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Selection of a rural arsenic treatment system using multi-criteria decision-making techniques

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ABSTRACT

In the last decade, arsenic contamination in water resources from natural and anthropogenic sources has become an important issue in Turkey. In particular, high arsenic levels have been detected in the groundwater of many small towns and villages in the Aegean Region and Central Anatolia. The implementation of appropriate treatment systems is essential to reduce the arsenic concentrations to acceptable levels. The ideal technology for rural areas should be effective in producing arsenic-free water but should also be low cost, have low energy demand and require little maintenance. Although technical and economic parameters play important roles in the selection of technology, it should also be environmentally friendly. As there are several important factors affecting decisions about treatment systems, in this study the analytical hierarchy process (AHP) method was used to solve the problem and determine the preferences. In the study, "chemical treatment", "adsorption", and "reverse osmosis" were chosen as alternatives. Treatment alternatives were evaluated considering technical, economic and environmental criteria. The results of the AHP analysis show that the operational features and treatment performance were the major influencing factors for rural settlements in decision-making. According to AHP, the best alternative was adsorption. The ranking order of the alternatives for rural settlements was adsorption > reverse osmosis > chemical treatment.

Keywords: Multiple criteria decision-making; Analytic hierarchy process; Arsenic treatment; Wellhead treatment; Rural area; Village

1. Introduction

Multiple criteria decision-making (MCDM) is a process that allows decisions to be made in the presence of multiple, usually conflicting, criteria. It provides strong decision-making in areas where the selection of the best alternative is highly complex [1]. In general, decision-making is performed in four steps; (i) identifying the problem, (ii) generating the criteria and alternatives, (iii) evaluating the alternatives, and (iv) selecting the best alternative. It is important to identify, understand and define the problem before deciding. Therefore, the first step in the MCDM approach is to clearly define the problem. The next step includes the identification of decision alternatives and criteria. For this stage, either "alternatives based" or "criterion-based" approaches can be applied. In the "alternatives based approach", several alternatives are presented for consideration and then the criteria are selected for their analysis. In other cases, the "criterion-based approach" can be implemented where the criteria are considered for reaching the goal(s), and then alternatives are formed. For example, several criteria are considered for analysis of a location problem, and then suitable alternatives for choosing the "best" one are formed. For evaluation purposes, various multi-criteria decision methods are proposed in the literature. Choosing the most suitable method to compare multiple alternatives is a critical issue because

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these methods may yield different results for the same problem [2].

There are two types of MCDM methods: compensatory and non-compensatory (outranking decision-making). Compensatory methods are based on a rational model that evaluates the choices using different criteria. Compensatory methods permit tradeoffs between attributes. A slight decline in one attribute is acceptable if it is balanced by some enhancement in one or more other attributes [3]. Simple additive weighting [4], a technique for order of preference by similarity to the ideal solution [5], analytical hierarchy process (AHP) [6], and fuzzy AHP [7–11] are some examples of compensatory techniques. Non-compensatory methods are based on the concept of outranking and do not permit trade-offs between attributes. An unfavorable value in one attribute cannot be offset by a favorable value in other attributes [3]. Each attribute must stand on its own, so comparisons are made on an attribute-by-attribute basis. Examples are elimination and choice expressing reality and preference ranking organization method for enrichment of evaluations.

Multi-criteria decision analysis has been applied in a wide variety of fields such as energy management, environmental planning, public services, healthcare, transportation, logistics, marketing, human resources management and finance [12–23]. Significant growth has been observed in environmental applications of MCDM over the last decade [12]. In the environmental field, MCDM methods have been applied particularly to solve problems in waste management, water quality/management, air quality, energy, natural resources, spatial/geographic information system, environmental impact assessment, etc. [24]. The selection of the water or wastewater treatment process is also a complicated MCDM problem that involves a detailed evaluation of the various factors. Numerous important non-tangible factors are affecting the preferences and it is very difficult to express them in numerical units. Recently, research has focused on the use of multi-criteria techniques for selection of the treatment process that considers both quantitative and qualitative criteria. Anagnostopoulos et al. [25] performed the fuzzy extension of AHP to evaluate alternative wastewater treatment processes considering economic, environmental and social criteria. Similarly, Karimi et al. [26] applied the AHP and fuzzy AHP methods to select the best wastewater treatment process. Curiel-Esparza et al. [27] presented an application of the AHP by integrating a Delphi process which was originally developed by Olaf Helmer and Norman Dalkey to select the best sustainable disinfection technique for wastewater reuse projects.

