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Multi-criteria decision making methods for rural water supply: a case study from Bangladesh

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Abstract

Multiple criteria decision making (MCDM) is a process of evaluating alternatives against relevant decision making criteria. Several methods are available to facilitate the evaluation steps. This paper deals with a rural water supply problem in the coastal areas of Bangladesh. Three different MCDM methods – weighted summation, analytical hierarchy process, and novel approach to imprecise assessment and decision environments – were used to evaluate the suitable water supply alternative. The ranking of alternatives obtained from these MCDM techniques produced similar results. Among five water supply alternatives evaluated, rainwater harvesting systems and deep tube wells scored first and second, respectively, for all three evaluation methods. In addition, sensitivity analyses were carried out for the MCDM techniques and these results did not show drastic variations either. This finding implies that while selection of MCDM technique is important, when evaluating similar problems more emphasis should be given to defining the problem comprehensively and thus selecting the relevant criteria and priorities to factor into the decision problem.

Keywords: Bangladesh; Cyclone prone area; Multi-criteria analysis; Rural water supply

1. Introduction

Multiple criteria decision making (MCDM) or multiple criteria decision analysis (MCDA) is a tributary of operational research or management science that explicitly assesses pertinent criteria in a decision making process. The method gradually evolved and became increasingly recognized by outranking cost/benefit analysis, particularly in the field of public policy analysis (Watson, 1981; Rauch, 1998). With the expansion of quantitative management science, decision making goals became increasingly imprecise and that led to the development of a plethora of MCDM methods that strive to provide solutions that consider a set of, often conflicting, criteria (Stewart, 1992). Bragge *et al.* (2010) conducted a bibliometric analysis and showed that the field experienced exponential growth from 1970 to 2007 and penetrated neighboring disciplines like mathematics, engineering, and

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information communication technology. To manage growing public concerns, conflicting views, and to ensure transparency as well as develop appropriate attributes of different criteria, MCDM, nowadays, is a widely used tool to deal with environmental decision making (Mustajoki *et al.*, 2004). Huang *et al.* (2011) showed a steady annual 7.5% growth of MCDM papers in environmental publications between 1990 and 2009.

MCDM is a practical and useful tool for solving real-life problems which often involve several conflicting criteria. To select the proper tool and use it efficiently, Stewart (1992) suggested considering three facts: (1) clear and meaningful input to the decision model, (2) transparency of the process and consistent translation from the input to the recommendation, and (3) simple and efficient model. MCDM has been successfully applied to evaluate and solve numerous environmental problems. Mendoza & Martins (2006) provided a critical review of MCDM techniques used in forestry and other natural resource management problems. The authors classified MCDM techniques into three categories: value measurement models, goal reference models and outranking models. They included a comprehensive review of different models used to evaluate various scenarios and concluded that MCDM is a potential approach for dealing with inherently complex natural resources management problems. Similarly, a systematic review of the fuzzy MCDM techniques used in different studies from 1994 to 2014 was conducted by Mardani *et al.* (2015). The authors have shown that there has been a dramatic increase in the successful application of these techniques in engineering, management and business, science and technology over the mentioned period.

Application of this technique in water resource management has increased during the last four decades. Hajkowicz & Collins (2007) conducted a review of MCDM techniques used for water resources planning and management and showed that a variety of techniques ranging from simple value function methods to relatively intricate fuzzy set analyses were widely used in studies published since 1973. Since conflicting benefits, environmental consequence, and multi-level stakeholder engagement are intrinsic characteristics of water resources planning and management, MCDM is a powerful tool to facilitate the decision making process (Urrutiaguer *et al.*, 2010; Hamouda *et al.*, 2012; Udias *et al.*, 2012). Moreover, stakeholder participation in water resources management is an essential requirement. Stakeholder participation, especially where contradictions between process criteria are likely to emerge, is positively linked with sound resource management (Carr *et al.*, 2012). Therefore, MCDM is increasingly used in various water management problems. However, as suggested by Theodor & Leanne (1995), while applying MCDM for water management, comprehensive problem structuring, precise delineation of alternatives and trade-offs among them should be established for effective decision making.

