining issues have not yet been taken into consideration or have been poorly addressed. First, the majority of earlier studies have been conducted in the developed regions of the world, and experiences in developing countries are as yet insignificant. Second, the ability of group decision-making (GDM) models to incorporate stakeholder participation in the decision-making processes concerning sustainability assessment of urban water systems has not been satisfactorily highlighted. Finally, it might be of particular interest for researchers and scholars to discover how fuzzy MCDM techniques can aid DMs in dealing with the uncertainties and ambiguities that lie in sustainability assessment models, especially when most of the available data and information are non-quantitative, and elicited from human judgements.
This paper presents the lessons learned from conducting a hypothetical case study in Tehran in the context of sustainability assessment of urban water systems. In this case study, the fuzzy analytic hierarchy process (FAHP) – which is a well-known MCDM – was employed in terms of a GDM model as the sustainability assessment method. The case study was performed for a synthetic region called ‘Small Town’ in Tehran; however, data and information obtained from Tehran’s urban water system were applied to simulate the real-world situation in the case study. The objective of the case study was sustainability assessment and prioritisation of development scenarios for Small Town’s urban water system.

In the rest of this paper, first the applied methods are briefly introduced, and then the results obtained from the case study are presented. Finally, some lessons learned from the case study are provided.

2. Methodology

2.1 Fuzzy analytic hierarchy process

Fuzzy set theory established by Zadeh (1965) provides a mathematical framework to deal with problems that suffer from vagueness and the lack of precision in parameters (Zimmerman, 1991). FAHP is a fuzzy extension of the well-known AHP method developed by Saaty (1980). AHP is based on the way a human thinks logically and furnishes a hierarchical structure to analyse complex decision-making problems. It adopts the pairwise comparisons method in order to elicit the weights of criteria and alternatives. The fuzzy extension of AHP has been developed by different researchers. For the purpose of this paper, the FAHP method proposed by Buckley (1985) was selected.

Saaty (1980) suggested using the scale presented in Table 1 to perform pairwise comparisons. After constructing the pairwise comparison matrices, it must be ensured that there is a reasonable degree of coherence between judgements. Since DMs express their preferences subjectively, it is common that some sort of inconsistencies exist in pairwise comparison matrices (Delgado-Galván et al., 2010). The details of consistency check can be found in Saaty (1980).

After checking the consistency ratio of crisp pairwise comparison matrices, they must be fuzzified. For the purpose of this study, triangular fuzzy numbers (TFNs) were employed to fuzzify the crisp values. A typical TFN is demonstrated in Figure 1. In this paper, all TFNs, such as $\vec{E} = (a, b, c)$, have the shape of an isosceles triangle.

The membership function of a given fuzzy number such as $\vec{E} = (a, b, c)$ is denoted by $\mu_{\vec{E}}(x)$ and can be defined as presented in Equation 1.

$$
\mu_{\vec{E}}(x) = \begin{cases} 
\frac{x-a}{b-a} & a < x < b \\
1 & x = b \\
\frac{c-x}{c-b} & b < x < c \\
0 & \text{otherwise}
\end{cases}
$$

Every crisp value, such as $b$, is fuzzified by a TFN such as $\vec{E} = (b - \delta, b, b + \delta)$, where $\delta$ is a positive real number. For the purpose of this study, the default value of $\delta$ was 1; in sensitivity analysis, this value was altered to observe the possible changes in final results. There are exceptions for boundary values. Table 2 shows selected fuzzy equivalents of crisp values.

After fuzzifying the crisp matrices, Buckley (1985) suggests using a geometric mean to elicit the fuzzy weights of criteria and alternatives. More details on the calculations of fuzzy weights can be found in Buckley (1985).

2.2 Borda count

In MCDM problems, a set of rankings is often produced; hence, a method is required to combine different rankings, if achieving a final ranking is necessary. Borda count is a simple MCDM in which the best alternative obtains $N$ point; the second best alternative obtains $N - 1$ point, and so on, all the way up to the least point for the alternative which is obtained the last place in the ranking (Srdjevic, 2007). If the number of alternatives is $K$, $N$ is usually considered equal to $K$. The