On the other hand, many pollutants in water streams have been identified as toxic and harmful to the environment and human health. Among them, arsenic is considered a priority number one. The inorganic forms consisting mostly of arsenite and arsenate compounds are toxic to human health. Humans are exposed to arsenic primarily from air, food, and water. Drinking water may be contaminated with arsenic from arsenical pesticide, natural mineral deposits or improperly handled arsenical chemicals. Cancer of the skin, lung and urinary bladder are important cancers associated with chronic arsenic toxicity [28]. Elevated arsenic levels in drinking water are the major cause of arsenic toxicity in the world [29]. However, numerous studies have reported various health effects caused by chronic exposure to low concentrations of arsenic [30]. Hence, the new maximum contaminant level of arsenic in drinking water has been set by authorities worldwide to 10 ppb from an earlier value of 50 ppb.

Recently, arsenic pollution has become an important topic on the agenda of Turkey. High arsenic levels have been detected in the drinking water supply systems of large metropolitan areas as well as remote villages [31]. The concentration of arsenic in groundwater in Izmir, Manisa, Afyon, Uşak, Kirikkale, Van is about 10–60 ppb and they are mainly related to the geothermal processes as well as geological formation [32–34]. Arsenic is also one of the major contaminants in Kütahya, Nevşehir, Aksaray, Balıkesir provinces, and shows high spatial variation ranging from 33 to 911 ppb in groundwater samples. This is most likely due to the arsenic compound in mines [34,35]. Accordingly, weathering and dissolution of arsenic minerals, water-rock interactions, and geothermal processes are caused by groundwater to be enriched in arsenic in many of these locations [34,35]. Since high As concentrations exceeding the provisional guidelines set by the World Health Organization in drinking water have been reported by many researchers [36], exploration of efficient and cost-effective methods to remove arsenic from drinking water resources in Turkey is urgently required.

Thus, the study aimed to apply a scientific approach to the selection of appropriate arsenic treatment solutions for remote rural villages in Turkey. The AHP method was applied due to its simplicity and ability to rank the criteria used to select the treatment system in order of importance. It has been reported that there are many small towns and villages in Turkey supplying their potable water from groundwater sources in which the arsenic levels are over the limits, i.e. 10 ppb [37,38]. As a result, the assessment of efficient and cost-effective methods compatible with rural communities to remove arsenic from drinking water resources has emerged as an important issue in Turkey in the last ten years. On the other hand, the selection of the appropriate technology is also quite a complex decision that is affected by various parameters such as water quality and quantity, target arsenic concentration, capacity, residual concentration, the complexity of the operation, and cost. In this study, using the alternative based approach, chemical treatment, reverse osmosis, and adsorption were compared with each other. Technical, economic and environmental criteria were weighted and evaluated, and the priorities of alternatives were determined. Finally, selection of the best among these processes was determined.

2. Material and methods

The AHP method, which is an effective technique for solving MCDM problems, was applied to the selection of arsenic treatment processes in small settlements in rural areas. The AHP technique has been widely used for MCDM and successfully applied to many environmental projects. The use of AHP instead of other multi-criteria techniques is for the following reasons:

- Quantitative and qualitative criteria can be included in the decision-making.
- A large number of criteria can be considered.

- A flexible hierarchy can be constructed according to the problem.
- Availability of user-friendly and commercially supported software packages.

The AHP methodology is summarized below and the goal, criteria, and alternatives considered in the study are structured within the hierarchy tree.