All available MCDM techniques give decision makers and analysts the capacity to make an informed decision even in a convoluted environment. Moreover, there are numerous examples of customizing – either by combining or modifying – these tools to use them for specific purposes (Kuo & Liang, 2011; Ebrahimnejad *et al.*, 2012; Ghassemi & Danesh, 2013). This development has led to the quandary of deciding which method to select for a given situation (Hajkowicz & Higgins, 2008). While some studies have shown variation in results when applied to the same problem (Zanakis *et al.*, 1998), some conjectured yielding the same results providing that the problem was structured comprehensively (Ozelkan & Duckstein, 1996; Hajkowicz & Higgins, 2008). Some researchers have proposed systematically selecting particular MCDM methods for decision making problems (Guitouni & Martel, 1998; Kurka & Blackwood, 2013).

In this study three MCDM methods – weighted summation, analytical hierarchy process (AHP), and novel approach to imprecise assessment and decision environments (NAIADE) – were used to see how the results varied and to understand the impact of using different methods. This study used the three methods to identify suitable alternatives from a range of water supply options. Although numerous studies have assessed the impact of using different methods to resolve various environmental and water resources management problems, this paper provides new evidence of how three different methods can be used to identify rural water supply options. The result shows that despite significant differences in calculation procedures of the MCDM methods the deviations in the results were marginal. It can be inferred from the findings that for similar categories of problems (moderate number of criteria and alternatives with the objective of selecting the best alternative) analog outcomes can be obtained using a simple MCDM method. The use of such methods will not only increase participation because they are easy to apply, but will also ensure transparency by allowing users to directly observe the implications of different weightages and scores assigned to criteria and alternatives.

2. Rural water supply planning and management

The Department of Public Health Engineering (DPHE) is the chief state agency for rural water supply and sanitation in Bangladesh. In addition, the Local Government Engineering Department is involved in implementing water supply and sanitation services through several projects. Moreover, the government supports and promotes involvement of development partners, non-governmental organizations (NGOs), and private partnership in developing water supply and sanitation services (Policy Support Unit (PSU), 2009). While DPHE is the main authority to install and maintain water options, the government encourages community empowerment, giving particular attention to engaging women in decision making and maintaining water supply facilities (Local Government Division (LGD), 1998).

The realm of rural water supply is predominantly governed by hand pump, tube well or borehole technology with groundwater serving as the source. During the early 1970s DHPE introduced tube well technology on a massive scale in rural areas, and today more than 10 million tube wells are operating throughout the country (Escamilla *et al*., 2011). Recently, however, a paradigm shift has occurred due to arsenic contamination in groundwater, unavailability of suitable aquifers, and seasonal lowering of the water table (LGD, 2011b). The first drinking water quality survey in the country found that 8% of the samples, mostly shallow tube wells, exceeded the Bangladesh standard (0.05 mg/L) for arsenic concentration (United Nations Children's Fund (UNICEF) & Bangladesh Bureau of Statistics (BBS), 2011). Apart from tube wells, rainwater harvesting systems (RWHSs), pond sand filters (PSFs), and natural ponds are the prominent water supply options in rural areas. The challenge of providing a safe and reliable water source becomes more difficult in littoral areas of the country (PSU, 2011). Owing to salinity in groundwater, shallow tube wells are not a preferred option. Moreover, tropical cyclones accompanied by saline water surge cause grave devastation of the water supply system in the coastal areas. Therefore, selection of water supply technology in coastal areas requires special consideration encompassing all the pertinent sustainability indicators.

3. The multiple criteria analysis methods

Typically MCDM methods are used to identify the most suitable option, to obtain a ranking of the options, to short-list a limited number of feasible options for further detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities (Department for Communities & Local Government (DCLG), 2009). MCDM problems can broadly be categorized as continuous and discrete. Continuous problems are those that have an infinite solution set, whereas the discrete problems deal with a finite number of solutions or alternatives (Belton, 1986). In the present paper, we applied three discrete MCDM methods since our problem of finding the most suitable water supply option has a defined number of alternatives. All these three methods were commonly used in environmental and water resource management decision making problems. A succinct description of the methods is provided below.