<table>
<thead>
<tr>
<th>Definition</th>
<th>Intensity of importance</th>
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<tr>
<td>Equal importance</td>
<td>1</td>
</tr>
<tr>
<td>Moderate importance</td>
<td>3</td>
</tr>
<tr>
<td>Strong importance</td>
<td>5</td>
</tr>
<tr>
<td>Very strong or demonstrated importance</td>
<td>7</td>
</tr>
<tr>
<td>Extreme importance</td>
<td>9</td>
</tr>
<tr>
<td>Intermediate values</td>
<td>2, 4, 6 and 8</td>
</tr>
</tbody>
</table>

Table 1. Saaty’s scale for pairwise comparisons (Saaty, 1980)

Figure 1. A typical TFN
In this paper, if the number of ranking modes – which is obtained from the sensitivity analysis stage – is considered equal to \( n \), Equation 2 can be applied to calculate the final score of each scenario and subsequently the final ranking of each scenario (Srdjevic, 2007).

\[ R_T = \sum_{i=1}^{n} w_i R_i \]

in which \( w_i \) is the assigned score to the \( i \)th rank, \( R_i \) is the number where the scenario obtains the \( i \)th rank and \( R_T \) is the final score of the scenario.

### 3. Case study

#### 3.1 Tehran’s urban water system

The city of Tehran is the capital of the Islamic Republic of Iran. With a population of 8.3 million, the city covers an area of 686.3 km². Tehran’s urban water system comprises a water supply and distribution system, wastewater collection and treatment system and a stormwater collection system. The main sources of water supply in Tehran are five storage dams (Amirkabir, Latyan, Lar, Taleghan and Mamloo) and groundwater wells. The minimum and maximum volumes of water that can be supplied annually by the storage dams are about \(640 \times 10^6\) \(m^3\) (in dry years) and \(940 \times 10^6\) \(m^3\) (in normal years), respectively. The annual withdrawal of water from groundwater wells varies from \(150 \times 10^6\) \(m^3\) to \(250 \times 10^6\) \(m^3\) according to the annual precipitation and the availability of surface water. There are five treatment plants in Tehran that purify the water to the level of potable use and deliver it to users through a conventional single-pipe distribution network (TWWC, 2010).

There are also some deep and semi-deep wells that are used to provide non-potable water (e.g., landscape irrigation); these are

<table>
<thead>
<tr>
<th>Crisp values</th>
<th>Fuzzy equivalents</th>
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<tr>
<td>1</td>
<td>(1,1,1)</td>
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<tr>
<td>2</td>
<td>(1,2,3)</td>
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<td>3</td>
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<td>(6,7,8)</td>
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<td>8</td>
<td>(7,8,9)</td>
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<td>9</td>
<td>(9,9,9)</td>
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Table 2. Fuzzy equivalents of crisp values

alternative (candidate) with the largest sum of points is considered as the best alternative (Srdjevic, 2007).

During the last few decades, the conventional method of wastewater disposal in Tehran was using seepage pits, which collect the domestic wastewater and discharge it into the groundwater aquifers without any treatment. Increase in groundwater resources pollution and the rise of the water table caused by extensive use of seepage pits was the main impetus for constructing Tehran’s new wastewater collection and treatment system; this development has been accelerated during recent years. The project has been planned and designed in two stages and requires two wastewater treatment plants (Tajrishy and Abrishamchi, 2005).

In Tehran, stormwater is collected by means of gutters, in which the runoff is led to conduits that are mostly located in the west and east sections of the city. Collected stormwater leaves the city with no specific in situ uses, and often is discharged into raw water resources (Tajrishy and Abrishamchi, 2005).

Urban water management in Tehran suffers from a variety of problems and shortcomings, which have meant that the sustainability goals in the urban water sector have not yet been fully achieved. These major issues are summarised below (Madani Larijani, 2005; Tajrishy, 2011; Tajrishy and Abrishamchi, 2005)

- increase in water demand and waste production due to population growth and socio-economic development
- decrease in availability of water per capita due to droughts and changing climatic patterns
- low water use efficiency and high losses of urban water (unaccounted-for water)
- local depletion and pollution of surface and groundwater
- insignificant participation by stakeholders in development planning and management
- limited coordination among stakeholders
- limited technical, institutional and financial capacity of water and wastewater companies
- a lack of clarity regarding the institutional responsibilities of sector entities
- non-transparent and inadequate tariff structures and levels
- mismanagement and lack of effective decision-making tools.