2.1. Analytical hierarchy process

The first step in an AHP analysis is to build a hierarchy for the decision. The AHP problem hierarchy consists of a goal (the decision), several alternatives for reaching that goal, and a few criteria on which the alternatives can be judged that relate to the goal. The first level of the hierarchy is the goal; in our case, the goal was selecting effective and environmentally friendly arsenic (As)treatment system for small rural settlements. The second level in the hierarchy is setting evaluation criteria. In this study, treatment efficiency, cost (investment and operational costs), waste generation (waste quantity and quality), area requirement, and operations and management were considered. The third level consists of the available alternatives; reverse osmosis, adsorption and chemical treatment were chosen in the study. Considering those conditions, a simplified decision hierarchy was assembled to select an appropriate arsenic treatment technique for small establishments as shown in Fig. 1.

Then, the priority setting of the criteria is done by pairwise comparison (i.e. weighting). Rating the relative "priority" of the criteria is done by assigning a weight between 1 (equal importance) and 9 (extreme importance) to the more important criterion while the reciprocal of this value is assigned to the other criterion in the pair. The results of the comparisons are shown in the form of a preference matrix. The weighting is then normalized and averaged to obtain an average weight for each criterion (i.e. preference vector) [39]. In this study, paired comparisons were made using the numerical values taken from the AHP absolute fundamental scale developed by Saaty [6]. The preference scale used for the AHP is shown in Table 1.

Following weighting, pairwise comparison of alternatives on each criterion is performed (i.e. scoring). For each pairing, within each criterion, the better option is awarded a score, again, on a scale between 1 (equally good) and 9 (absolutely better), whilst the other option in the pairing is assigned a rating equal to the reciprocal of this value. Each score records how well option "X" meets the criterion "Y" [39]. Afterward, the ratings are normalized and averaged [39].

In the final step, the option scores are combined with the criterion weights to produce an overall score for each option and a consequent ranking. The global score for a given option is a weighted sum of the scores it obtained to all the criteria.

Since the numeric values are derived from the subjective preferences of individuals, it is impossible to avoid some inconsistencies in the final matrix of judgments. The question is: how much inconsistency is acceptable? For this purpose, AHP calculates a consistency ratio (CR) comparing the consistency index (CI) of the matrix in question versus the CI of a random-like matrix (RI). In AHP, the CR is