3.1. Weighted summation method

Weighted summation is a commonly used method in environmental and water resource management problems (Chowdhury & Rahman, 2008; Hajkowicz & Higgins, 2008; Al-Hadu *et al*., 2011). This method can provide solutions for problems that have a finite and discrete number of alternatives by evaluating conflicting criteria. Using this MCDM technique, alternatives are evaluated by summing the weighted scores against each criterion and finally comparing the total scores to obtain the ranking (San Cristóbal, 2012). The decision maker has the latitude to prioritize any criterion or set of criteria depending on its relative importance to the decision environment. The calculation of total value score for each alternative, considering assigned weight, is done using Equation (1).

$$V(A_j) = \sum_{i=1}^{n} w_i \, v_i(a_j) \tag{1}$$

If there are m alternatives ($j = 1, 2, \ldots, m$) and n criteria ($i = 1, 2, \ldots, n$), the total score of alternative A_j is $V(A_j)$ and can be obtained by summing all the scores A_i received in the evaluations. The scores for each criterion are calculated by multiplying the standardized score, i.e. $v_i(a_j)$ by the respective weight w_i. The best alternative is the one with the maximum score. Typically, standardization is carried out using Equation (2).

$$\mathrm{STD}_{k,j} = (\mathrm{ACT}_{k,j} - \mathrm{WORST}_{k,j})/(\mathrm{BST}_{k,j} - \mathrm{WORST}_{k,j}) \tag{2}$$

where $\mathrm{STD}_{k,j}$ is the standardized score value of the kth criterion and jth alternative. $\mathrm{ACT}_{k,j}$ is the actual value, $\mathrm{WORST}_{k,j}$ and $\mathrm{BST}_{k,j}$ are the worst and best value of the kth criterion, respectively.

3.2. Analytical hierarchy process

AHP is a widely used method, and it has been applied in almost all the models related to decision making (Vaidya & Kumar, 2006; Wang *et al*., 2009; Bragge *et al*., 2010; Huang *et al*., 2011). Likewise, AHP has widespread application in dealing with the convoluted problems of water resource management (Hajkowicz & Collins, 2007). Two steps are involved in using AHP for decision making: hierarchic design and evaluation (Vargas, 1990). The former step requires knowledge of the problem area, and the main objective is to structure the problem hierarchy. Depending on the decision maker's knowledge, perspective, and experience, the structures may vary from one to another.

Typically, however, it starts with a goal at the top of the hierarchy, evaluating criteria forms the intermediate level, and decision options are at the bottom level. The evaluation step is guided through a series of pair-wise comparisons that help to determine relative strength of impact of the compared elements with respect to a specific element that occupies the immediate level above in the hierarchy. All the comparisons in the evaluation process are carried out using a semantic scale and associated 1–9 ration scale (Saaty, 1990). The final result is obtained through the following steps:

- Weighting the criteria: linguistic terms are used to form a judgment matrix that results from the pair-wise comparison of the criteria. This indicates how important one criterion is compared to the other with respect to the goal.
- Pair-wise comparison of alternatives with respect to criterion: the alternatives are compared pair-wise to identify relative strengths considering each criterion. Matrices are formed from the judgment of the decision maker that enables the computation process and the notion of principal right eigenvector is used to obtain the relative priorities of each pair.
- Overall score of alternatives: the final synthesis is a process of multiplying and combining the priorities. The relative priorities obtained from the first step are multiplied by the relative priorities of the second step and finally the scores are added for each alternative to obtain the final score from which the ranking can be determined.

3.3. Novel approach to imprecise assessment and decision environments

NAIADE is also a discrete multiple criteria method; it was developed at the Joint Research Center (JRC) by Munda (1995). The method can synthesize both qualitative and quantitative information concerning socio-environmental evaluation problems. Owing to NAIADE's flexibility to manage a wide range of scoring patterns (i.e., crisp, stochastic, fuzzy, and linguistic) and its ability to provide acceptability of the result among different stakeholder groups, the method has been used to evaluate several environmental and water management problems (Munda, 2006; Salgado *et al*., 2009; Browne *et al*., 2010).