During the last two decades, the predominant approach adopted to battle against the long-term problem of water shortage in Tehran was relying on supply-side approaches in terms of surface water resources augmentation (constructing
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Taleghan and Mamloo dams) and depletion of more water from groundwater resources. Fast urban population growth, however, alongside the occurrence of two severe droughts in water years 1999 and 2001 and a high percentage of water loss in water distribution networks (41% in 1998 based on TPWWC’s report), forced urban water policy makers and managers of Tehran to take demand-side approaches more seriously into account. Some water demand management programmes in Tehran that have been implemented in recent years are listed below.

- Pressure and leakage management in water distribution networks and combating of illegal water connections and water thefts (as a result, the percentage of unaccounted-for water decreased from 41% in 1998 to 32.9% in 2003). The final aim is to decrease the percentage of unaccounted-for water to 17% in 2021).
- Significant changes in water pricing schemes and water tariff systems. (In 2010, the Iranian parliament approved a law called the ‘targeted subsidy plan’ or ‘subsidy reform plan’. One remark in this law is that the Iranian government must increase the average price of water for agricultural, domestic and industrial uses to the prime cost of water within 5 years.)
- Construction of a modern wastewater collection and treatment system (treated wastewater produced by the system is used for irrigating farmlands in the south of Tehran).
- Promotion of the use of water-saving and water-efficient appliances among water users.
- Educational and cultural programmes have been conducted to publicise water conservation.
- Planning for in situ use of urban runoff and treated wastewater.

The implemented water demand management schemes were efficient in alleviating the water shortage problem of Tehran to some degree; nevertheless, there is as yet a profound lack of robust and useful decision-making frameworks and tools capable of incorporating the objectives of sustainable development into the decision-making processes of urban water systems development. The case study presented here primarily addresses this specific area of study and may be treated as one of the first efforts to promote sustainability principles among urban water policy makers and managers in Tehran.

### 3.2 Sustainability assessment of urban water systems development scenarios

The goal of this case study is to assess the sustainability of different urban water system development scenarios for a synthetic area in Tehran and rank them based on their sustainability scores. To better illustrate how scenarios can make progress towards a more sustainable future, the existing urban water system is also considered as one of the scenarios. The general characteristics of ‘Small Town’ are presented in Table 3.

The data on water use of Small Town were received from Tehran’s city Water and Wastewater Company (TWWC) and belong to a small area in the east of Tehran. The area has a population of approximately 55,000 people, includes a total of 13,020 water users (10,683 households, 2,328 non-domestic users and nine landscape users) with an annual water use of 7.81 × 10^6 m^3, which is 0.8% of the total annual water use of Tehran (TWWC, 2010).

For the purpose of this study, the length of time horizon was set to 15 years (i.e. 2010–2025). The main impetus for this selection is that, based on the report of the International Water Management Institute (IWMI), Iran is among countries which will be faced with ‘physical water scarcity’ in the year of 2025. This means that the volume of water demand will exceed the

<table>
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<th>Characteristic</th>
<th>Description</th>
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| Share of water uses | (a) Domestic users (with a share of 80-4% of total water use).  
(b) Non-domestic users (with a share of 17-4% of total water use).  
(c) Landscapes (with a share of 2-2% of total water use). |
| Water supply and distribution system | Conventional single pipe is used to provide both potable and non-potable uses. There are also some groundwater wells in the area, which are owned by Small Town’s municipality. The quantity and quality of these resources is appropriate to provide the non-potable uses of domestic and non-domestic users; however, they are currently utilised to irrigate the landscapes. |
| Urban drainage system | Wastewater and stormwater is collected by means of a sewer system and conveyed to a central treatment plant located outside Small Town. |
| Other assumptions | It is assumed that the residents of Small Town have the same income level and have common cultural values. |

Table 3. General characteristics of Small Town
volume of available water (Penning de Vries et al., 2003). Thus preserving the balance between water demand and supply is vital for fulfilling the objectives of sustainable development; the time scope should be selected with regard to the forthcoming events.

Four main interest groups were identified as the stakeholders of Small Town’s urban water system. These groups are listed below:

- Small Town’s Water and Wastewater Company (STWWC), which provides the residents of Small Town with water and sanitation services.
- Small Town’s water users (STWUs), including households and non-domestic users who pay for the services.
- Small Town’s environmental agency (STEA), which is responsible for protecting the environment of Small Town and the residents’ health and hygiene.
- Small Town’s municipality (STM), which uses water for landscape irrigation and also has some groundwater wells situated in Small Town.