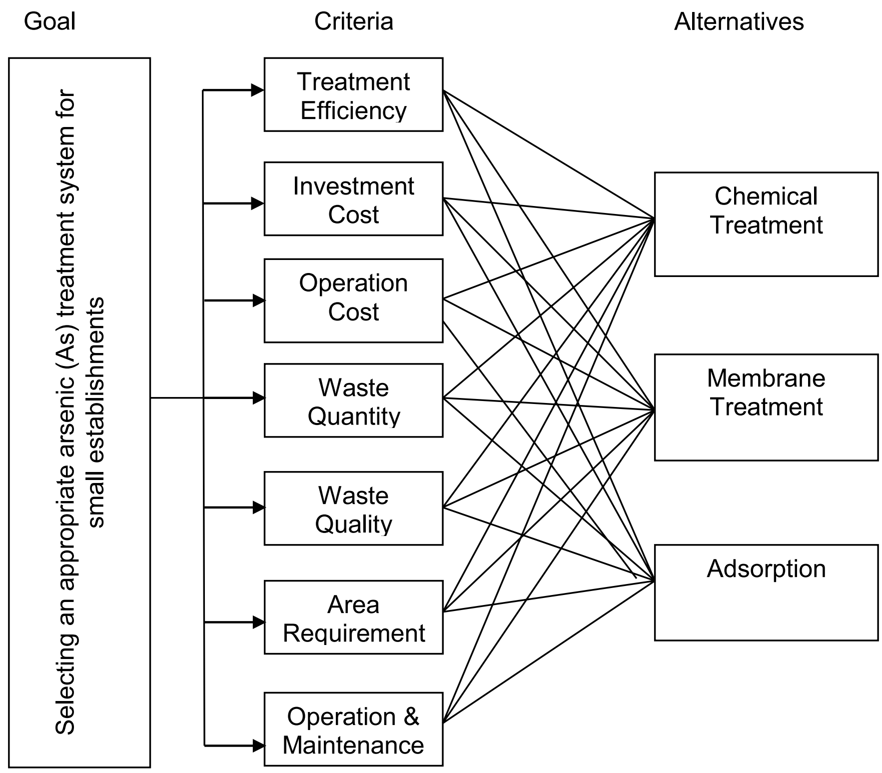

Fig. 1. Decision hierarchy.

Table 1
Saaty's pairwise comparison scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgment slightly favor one activity over another.
5	Essential or strong importance	Experience and judgment strongly favor one activity over another.
7	Very strong or demonstrated importance	Activity is strongly favored, and its dominance demonstrated in practice.
9	Extreme importance	Evidence favoring one activity over another is of the highest possible order of affirmation.
2,4,6,8*	Intermediate values	When compromise is needed.

*Intermediate values are used to address situations of uncertainty. For example, when the decision-maker is in doubt whether to rate a pairwise comparison as "moderately more important (3)" or "strongly more important (5)", a possible solution is to rate it as "From moderately to strongly more important;" that is, a 4.

calculated by dividing CI by RI. Saaty [39] has shown that a CR of 0.10 or less is acceptable to continue the AHP analysis. If the CR is greater than 0.10, it is necessary to revise the judgments to locate the cause of the inconsistency and correct it.

2.2. Treatment alternatives of arsenic

Chemical treatment (coagulation with alum or iron salts plus flocculation plus precipitation), oxidation, ion exchange, membrane processes, and adsorption are reported as the best-known techniques for arsenic removal [40]. In our case, chemical treatment, adsorption, and membrane methods (i.e. reverse osmosis) were evaluated as treatment options considering the local experience in arsenic removal. In chemical treatment, dissolved arsenic is transformed by the chemicals into an insoluble solid, which undergoes precipitation later [41,42]. The valence state of arsenic, pH, and the presence of other compounds are principal factors affecting the performance of the chemical treatment. In general, the coagulation and flocculation process is highly effective for arsenic removal. It is also reported that removal efficiencies are relatively higher for As(V) than for As(III) [43]. The main limitations of the process for small-scale applications, e.g. in villages, are the need for a trained operator, high waste generation, and chemical costs [44]. Consequently, it is mostly used in centralized removal systems [45].

Membrane processes work under pressure and can remove arsenic using selective membranes. Two classes of membrane filtration can be considered: low-pressure membranes, such as microfiltration (MF) and ultrafiltration (UF), and high-pressure membranes such as nanofiltration (NF) and reverse osmosis [46]. The use of MF and UF membranes is dependent on the size of arsenic particles removed from the water. However, NF and reverse osmosis (RO) membranes are efficient in removing dissolved arsenic compounds. The presence of certain constituents such as suspended solids, dissolved solids, organic compounds, and colloids in the feed stream may cause membrane fouling. To prevent fouling, reverse osmosis or nanofilters are often preceded by a pretreatment (i.e. filtration) step. Another disadvantage of using membrane processes is high cost due to the membrane itself and energy consumption. However, recent advances particularly in operating low-pressure systems at high recovery rates could make membrane methods feasible and cost-effective systems for arsenic treatment [39–41].

Adsorption is a fixed bed process through which ions in solutions such as arsenic are removed by available adsorptive sites on the adsorptive media. It has been reported as the most widely used technique for arsenic removal due to several advantages including relatively high arsenic removal efficiencies, easy operation, cost-effectiveness and lack of sludge production [36,42]. For arsenic removal, conventional adsorbents such as activated carbon, hydrous metal oxides like activated alumina, and ion exchange resins have been used [47]. Also, recent data indicate that hydrous ferric oxides such as granular ferric hydroxide (GFH), ferrihydrite and goethite are effective in the removal of arsenic species [48,49]. Removal efficiency depends on the initial As concentration, oxidation state, adsorbent type, pH and competing anions. Itis usually less complex and requires less operator expertise and monitoring so operators of smaller drinking water treatment systems are more likely to select adsorption units to treat arsenic. The main disadvantage of using the adsorption process for drinking water is the disposal of both the spent media and the wastewater produced during regeneration/cleaning of the column.