NAIADE allows two types of evaluation. The first is carried out using the score values provided in an impact matrix (alternatives versus criteria). Pair-wise comparison is performed using a defined preference relationship to calculate the credibility indexes. There are six defined preference relationship functions to express, for each criterion, an index of credibility of the statements that an alternative is much better, better, approximately equal, equal, worse and much worse than another. The credibility index value ranges from 0 to 1 with 1 being definitely credible. Then using an aggregation algorithm of the credibility indexes, the model determines a preference intensity index of one alternative with respect to another. The user can define a preference intensity index to determine which criteria (from the preference relationship) will be included for the analysis. Finally, based on the preference intensity indexes and corresponding entropy (value varying from 0 to 1 that gives an indication of the variance of the credibility indexes that are above the threshold), NAIADE provides the final ranking of alternatives (JRC, 1996). Besides, the ranking of alternatives, NAAIDE can also calculate the degree of conflict among different interest groups using an equity analysis. The present study was focused on the ranking of alternatives and did not use the equity analysis.

4. Study area and water supply alternatives

Historically, the pre-1970s rural water supply was mainly based on protected ponds (Ahmed, 2002). Later tube wells (shallow and deep) were dug on a large scale throughout the country to ensure access to safe water, and the coverage reached 96% of the total population (Hoque *et al*., 1996). Afterward, detection of arsenic, seasonal lowering of the groundwater table, and salinity in coastal groundwater reduced universal access to safe drinking water (LGD, 2011b). To provide access to such areas PSFs and RWHSs were introduced (Alam & Rahman, 2010). The study was conducted in Barguna, one of the coastal districts of Bangladesh, in the villages of Gajimahamud and Nishan Baria in Barguna Sadar sub-district and Padma and Shingra Bunia in Patharghata sub-district (shown in darker color in Figure 1). All four villages are located in the exposed coastal zone defined by the national Coastal Development Strategy and are vulnerable to cyclonic storm surge (Water Resources Planning Organization (WARPO), 2006). The area was severely affected area by cyclone Sidr (Government of Bangladesh (GoB), 2008) and unlike many other coastal areas where deep groundwater is the only drinking water source, the study villages have different sources of water supply (Uddin & Rahman, 2005). All the aforementioned facts and accessibility to the study site were considered while selecting the villages. Demographic data collected from the local Union Council Office (local government at union level) show that total 12,718 people (2,574 households) live in an area totaling 6.8 km^2 in these four villages. The main livelihood activity of the area is agriculture (78%) followed by fisheries and per capita income is $216.70. Average

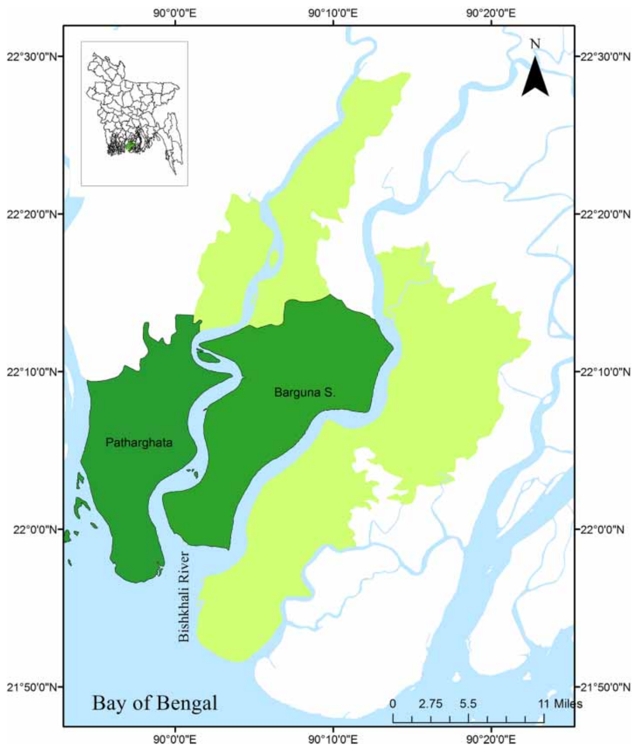

Fig. 1. Study area (light color showing the district boundary and darker color showing study sub-district).

total annual rainfall is 2,659 mm, and 90% of this rainfall occurs during monsoon season, which is from June to October (Uddin & Rahman, 2005). Brackish groundwater is available within 0–2.5 m below the ground surface, and low saline groundwater is available in some places in deep aquifers at a depth greater than 200 m (Ahmed, 1996). A brief introduction to the water supply technologies available in the area is provided below.

