Participatory multi-criteria evaluation of alternative options for water supply in cyclone-prone areas of Bangladesh

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ABSTRACT

Availability of safe drinking water is considered a key challenge in the coastal region of Bangladesh. High concentrations of salinity, iron and arsenic, and the unavailability of suitable aquifers, have deterred the exploitation of groundwater resources. In addition the cyclonic storm surge is a major threat to this system. Cyclones accompanied by storm surges in the coastal area cause significant deterioration of drinking water supply and sanitation. Water professionals have launched some initiatives to promote small-scale, alternative safe water sources (e.g. rainwater harvesting, pond sand filters and piped water techniques) to provide sustainable solutions to the problem. However, a systematic evaluation of the alternatives that considers social, technical and economic criteria has not been carried out so far. The present study is an attempt to evaluate the alternative options for drinking water supply in a cyclone-prone area. The authors conducted a multi-criteria analysis and reached the conclusion that rainwater harvesting is the most suitable option for the area. Moreover, the final result was shared with the users to obtain their feedback to ensure sustainability of the water source.

Key words | coastal area, cyclone, drinking water supply, participatory multi-criteria analysis, water supply option

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INTRODUCTION

The integrated water resource management (IWRM) approach is gaining traction in the field of water resource planning and management. The aim of this interdisciplinary approach is to consider technical, social, economic and environmental aspects of a given problem (Zarghaami 2006). Multi-criteria decision analysis (MCDA) is an effective tool for decision-making using the IWRM approach. This ensures the active participation of stakeholders and experts from different disciplines in the decision-making process. To make a water resource project successful and sustainable it is important to involve users, government agencies, nongovernmental organizations and other development stakeholders in the decision-making process. In Bangladesh, however, stakeholder participation during planning is not a very common phenomenon (Chowdhury & Rahman 2008). As a result, lack of stakeholder participation is one of the causes of the failure of many schemes to function as expected (Chadwick & Datta 2003).

Public sector planning and management problems are always challenging and complex. Decision makers have to deal with a number of alternatives and evaluate them based on some incompatible criteria. To ensure social equity, technical feasibility and economic efficiency, the conventional cost–benefit analysis method is not very effective as it applies the valuation technique and converts all the impact into monetary value (Munda 1995). Stakeholders need to be involved as early as possible in the analysis and to focus that involvement on refining objectives and criteria, rather than on adjusting a proposed solution (Bruen 2002). The MCDA approach provides a flexible way to deal with

doi: 10.2166/washdev.2014.094

both qualitative and quantitative multidimensional effects of a given problem. Using this technique, practitioners look at complex problems characterized by any mixture of monetary and non-monetary objectives, break the problem into more manageable pieces, and apply data and judgments to the analysis of each component. After this exercise, the pieces are reassembled to present a whole coherent picture to decision makers (DCLG 2009).

The coastal zone of Bangladesh is a place of multiple vulnerabilities and opportunities. Records of the last 200 years show that about 70% of the cyclones that originated in the Bay of Bengal have made landfall in Bangladesh (Islam & Ahamed 2004). Rural water supply in Bangladesh is mainly dependent on groundwater. But establishing a safe and reliable source of drinking water is one of the major challenges in the coastal areas because of salinity in groundwater (PSU 2011). The situation deteriorates further when a cyclone strikes. To establish a reliable and consistent source of water, government and other organizations have installed and constructed different water supply options (Paudyal 2009). This study is an attempt to apply MCDA in evaluating the existing water supply options in the study area, ensure stakeholder participation and develop a ranking of the alternatives.

MATERIALS AND METHODS

Multi-criteria analysis is a well-known tool to use when stakeholder participation and conflict management are among the objectives of the decision-making process. Some examples of applying multi-criteria analysis successfully in environmental and water resource management issues are found in Raju *et al*. (2000), Hostmann *et al*. (2005) and Herath (2004). A participatory multi-criteria analysis method was applied to evaluate the alternative water supply options of the area. The study also assessed technical and social feasibility of the different options. Questionnaire surveys and participatory rural appraisal tools were applied to identify the existing alternatives and also to derive the evaluating criteria from the stakeholders. Multi-criteria analysis was conducted using an impact matrix, in which different options were ranked following both quantitative and qualitative analysis of options against the criteria. Then users were asked to suggest sustainable solutions to equity issues that were identified during the questionnaire survey. Finally, some recommendations were made that would ensure sustainability of the intervention.