For each of above groups, some individuals in the real world were considered as the representatives to play the role of the stakeholders of Small Town’s urban water system. A few mid-level managers in governmental organisations such as the National Water and Wastewater Company (NWWC) and TPWWC play the role of STWWC’s representative. Some academics who have expertise in water and wastewater engineering were selected to present the perspectives of water users in the decision-making process. To preserve the environmental values in decision making, an environmental health engineering expert with considerable experience of consulting works in governmental organisations and non-governmental organisations (NGOs) was selected. Finally, some mid-level managers in Tehran’s municipality played the role of the representative of Small Town’s municipality.

In addition to the aforementioned groups, a few experts from governmental organisations and NGOs (i.e. engineering consulting companies) were considered as DMs; however, the viewpoints of experts and stakeholders were employed separately at different levels of decision making. It should be noted that the list of DMs presented here is non-exhaustive and, for the purpose of this study, just the chief DMs are selected.

As a common feedback received from DMs, instead of designing sole systems as scenarios, a variety of strategies were adopted to build development scenarios. Hence, some conventional water demand management measures were employed to develop the scenarios, which are introduced here.

- Reform in domestic water tariff system: as a prime water demand management strategy, it was assumed that in all scenarios (i.e. development scenarios), the price of water increases for all Small Town’s water users (i.e. households, non-domestic users and landscapes) during the first 5 years of the time frame (i.e. 2010–2015), and it will remain equal to the full cost of supply until the end of the time frame (i.e. 2025). It should be noted that, currently, water tariffs cover less than 25% of the full cost of supply. From January 2011, the Iranian government has paid a monthly stipend (subsidy) to Iranian households as part of a ‘targeted subsidy plan’. It was assumed that full-cost recovery of water services can be primarily gained through a combination of incentives and punitive measures. This means that by achieving a greater decrease in water consumption, households not only pay less for water, but also they will be able to save larger amounts of the monthly stipend (subsidy) received from the government.
- Water quality cascading: this refers to the principle that water with the highest quality should be used for the most important demand (i.e. drinking), and for less important demands the quality of water should be degraded (Brooks, 2005). The allocation of water with regard to the importance of end use is an almost new topic, essentially originated from the idea of a ‘soft path for water’. A soft path for water is an innovative and problem-based management paradigm, which seeks to reduce the inefficiencies in conventional water demand and supply management approaches, and primarily relies on a multitude of mostly non-structural and relatively small-scale demand-side strategies (Brooks, 2005).
- Local groundwater wells as new resources: based on information received from TPWWC, there are numerous groundwater wells in Tehran which are not under the supervision of TPWWC; they are used by other governmental organisations, such as Tehran’s municipality, to supply their private uses. In interviews with experts of TPWWC, it was understood that these groundwater wells typically have acceptable quality (i.e. turbidity and conductivity) and quantity to satisfy the non-potable uses at local scales. The municipality currently uses a mixture of raw water – which is extracted from groundwater wells – and treated water to irrigate the urban landscapes in Tehran. Based on an agreement between the Ministry of the Interior and Ministry of Energy, the use of treated water by municipalities in different cities of Iran must be stopped as soon as possible (TWWC, 2010).
- Treated greywater as a new resource: greywater comprises 50–80% of domestic wastewater and includes flows from clothes washers, bath tubs, showers, sinks and laundry water, but does not include flows from toilets (i.e. blackwater), kitchen sinks and dishwashers (Al-Jayyousi, 2003). Islamic laws do not forbid Muslims from using treated greywater for non-potable uses; however, greywater reuse systems have not been used much in Iran, primarily owing...
to low water tariffs and poor publicising of the water shortage problem.

- Treated wastewater as a new resource: as a part of Tehran’s integrated wastewater management plan, 20 large-scale decentralised wastewater treatment plants will be constructed in Tehran until 2021; these will supply the required water to irrigate the urban landscapes and recharge the urban aquifers (TWC, 2011).

In one-to-one interviews, awareness was fostered among DMs that they must represent their organisation’s viewpoints in the decision-making process, and not incorporate their personal opinions into decision making.

4. Results

A simple comparison between the crisp weights of sustainability criteria allocated by DMs is made and shown in Figure 2. In Figure 2, the numbers 1, 2, 3 and 4 on the horizontal axis represent STWWC, STWU, STEA and STM, respectively.

Fuzzy weights of sustainability criteria ($\bar{W}$) are calculated and presented in Equation 3. It should be noted that in Equation 3 the weights of DMs’ viewpoints are considered equal (i.e. 0.25).

$$W = \begin{bmatrix} W_s & W_e & W_t \end{bmatrix}$$

An example of expert assessments of sustainability indicators is provided in Table 6.