- Shallow tube well (STW): this technology uses a number 6 manually operated hand pump to extract water from a shallow aquifer (<150 m deep). This is a suction mode pump that creates a vacuum to withdraw water from a maximum depth of 7.5 m. Owing to salinity in shallow aquifers in coastal areas the technology is not very popular, yet a number of tube wells function in the area.
- Deep tube well (DTW): this extracts water from a deeper aquifer using the same number 6 hand pump as the shallow tube well. In cases where the groundwater table is lower than the suction capacity of the pump, the arrangement of the vacuum cylinder is lowered using additional parts to withdraw water. Similar to other parts of the country, deep tube wells are a common technology in the study area.
- Rainwater harvesting system: this is an arrangement for harnessing rainwater typically collected during the monsoon from roofs and stored in a collection tank. A PVC or steel gutter is used to convey water from the roof to the tank. Commonly, plastic and brick masonry and ferrocement are used as tank material, and if properly collected the water can cover a household's needs for the entire year (Ahmed, 1999).
- Pond sand filter: this is a surface water filtration unit that uses both a roughing filter and slow sand filter to treat pond water (Sikder, 2011). The first chamber (i.e. roughing filter) mainly reduces turbidity and the second chamber (slow sand filter) improves the microbial quality of the water.
- Pond: due to the ubiquitous presence of ponds in the study area, this was also considered as a water supply option. Although, the ponds are not very commonly used for collecting drinking water, they do serve as a primary source for some households that do not have access to any of the above-mentioned technologies.

5. Problem structuring and evaluating criteria

The water supply problem that the current study deals with is very common and at the same time involves conflicting decision criteria in rural areas of Bangladesh. It is always a challenge to determine a safe and reliable water supply alternative considering the social, economic, and technical criteria, particularly in a context as delineated in sections 2 and 3 of this paper (Sikder & Salehin, 2014).

Criteria are the measures of performance by which the alternatives will be judged. A measurement or judgment needs to specify how well each alternative meets the objectives expressed by a criterion (DCLG, 2009). The criteria for the analysis were selected by ensuring the active participation of stakeholders through questionnaire surveys. The survey asked about respondents' current water option, water quality, quantity, associated cost, satisfaction about the water source, cyclone resistance, etc. A partial list of selection criteria was included in the form following different guidelines for low-cost water supply systems (Ahmed & Rahman, 2000; Brikké & Bredero, 2003) and respondents were asked to add or remove from the list and prioritize the criteria. A total of 100 households were surveyed from the four villages. The sample size was selected considering the time requirement and associated expense of the study and this represents 3.88% of the total households of the area. Twenty-five households from each village were included in the survey, and at least four households representing each type of water option were surveyed. After the researchers identified users of the different water supply options, the respondents for the survey were selected randomly. The study took place with the approval of the Committee for Advanced Studies and Research of Bangladesh University of Engineering and Technology. The criteria identified from the survey are listed according to their corresponding groups in Table 1.

In the economic group, three criteria (implementation cost, operation and maintenance cost, and economic impact) were included. The implementation cost includes the expenses associated with the installation of the water supply option. Operation cost is the annual expenditure to maintain a functional facility, including spare parts and labor. Economic impact seeks to explore whether the option has any financial implication, either positive or negative, on the users.

The technical group comprises water availability, water quality, and cyclone-resistance criteria. Water availability deals with the issue of whether the water source produces water year-round and if not for how many months. The water quality criterion investigates the odor, color, and taste of the water sources. Finally, cyclone resistance is the ability of the water source to withstand cyclonic storm surge and produce safe water.

Lastly, the only criterion in the social group (social acceptance) indicates users' perceptions about a given water supply technology – if there is any presumptive notion among users about any of the technologies.