2.3. Criteria

Many criteria influence the selection of the treatment process. In this paper, the alternatives for wastewater treatment were evaluated using three sets of criteria classified as technical, economic, and environmental. Current knowledge and data as well as the views of several specialists in the operation of arsenic treatment plants were used to determine the criteria. Performance (or efficiency) and operational simplicity were taken into consideration as technical sub-criteria. Economic criteria were broken into the next three sub-criteria: that is, capital cost, operation and maintenance cost, and land requirement. Finally, the sludge quantity and quality produced by each alternative were evaluated as environmental criteria.

An extensive literature review was conducted to compare the alternatives given the criteria. All criteria weights and scores were derived from the authors' experience.

Technical information gathered from the United States Environmental Protection Agency (USEPA) handbook for small systems was used for pairwise comparison of alternatives [50]. Thus, based on the authors' experience in this area and reports on arsenic treatment systems for small establishments [36,37,44,45], a table was developed to screen technologies using the identified criteria (Table 2). In the study, the parameter weight was assigned with respect to the data summarized in Table 2.

Experience gathered from full-scale plants and research show that arsenic can be removed from water to a high-degree (i.e. >90%) by conventional chemical treatment using ferric or aluminum ions, by adsorption using activated alumina, GFH and/or greensand media, and by high pressure membrane processes, i.e. reverse osmosis [51]. The presence of the more soluble trivalent state of arsenic might reduce the removal efficiency in both chemical treatment and adsorption processes. Therefore, oxidation of the influent stream to convert As(III) to As(V) will also result in an increase in arsenic removal efficiency in adsorption as well as chemical treatment [52].

Waste disposal is an important consideration in the selection of the treatment process. Arsenic removal technologies can produce several different types of liquid and solid wastes, including sludge, brine streams (reject waste), backwash water, and spent media (i.e. adsorbent, membrane, etc). Chemical treatment typically generates huge amounts of sludge, which is considered as a solid residual. Sludge produced from chemical processes could be considered hazardous waste and require additional treatment before disposal or require disposal as hazardous waste. The adsorption process generates spent regenerating solution and solid spent media. The regeneration process for some materials like active alumina, iron oxide coated media consists of backwashing, regeneration, neutralizing and rinsing steps. The regeneration might produce a sludge that contains a high concentration of arsenic. In general, the regeneration of media is likely to be an unfeasible option for most small water systems. Membrane filtration generates a liquid reject stream. Based on concentrations of the removed contaminant, further treatment might be required prior to disposal or discharge.

In the literature, limited cost information is available for arsenic treatment. In many cases, some data are for operations and maintenance costs only and do not specify the associated capital costs. In other cases, a cost per unit of water treated is provided, but total costs are not. In this study, the cost data taken mainly from the arsenic demonstration program conducted by USEPA [50,53,54] were used to express the unit costs. Costs do not include pretreatment or management of treatment residuals.

The complexity of system operation is an important issue, especially for small systems. Complex systems often require more skilled operators. On the other hand, the level of automation available for systems operation can significantly decrease the complexity. During technology selection, the backwash frequency, chemical addition requirement (i.e. pH adjustment, dosing, etc.) and frequency of media should be considered within the operational issues. Primarily due to their simplicity of application and operation, adsorption media have been more widely accepted and applied than other technologies. Chemical additions, feed pumps, and real-time monitoring are generally not required, which makes operation and maintenance comparatively simple.