After checking the consistency of the completed pairwise comparison matrix (shown in Table 6), it was fuzzified using fuzzy equivalents as presented in Equation 4.

$$A = \begin{bmatrix} I_1 & I_2 & I_3 \\ I_1 & (1,1,1) & (2,3,4) & (2,3,4) \\ I_2 & \left( \frac{1}{4} \right)^3 \frac{1}{3} \frac{1}{2} (1,1,1) \\ I_3 & \left( \frac{1}{4} \right)^3 \frac{1}{3} \frac{1}{2} (1,1,1) \end{bmatrix}$$

The final fuzzy decision matrix (performance matrix) is presented in Table 7.

Fuzzy membership functions of development scenarios (alternatives) are calculated and illustrated in Figure 3. In Figure 3, Alt. 1 to Alt. 6 represent the six development scenarios.

For the purpose of this study, three different approaches were adopted to analyse the effect of uncertainties on the ranking in the sustainability assessment model. First, the weights of the high-level DMs’ viewpoints—which cause some changes in the weights of sustainability criteria indirectly—were changed from the existing value (0.25) to extreme values (0.05, 0.15, 0.55, 0.85, 1).
In this scenario, the existing physical structure of Small Town’s urban water system will be kept until the end of the time frame. It is assumed that the average price of water for different uses will be increased during this time, just up to 25% of the full cost of supply. Also, Small Town’s Water and Wastewater Company (STWWC) will adopt solely conventional water demand management strategies, such as rehabilitation of water distribution networks and educational programmes for users; hence, there will be no strong incentive in this scenario to reduce the overall water consumption.

In this scenario, the average price of water for different users will be increased gradually during the first 5 years of the time frame up to the full cost of supply. In the remaining 10 years, STWWC will adopt solely conventional water demand management strategies, such as rehabilitation of water distribution networks and educational programmes for users; hence; increasing the water tariff is the prime incentive to reduce the overall water consumption.

In this scenario, the average price of water for different users will be increased gradually during the first 5 years of the time frame up to the full cost of supply. Also, during the first 5 years, STWWC will install greywater reuse systems for households and, from the sixth year, this system will begin to provide households with treated greywater to use for garden irrigation and toilet flushing. This new system has no separate monthly charges and households just pay for annual maintenance costs. There will be no changes in supplying water for non-potable users and landscape irrigation. Furthermore, STWWC will adopt conventional water demand management strategies, such as rehabilitation of water distribution networks and educational programmes for users. Increasing the water tariff and the greywater reuse system are two incentives to reduce the overall water consumption.

In this scenario, the average price of water for different users will be increased gradually during the first 5 years of the time frame up to the full cost of supply. Also, during the first 5 years, STWWC and STM will reach an agreement that STM will receive treated wastewater from STWWC with a reasonable price for landscape irrigation, instead of giving its groundwater wells to STWWC. STWWC will employ the groundwater wells to supply the non-potable (washing) uses of non-domestic users. STWWC will install on-site chlorinating units for groundwater wells, and construct a new water distribution system for non-domestic users during the first 5 years and, from the sixth year, this system will be operated. This new system has a separate monthly charge determined based on the full cost of supply. There will be no changes in supplying water for households. Furthermore, STWWC will adopt conventional water demand management strategies, such as rehabilitation of water distribution networks and educational programmes for users. Increasing the water tariff and supplying the non-potable uses of non-domestic users from groundwater wells are two incentives to reduce the overall water consumption.

In this scenario, the third and fourth scenarios ($S_3$, $S_4$) will be implemented simultaneously. Increasing the water tariff, the greywater reuse system, and supplying the non-potable uses of non-domestic users from groundwater wells are three incentives to reduce the overall water consumption.