6. The evaluation matrix

The evaluation matrix is common to all three methods, and thus the formation does not require consideration of the calculation procedure variations of the methods. The evaluation matrix for the analysis was formed by using both quantitative and qualitative (linguistic) data. To assign scores to each alternative against each criterion both responses from the questionnaire survey and data from pertinent literature and technical reports were used.

Under the economic group, the implementation cost was calculated by estimating material costs for each option. Maintenance costs were obtained from the questionnaire survey data. An average value for each of the options was used as the cost of maintenance was not constant for all the interviewees. Qualitative data were collected and used to determine economic impact. Respondents reported positive economic impacts of all the options (no economic loss due to the water option) except the users of PSFs. This difference can be explained by the prohibition of commercial fish cultivation in ponds using PSFs, which limits owners' income generation options.

In the technical group, the water availability criterion was determined using both survey data and technical analysis results. To define the criterion of water quality both user perception and data from

Table 1. Evaluation criteria according to group.

Economic	Technical	Social
Implementation cost	Water availability	Social acceptance
Operation and maintenance cost	Water quality	
Economic impact	Cyclone resistance	

the relevant studies were used (Ahmed, 1996; Islam *et al*., 2001; Kawahara *et al*., 2004; Rahman & Jahra, 2007). Water from the PSF and RWHS scored well as both the options are capable of supplying safe water if designed and maintained properly (Ahmed, 1999; Ferdausi & Bolkland, 2000; Islam *et al*., 2007; Texas Water Development Board (TWDB), 2011; Harun & Kabir, 2013), and the users were also satisfied with the quality. Because the water from DTWs is bacteriologically safe, this water option scored higher than the STWs, which are at risk of bacterial contamination from the nearby pit latrines, but lower than PSFs and RWHSs because of salinity. Survey data were used to determine cyclone resistance. Respondents were asked about the experience of their water source after the last cyclone (Cyclone Sidr). The technical feasibilities of the water alternatives were also compared while scoring. RWHS scored the highest because the storage chamber used with this option is made of strong plastic, ferrocement, or brick masonry, which keeps water safe even during tropical cyclones accompanied by significant rainfall (Shahed & Sikder, 2010). DTW and STW are vulnerable as the surge water inundates the base of the pump. The main source of water in a PSF is the pond, so the pond and PSF are equally vulnerable to cyclone damage; however, PSF user committees take preventative measures by building embankments around their ponds so they are more protected than natural ponds. Considering this fact PSFs scored higher than natural ponds.

For the social acceptance criterion, DTW, PSF, and RWHS received good scores from respondents. A few interviewees were not satisfied with STW because of high salinity and unavailability of water year-round. Users of pond water said they do not want to drink it because it is not safe and requires further treatment.

During the questionnaire survey the respondents were asked to prioritize the evaluating criteria. The response shows that both economic and technical criteria are considered more important than the social criteria.

7. Application of MCDM methods

After formation of the evaluation matrix the analysis was carried out using the above-mentioned three methods. For the weighted summation method, no specialized software was used and the calculation was carried out using Excel. For AHP, SuperDecision software was applied, a decision making tool that follows the principle of the AHP developed by Creative Decisions Foundation (Saaty, 2003). Evaluation in the NAIADE method was carried out using NAIADE software developed by the Joint Research Centre of the European Commission – Ispra Site (JRC, 1996).

For the weighted summation method, five linguistic variables: very good (VG), good (G), moderate (M), bad (B), and very bad (VB) were used to score the qualitative data in the evaluation matrix. Since the economic and technical criteria were considered more important than the social criteria by the respondents in the questionnaire survey, the weightage of these two categories was 1.5 (except the implementation cost) and the social criteria was 1. The implementation cost is not fully borne by the user. Either the government or another organization recompenses the major portion; a small percentage of the total cost is taken from the user to develop ownership (LGD, 2011a). So, the weight of the implementation cost was determined to be 1. Standardization of value scores was carried out to perform the calculation, and the final ranking of the five alternatives according to the score is RWHS, DTW, PSF, STW, and ponds.

AHP was applied by forming the hierarchical decision model using the SuperDecision software. The first cluster was the goal, i.e., to find an appropriate water supply alternative. In the second cluster each criterion was assigned as an element, and in the third cluster each alternative was assigned as an element. To facilitate the pair-wise comparison the semantic scale of nine linguistic variables was used to assign priorities. The goal was connected with each criterion, and each of the criteria was connected with each alternative.