3. Results and discussion

The AHP started by creating a pairwise comparison matrix (see Table 3) to compute the weights for the different criteria. The relative importance between the two criteria was measured according to a numerical scale from 1 to 9, as shown in Table 1. For example, when the criterion of treatment efficiency (C_1) in the row as compared to the criterion of the operation and maintenance (C_7), the value 1 was assigned. Since, small scale establishments (villages) in a rural area are constrained by lack of operators, the criteria C_1 and C_7 were weighed equally. Also, insufficient financial sources are one of the characteristics of small establishments, i.e. villages. Therefore, treatment alternatives having low investment costs, are primarily taken into consideration in decision-making, and thus weighted with 1, as well. Once the comparison matrix was built, it was normalized by making the sum of the entries on each column equal to 1. Finally, the criteria weight vector was built by averaging the entries

Table 2
Evaluation of the treatment alternatives considering the criteria

Criteria	Treatment alternatives		
	Chemical treatment	Adsorption	Reverse osmosis
Treatment efficiency (%)	90–95	95	>95
Area requirement	High	Low	Low
Waste generation	High	Low	High
Quantity & quality	Sludge with high as content	Backwash water & spent media containing as	Reject water with high as content
Cost ($/m^3)			
Capital cost (CC)	0.096	0.103	0.110
Operational cost (OC)	1.21	3.24	2–4
Operation and maintenance	High	Low	Medium

Table 3
Pairwise comparison matrix for criteria and results of overall priorities

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Overall priorities
C_1	1	5	1	7	9	3	1	0.277
C_2	1/5	1	1	3	5	3	1/3	0.121
C_3	1	1	1	5	7	3	1/3	0.174
C_4	1/7	1/3	1/5	1	3	1/3	1/5	0.045
C_5	1/9	1/5	1/7	1/3	1	1/3	1/5	0.028
C_6	1/3	1/3	1/3	3	3	1	1/5	0.073
C_7	1	3	3	5	5	5	1	0.282

C_1: Treatment efficiency; C_2: Area requirement; C_3: Capital cost; C_4: Operational cost; C_5: Waste quality; C_6: Waste quantity; C_7: Operation and maintenance

on each row of the normalized matrix. From the normalized matrix, the overall or final priorities were obtained by simply calculating the average value of each row (Table 3).

CR was calculated by dividing the CI by RI. RI is the average random CI provided by Saaty [39]. RI value was 1.32 for criteria of 7 and CR value was calculated as 0.06. Since CR was less than 0.10, we assumed that our judgments matrix was reasonably consistent.

After that, the matrix of alternatives was formed. A pairwise comparison matrix was evaluated for each of the criteria (Table 4). Here, treatment alternatives were compared to determine which alternative was preferred given a particular criterion. Regarding treatment efficiency, since maximum treatment efficiency is obtained in the reverse osmosis process (i.e. >95%), the highest weight was attributed to the reverse osmosis technique. Other methods (i.e. adsorption and chemical treatment) were equally weighted. Area requirement is considerably high in chemical treatment (i.e. coagulation and flocculation), thus the highest weight was attributed to the chemical treatment. Chemical treatment can be achieved with less investment, thus the highest weight is assigned to chemical treatment. Using membrane filtration is very effective however, it can be expensive due to the membrane itself. Also, capital cost for adsorption is more likely than reverse osmosis. Thus, both reverse osmosis and adsorption were equally weighed. Operating costs are also significantly higher in reverse osmosis due to high operating pressures. On the other hand, chemical treatment might result in low operational costs due to metal salts are used as coagulants in treatments efficiently. Therefore, the highest weight was attributed to reverse osmosis whereas chemical treatment was weighted with low score. Finally, treatment alternatives were evaluated in terms of waste production. Each alternative produces arsenic containing wastes. The management of this sludge is necessary to prevent the consequence of secondary pollution of the environment. Regarding to quality, there is no difference therefore all alternatives were equally weighed. However, quantity of waste shows differences therefore it has to be considered in process selection. In coagulation-flocculation process, large quantity chemicals are supplied and the volume of sludge is huge. Reverse osmosis also produces high volume liquid waste streams. The high liquids content makes dewatering uneconomical and sanitary or hazardous waste landfill might be costly. Among the alternatives, the minimum waste is obtained by adsorption thus the highest weight is attributed to adsorption.