In this scenario, the average price of water for different users will be increased gradually during the first 5 years of the time frame up to the full cost of supply. Also, during the first 5 years, STM will construct a new water distribution network to provide households and non-domestic users with raw water extracted from groundwater wells without any treatment; this water will be used for garden irrigation and toilet flushing. This new system has a separate monthly charge determined based on the full cost of supply as received by STM. There will be no other changes in the structure of Small Town’s urban water system. Furthermore, STWWC will adopt conventional water demand management strategies, such as rehabilitation of water distribution networks and educational programmes for users. Increasing the water tariff and the new raw water distribution system are two incentives to reduce the overall water consumption.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Description</th>
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<tbody>
<tr>
<td>$S_1$</td>
<td>In this scenario, the existing physical structure of Small Town’s urban water system will be kept until the end of the time frame. It is assumed that the average price of water for different uses will be increased during this time, just up to 25% of the full cost of supply. Also, Small Town’s Water and Wastewater Company (STWWC) will adopt solely conventional water demand management strategies, such as rehabilitation of water distribution networks and educational programmes for users; hence, there will be no strong incentive in this scenario to reduce the overall water consumption.</td>
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<tr>
<td>$S_2$</td>
<td>In this scenario, the average price of water for different users will be increased gradually during the first 5 years of the time frame up to the full cost of supply. In the remaining 10 years, STWWC will adopt solely conventional water demand management strategies, such as rehabilitation of water distribution networks and educational programmes for users; hence; increasing the water tariff is the prime incentive to reduce the overall water consumption.</td>
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<tr>
<td>$S_3$</td>
<td>In this scenario, the average price of water for different users will be increased gradually during the first 5 years of the time frame up to the full cost of supply. Also, during the first 5 years, STWWC will install greywater reuse systems for households and, from the sixth year, this system will begin to provide households with treated greywater to use for garden irrigation and toilet flushing. This new system has no separate monthly charges and households just pay for annual maintenance costs. There will be no changes in supplying water for non-potable users and landscape irrigation. Furthermore, STWWC will adopt conventional water demand management strategies, such as rehabilitation of water distribution networks and educational programmes for users. Increasing the water tariff and the greywater reuse system are two incentives to reduce the overall water consumption.</td>
</tr>
<tr>
<td>$S_4$</td>
<td>In this scenario, the average price of water for different users will be increased gradually during the first 5 years of the time frame up to the full cost of supply. Also, during the first 5 years, STWWC and STM will reach an agreement that STM will receive treated wastewater from STWWC with a reasonable price for landscape irrigation, instead of giving its groundwater wells to STWWC. STWWC will employ the groundwater wells to supply the non-potable (washing) uses of non-domestic users. STWWC will install on-site chlorinating units for groundwater wells, and construct a new water distribution system for non-domestic users during the first 5 years and, from the sixth year, this system will be operated. This new system has a separate monthly charge determined based on the full cost of supply. There will be no changes in supplying water for households. Furthermore, STWWC will adopt conventional water demand management strategies, such as rehabilitation of water distribution networks and educational programmes for users. Increasing the water tariff and supplying the non-potable uses of non-domestic users from groundwater wells are two incentives to reduce the overall water consumption.</td>
</tr>
<tr>
<td>$S_5$</td>
<td>In this scenario, the third and fourth scenarios ($S_3$, $S_4$) will be implemented simultaneously. Increasing the water tariff, the greywater reuse system, and supplying the non-potable uses of non-domestic users from groundwater wells are three incentives to reduce the overall water consumption.</td>
</tr>
<tr>
<td>$S_6$</td>
<td>In this scenario, the average price of water for different users will be increased gradually during the first 5 years of the time frame up to the full cost of supply. Also, during the first 5 years, STM will construct a new water distribution network to provide households and non-domestic users with raw water extracted from groundwater wells without any treatment; this water will be used for garden irrigation and toilet flushing. This new system has a separate monthly charge determined based on the full cost of supply as received by STM. There will be no other changes in the structure of Small Town’s urban water system. Furthermore, STWWC will adopt conventional water demand management strategies, such as rehabilitation of water distribution networks and educational programmes for users. Increasing the water tariff and the new raw water distribution system are two incentives to reduce the overall water consumption.</td>
</tr>
</tbody>
</table>

Table 4. Development scenarios (alternatives) for Small Town’s urban water system