The NAIADE software creates the evaluation matrix as well as an impact matrix window. Implementation cost and operation and maintenance cost criteria were defined as quantitative, and direct numeric values were entered for each alternative. Other criteria were defined as qualitative, and scores for the alternatives were defined by the predefined linguistic variables of the software.

8. The rankings and sensitivity analyses

The ranking of five alternatives using the aforementioned criteria are presented in Table 2 below. For weighted summation the ranking was obtained by comparing the total scores of the alternatives, and for AHP and NAIADE the rankings were generated by the outputs of the respective programs.

The ranking from the above table clearly shows that the preference from the three different MCDM methods for the first two alternatives is identical.

To check the effect of criteria or their corresponding strength in the final ranking, sensitivity analysis was carried out for the MCDM methods.

For weighted summation, six cases were considered by altering the weights assigned to the criteria (Figure 2). Case 0 was the original analysis; case 1 was calculated changing all the 1.5 weightages to 1 in the original matrix; case 2 changed all 1 weightages to 1.5; case 3 analyzed the inversion of the actual weightages; case 4 changed the 1.5 weightages to 2; and case 5 increased the 1.5 weightage to 3.

Table 2. Ranking of alternatives from the three MCDM methods.

Position	Weighted summation	AHP	NAIADE
1st	RWHS	RWHS	RWHS
2nd	DTW	DTW	DTW
3rd	PSF	PSF	STW
4th	STW	STW	PSF
5th	Pond	Pond	Pond

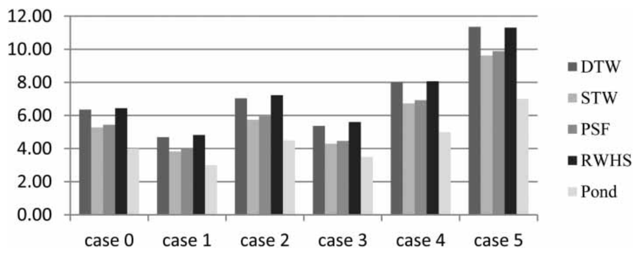

Fig. 2. Sensitivity analysis of weighted summation method.

The results from the sensitivity analyses show that in all the cases the ranking was almost the same. Only when the important criteria (defined by the users) were weighted threefold compared with the others, did the position of the first two water supply alternatives change. This implies, if the social acceptance and implementation cost were not included or given minimal importance, the ranking could have changed.

AHP sensitivity analysis was carried out to see how the rankings changed when assigning 0 priority to different criterion one at a time (Figure 3). Assigning 0 priority implies the corresponding criteria have no effect on the decision making process and therefore allows assessment of the ranking changes if that specific criterion was not considered in the calculation.

Since there were seven criteria, seven cases were considered by assigning 0 priority to one criterion except case 0, which was the actual ranking. From case 1–7 the criteria that were assigned 0 priority were water availability, economic impact, cyclone resistance, implementation cost, operation cost, water quality, and social acceptance, respectively. It is evident from Figure 3 that except for case 3 all other arrangements suggested the same preference for the best water supply alternatives. In case 3, when cyclone resistance was not considered, PSF outranked RWHS for the first position.

And finally, in NAIADE, since there is no weightage assigned to the criteria, the sensitivity analysis was carried out by changing the value of parameter α. α is an aggregation operator that allows the definition of criteria with which intensity of preference or indifference will be considered for the pair-wise comparison. Higher value of α indicates only the criteria with higher intensity of preference or indifference are used in the calculation, and a lower value refers to the opposite (Munda, 1995). Results of the sensitivity analysis are shown in Figure 4. Case 0 is the original result considering $\alpha = 0.5$, and case 1–5 were obtained by changing the value to 0.45, 0.40, 0.55, and 0.60, respectively.