The AHP applied to each matrix the same two-step procedure described for the pairwise comparison matrix. That is, it divides each entry by the sum of the entries in the same column and then it averages the entries on each row, thus obtaining the score vectors. Finally, the score matrix (i.e. matrix of priority vectors and overall priorities for each of the treatment technologies) is obtained. Once the weight vector and the score matrix were computed, the global score vector was obtained by multiplying weight vector and score vectors (Table 5).

The results show that the main criteria for selecting the proper technique for small establishments in rural areas were: operation/maintenance (28.2%), treatment performance (27.7%), and capital cost (17.4%). Operational features, i.e. operator requirement, operational simplicity, maintenance, etc., and treatment performance were found to be the major influencing concerns in the decision-making for the choice of the appropriate alternatives. It was no surprise that the criterion ranked the highest among influencing concerns because small establishments are mainly located in remote areas where no skilled operator is employed.

Table 4
Preferences of the alternatives with respect to each criterion

Treatment alternatives	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Chemical treatment	0.11	0.09	0.63	0.72	0.33	0.15	0.07
Reverse osmosis	0.78	0.45	0.11	0.08	0.33	0.07	0.01
Adsorption	0.11	0.45	0.26	0.19	0.33	0.78	0.64

Table 5
Score matrix

Treatment alternatives	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Overall priorities
Chemical treatment	0.03	0.01	0.11	0.03	0.009	0.01	0.02	0.2232
Reverse osmosis	0.22	0.05	0.02	0.003	0.009	0.05	0.003	0.3577
Adsorption	0.03	0.05	0.04	0.008	0.009	0.06	0.18	0.3837

The least concern among the criteria was the number of residuals (i.e. waste quantity), whose value was 2.8%.

The ranking order of the alternatives with the AHP method was as follows: adsorption > reverse osmosis > chemical treatment. Small capacity arsenic treatment systems for villages should have lower operating and maintenance costs, and require less operator expertise. Coagulation-flocculation, that is, chemical treatment is frequently capable of successfully treating a wide range of arsenic-contaminated influent concentrations to achieve or surpass drinking water standards. Systems using this method generally require skilled operators: for this reason, it is more cost-effective at large scale where labor costs are spread over a larger quantity of treated water. The effectiveness of reverse osmosis for arsenic removal is satisfactory however, it is not economically applicable because it requires high investment and operational costs. Therefore, it is used less frequently in small community systems. The effectiveness of adsorption for arsenic treatment is more likely higher than precipitation processes. Small capacity systems using adsorption tend to have lower operating and maintenance costs and require less operator expertise. Adsorption, therefore, tends to be used more often when arsenic is the only component to be treated, for relatively smaller systems.

4. Conclusion

Selection of the arsenic treatment process for small establishments is a complicated multi-criteria decision-making process. In this paper, a practical approach is demonstrated for selecting and weighing the treatment processes problem based on the AHP method. The technical, economic and environmental criteria were used in decision-making. These criteria were evaluated to determine the order of treatment alternatives for selecting the most appropriate one. The alternatives were chemical treatment, reverse osmosis and adsorption. By using the AHP method, the ranking order of the alternatives was found as follows: adsorption > reverse osmosis > chemical treatment. As there is no skilled labor for the proper operation and maintenance of the treatment facilities in small establishments (e.g. villages), adsorption, which offers lower operation and maintenance cost with very low operator involvement, appeared to be the best alternative. However, decision-makers should remember that MCDM methods are decision support tools and should not be taken as the means for deriving the final answer. The conclusions of the solution should be taken lightly and used only as indications of what may be the best answer.

In this study, the criteria used in the comparisons were obtained from the literature (i.e. full scale or laboratory scale plants). In future studies, a group of decision-makers working in design, operations and other services could be involved to the process and other multiple criteria methods that consider group decisions (e.g. PROMETHEE) could be used for the selection of the treatment process.

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