0.85). Second, the shape of the fuzzy membership function applied for fuzzifying the crisp numbers was changed by increasing and decreasing the value of the $\delta$ parameter in TFNs. Finally, what effect the risk tolerance of the individual who ranks the alternatives has on the ranking was evaluated. After performing sensitivity analysis, a sum of 41 ranking modes was synthesised. As a maximum of six ranks can be achieved by the scenarios, the scores considered for the first, second, third, fourth, fifth and sixth ranks were 6, 5, 4, 3, 2 and 1, respectively. Table 8 presents the Borda count scores and final ranking of scenarios.
<table>
<thead>
<tr>
<th>No.</th>
<th>Sustainability criteria</th>
<th>Sustainability indicators</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Social</td>
<td>Benefits for future generations (l_1)</td>
<td>This indicator refers to the ability of scenarios to reach a reasonable and sustainable balance between water supply and demand from the future generations' perspective. This indicator gives an extra penalty to scenarios in which no significant effort is made to preserve the scarce resources for the future generations.</td>
</tr>
<tr>
<td></td>
<td>The cultural acceptability of alternatives (l_2)</td>
<td>This indicator refers to the degree of cultural acceptability of scenarios among the water users. It is assumed that scenarios which involve fewer changes in the existing situation of Small Town’s urban water system receive better scores from this indicator.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total savings in the monthly stipend (l_3)</td>
<td>This indicator refers to the potential amount of the monthly stipend which can be saved through reducing the water consumption by users. In this regard, scenarios which can potentially reduce a greater volume of water consumption are considered more preferred by this indicator.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Economic</td>
<td>Extra costs Construction costs (l_4)</td>
<td>This indicator refers to all costs required for implementing the development scenarios for urban water system of Small Town. As there was no real pilot study available, this indicator measured qualitatively based on the judgements of experts.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operation costs (l_5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maintenance costs (l_6)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Environmental</td>
<td>Potential impacts caused by withdrawal from groundwater wells (l_7)</td>
<td>This indicator refers to the potential impacts of development scenarios on the Small Town’s aquifers. Scenarios which involve extracting a smaller volume of water from the groundwater wells receive a better score from this indicator.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Potential health impacts (l_8)</td>
<td>This indicator refers to the possible health and hygiene issues that may arise after the implementation of scenarios – especially those that involve water reuse and recycling – and result in concerns over public health among water users.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Potential conflicts between the stakeholders (l_9)</td>
<td>This indicator refers to the conflicts between the stakeholders which may occur during the implementation of scenarios. In this case study, few scenarios involve the signing of agreements between major stakeholders such as STWWC and STM, where the failure of cooperation between these organisations could halt the development scenario.</td>
</tr>
<tr>
<td>4</td>
<td>Technical</td>
<td>Ability to put water quality cascading into practice (l_{10})</td>
<td>This indicator refers to the ability of each scenario to match the quality of water supplied and the importance of water use. The greater importance of the use, the better the quality of water supplied. In this regard, scenarios that cannot provide multiple qualities of water for users to satisfy their diverse needs for water receive worse scores from this indicator.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Potential decrease in water consumption (l_{11})</td>
<td>This indicator refers to the potential decrease in water consumption that may occur by implementing each of the scenarios. This is a solely quantitative indicator, which is calculated based on estimations that exist in the literature and viewpoints received from water experts.</td>
</tr>
</tbody>
</table>

Table 5. Proposed sustainability criteria and indicators
Based on the final ranking, the second development scenario ($S_2$), which involved no significant changes in the existing urban water system of Small Town, gained the first rank. Also, the sixth development scenario ($S_6$), which involved constructing a new water distribution network, received the least score and last rank.

5. Conclusion

This paper presents the results of a case study implemented for a synthetic region in Tehran called Small Town in the context of sustainability assessment of urban water systems. The objective of the case study was the sustainability assessment and prioritisation of development scenarios for Small Town’s urban water system. An FAHP – which is a well-known MCDM method – was employed in terms of a GDM model as the sustainability assessment method. Four sustainability criteria (social, economic, environmental and technical) and 11 sustainability indicators were used to prioritise six development scenarios. To evaluate the robustness of results against uncertainties, a sensitivity analysis was also conducted. The results of the case study demonstrate that GDM models are efficient tools to provide a framework for incorporating stakeholder participation into the decision-making processes of urban water systems development. Furthermore, fuzzy MCDM techniques can aid DMs in dealing with the uncertainties and ambiguities that lie in sustainability assessment models, particularly when most data and information are non-quantitative. Some lessons learned from the implemented case study are listed below.

- The main limitation of the applied sustainability assessment method is that it is time insensitive. In other words, by changing the time frame of study, results may not differ significantly. Moreover, in general, MCDM models are usually not capable of modelling the interactions which exist in socio-economic systems and which affect the behaviour of the system when viewed over the long term. One possible solution to overcome these limitations is coupling a MCDM sustainability assessment model with a system dynamics model. The dynamic model can provide DMs with insights about how the whole system (urban water system and its users) will behave against different demographic, hydrologic, economic, social and technical changes in the long term.