Each case shows two outcomes from the NAIADE model $\Phi+$ and $\Phi-$, which refers to the leaving (positive) and entering (negative) flow individually. Higher value in the leaving flow and lower value in

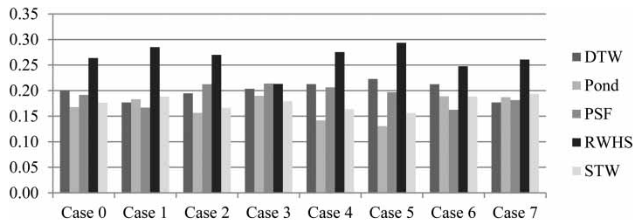

Fig. 3. Sensitivity analysis of AHP method.

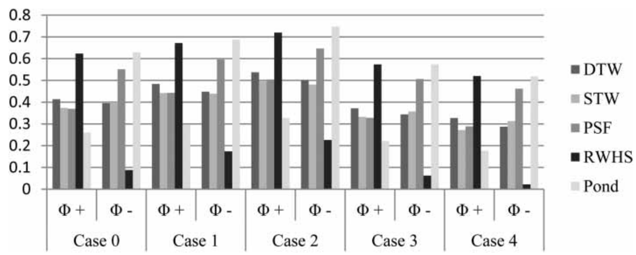

Fig. 4. Sensitivity analysis of AHP method.

the entering flow implies better position in the ranking. Similar to the other two analyses, Figure 4 clearly shows that the best choice was consistently the same for NAIADE in all the cases.

9. Discussion and conclusion

This study finds strong concordance among the results of three different MCDM methods. Although the low-ranked alternatives were not always positioned alike, the best and second best choices were the same for all three results. Similarly, the least preferred alternative was also the same.

The important fact to note here is, despite the variety of data synthesis procedures and level of intricacy involved with these methods, the suggestions were similar for the preferred alternatives. Since most of the water supply related problems seek to find the best suitable alternatives (Hajkowicz & Higgins, 2008), it could be inferred from the findings of the study that both simple and comprehensive MCDM methods yield the same output. Selection of suitable MCDM techniques is certainly an important feature of the decision making process, but for problems similar to the one discussed in the paper, that deal with a relatively small number of alternatives and criteria, an easy technique like weighted summation will offer the same desired result.

Instead of applying more sophisticated and complicated techniques, time would be better spent structuring the problem meticulously. If one contributing element is ignored during problem structuring and the pertinent criteria is not considered, the result may change significantly and will probably not provide the appropriate solution. For instance, case 3 of the AHP sensitivity analysis showed that when 0 priority was assigned to the cyclone resistance criterion, PSF became the best choice instead of RWHS. For coastal water supply, cyclone resistance is a pivotal factor though in other parts of the country it is not. Therefore, if the problem had been structured in line with general rural water supply problems, the best choice would have been an alternative that is somewhat vulnerable to cyclonic storm surge. Similarly, it is also crucial for decision makers to assess the actual weightage of each criterion (for methods where weightages are directly assigned). As found in case 5 of the sensitivity analysis of the weighted summation method, when the differences between normal and important criteria were increased threefold, DTW replaced RWHS and became the best choice. This example illustrates how overemphasis can change the result. Therefore, the weightages should be assigned prudently, and magnitude of relevancy of each criterion as it relates to the decision making problem should be considered when determining the weightage. In addition, relevant stakeholders could be involved to collectively decide on the weight for different criteria which will also enhance ownership and acceptance of the MCDM result (Honkalaskar *et al*., 2014).

As indicated above, although DPHE is the primary state authority for rural water supply, other actors like NGOs and development partners are also playing a vital role in ensuring this service. Simultaneously, public–private initiatives to install their own water points are also present. Regardless of the source – government, NGO, or private – the necessity of considering pertinent criteria and thus using MCDM techniques is inexorable. However, the challenge surfaces when selecting an appropriate MCDM method that can be easily used by the associated decision makers and ultimately ensure transparency and participation of related actors. To find a way forward, the authors would like to propose the selection of a simple MCDM method like weighted summation to deal with relatively less complicated problems like the one mentioned in the paper. Instead of investing much effort on understanding and selecting sophisticated analysis methods, more attention should be devoted to problem structuring, defining criteria, and determining relative priority of the criteria. The findings from this exercise could be rendered to similar cases and eventually to reinforce water supply strategy by including a ranking of preferred alternatives for different regions.

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