- In the implemented case study, it was assumed that all residents of Small Town had the same income level. The main impetus for making this assumption was that the water tariff system in Iran has experienced significant changes since January 2011. As mentioned before, the Iranian government has paid a monthly stipend (subsidy) to Iranian households as part of a ‘targeted subsidy plan’. High-income Iranian households often do not receive the monthly stipend from the Iranian government and an increase in the water tariff to a level equal to the cost price does not make any significant impact on their financial condition. On the other hand, low-income Iranian households are highly dependent on the monthly stipend, and without a decrease in their water consumption, they may be faced with serious difficulties in paying water costs. The situation for mid-level income households is somewhere between the low- and high-income situations. Thus, three groups of households in Iran show different behaviours against an increase of water tariffs. In this regard, a

<table>
<thead>
<tr>
<th>No.</th>
<th>Sustainability indicators</th>
<th>Are these indicators equally important?</th>
<th>Which one is more important?</th>
<th>Express the degree of importance according to Saaty’s 1 to 9 scale</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Benefits for future generations ($I_1$)</td>
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<td>3</td>
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<tr>
<td></td>
<td>The cultural acceptability of alternatives ($I_2$)</td>
<td></td>
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</tr>
<tr>
<td>2</td>
<td>Benefits for future generations ($I_1$)</td>
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<td>•</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Total savings in the monthly stipend ($I_3$)</td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td>The cultural acceptability of alternatives ($I_2$)</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Total savings in the monthly stipend ($I_3$)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. An example of expert assessments of sustainability indicators
Expert judgements may be useful at the preliminary stages of scenarios in achieving sustainability objectives. Therefore, it makes sense for water users of Small Town to use treated greywater or treated wastewater for non-potable uses.

- Expert judgements may be useful at the preliminary stages of planning for urban water systems development; however, they cannot solely be used for decision making as they are highly subjective. They should be merged with other analytical tools such as life-cycle assessment, life-cycle costing and so on, in order to provide a more realistic perspective of development scenarios in achieving sustainability objectives.

- The pros and cons of a specific scenario for the development of urban water systems should be weighted and considered together in an integrated manner; neglecting the adverse impacts of development scenarios – which is so common in the context of decision making in developing countries such as Iran – usually leads to difficulties and burdens for future generations.

When a sustainability assessment study is conducted, imposing some limitations for decision making with regard to the objectives of sustainable development can ensure that stakeholders do not select unsustainable practices for the development of urban water systems, which actually act against their own benefit, when viewed with a long-term perspective.

Some changes in the existing situation of urban water systems such as increasing the water tariffs or using treated greywater may appear unpleasant for water users at first, but if the long-term advantages of these changes are sufficiently well publicised, then water users will show more interest in accepting the changes.

Iran, in common with most developing countries, suffers from the lack of sufficient and reliable quantitative data on the performance of urban water systems. Also, existing data, which are necessary to quantify the sustainability indicators, are not available through well-structured databases.
The significance of sustainability and sustainable urban water management has still not been fully recognised by urban water managers and DMs in developing countries such as Iran. This is chiefly because, in Iran, sustainable development is still treated as a luxury not a necessity. Furthermore, decisions for urban water systems development are still made within technocratic, centralised frameworks, and the degree of stakeholder participation in the decision-making processes has been insignificant. Thus, conducting case studies such as the one presented in this paper can potentially help to promote sustainability principles among the managers and policy makers of urban water systems.

Acknowledgements

Carrying out the case study in this paper would not have been possible without the effective cooperation of interviewees and experts. The authors of this paper appreciate all individuals from the Deputy of Water and Wastewater in the Ministry of Energy, the National Water and Wastewater Company (NWWC), the Tehran Province Water and Wastewater Company (TPWWC), the Tehran City Water and Wastewater Company (TWWC), Tehran’s municipality, the environmental committee of Tehran’s city council, experts of non-governmental companies, and academics who assiduously collected the questionnaires and expressed their viewpoints in the one-to-one interviews.

REFERENCES


### Table 8. The Borda count scores and final ranking of scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>First rank</th>
<th>Second rank</th>
<th>Third rank</th>
<th>Fourth rank</th>
<th>Fifth rank</th>
<th>Sixth rank</th>
<th>The Borda score</th>
<th>The final rank</th>
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<td>6</td>
<td>4</td>
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<td>28</td>
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<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>34</td>
<td>51</td>
<td>6</td>
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