Study area

The study was conducted in Barguna, one of the coastal districts of Bangladesh. The villages of Gajimahamud and Nishan Baria in Barguna Sadar subdistrict and the villages of Padma and Shingra Bunia in Patharghata subdistrict were selected because of their vulnerability to cyclone and storm surge. All four villages are located in the exposed coastal zone defined by the national Coastal Development Strategy (Water Resources Planning Organization 2006) and along the bank of the tidal river Bishkhali. The data on demographics and total land area of the study area were collected from the respective Union Council Offices (local government at Union level). The total population is 12,718 (2,574 households) and total land area is 6.8 km^2. Among the villages, Nishan Baria has the largest population with a total of 857 households and Padma has the smallest, 511 households. Average 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).

In the coastal area brackish groundwater is available within 0 to 2.5 m below the ground surface. In some regions low saline groundwater is available in deep aquifers at a depth greater than 200 m (Ahmed 1996). The area is only a few feet above sea level and the entire southern part is exposed to the Bay of Bengal (Uddin & Rahman 2005). Geographical positioning has made the district highly vulnerable to cyclone and storm surge (Islam & Peterson 2009).

Origin and extent of the problem

In the Coastal Development Strategy (Water Resources Planning Organization 2006) of the Bangladesh Government, lack of safe drinking water was identified as a key concern. Water supply in the area is mainly dependent on hand pump tubewells. Pond water is also used especially where groundwater is either saline or unaffordable. Data from a recent multiple indicator cluster survey showed that 85.7% of the population has access to deep tubewells

(BBS and UNICEF 2010). But in recent years, the groundwater-based water supply in coastal areas has suffered from a number of major problems, primarily arsenic contamination, lowering of the water table, salinity and nonavailability of a suitable aquifer (Ahmed & Rahman 2003). The problem becomes more critical when a cyclone or storm surge strikes the area and damages the water supply sector critically. All the ponds of the inundated area become contaminated by saline and turbid surge water. Surge water also deteriorates the quality of the tubewell water. Saline water goes through the suction pipe and contaminates the water in the aquifer. In Barguna a total of 1,343 tubewells were damaged by the devastating Cyclone Sidr in 2007 (MoFDM 2008). Without proper treatment the water cannot be used for drinking purposes. After a cyclone strikes, the population of the coastal area suffers a massive deficiency of safe drinking water and this results in the outbreak of waterborne diseases (Rahman & Bux 1995).

Selection of alternatives and criteria

To meet the drinking water demand, various water supply technologies were introduced in the area. Formerly, people drank rainwater during the monsoon, and they stored the water in large-sized earthen pitchers during this season (Hussain & Ziauddin 1992). During the dry season the main source of drinking water was ponds, which were specially conserved for drinking purposes (Ahmed 2002). Then shallow and deep tubewells were introduced. The tubewell reduced the prevailing problem of water supply and quality to some extent but created some new problems as referred to in the section above. Options such as pond sand filters (PSF) and rainwater harvesting systems (RWHS) were also introduced in the area to minimize dependency on groundwater. For this study all five water supply options in the community were considered. They are: hand pump connected with deep (DTW) and shallow (STW) tubewells, PSF, RWHS, and natural ponds.

The 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 ensuring the active participation of the stakeholders through questionnaire surveys (incorporating partial lists of criteria and asking the respondent to accept or reject and add new criteria if necessary). A total of 100 households were surveyed from the four villages. 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 criteria listed on the questionnaire survey were: implementation cost, operation and maintenance cost, economic impact of the facility over the users, water availability, water quality, social acceptance, and cyclone resistance. The criteria were then grouped into three categories: economic, technical and social. The study took place with the approval of the Committee for Advanced Studies and Research of Bangladesh University of Engineering and Technology.

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 also 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. Water quality criterion investigates the odor, color and taste of the water sources. And 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 the users' perceptions about a given water supply technology – if there is any presumptive notion among users about any of the technologies. The criteria and their groups are shown in Table 1.

MULTI-CRITERIA ANALYSIS

A weighted sum method was used in this study to perform the multi-criteria analysis. The alternatives were calculated

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	

based on the score value and respective weight assigned to them using Equation (1)

$$V(A) = \sum w_i v_i(a_i) \quad (1)$$

where, w_i is the weight of the criterion i, v_i (a_i) is the score of one alternative with respect to criterion i, and $V(A)$ is the resultant value of the alternative A. Both qualitative and quantitative data were used as the scores so standardization was necessary to convert all scores into the same unit. The standardization was performed by assigning a score of zero to the worst strategy and 1 to the best by using Equation (2)

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

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. Finally the ranking of the alternatives was developed by using the total score ($V(A)$) obtained by the analysis.

Impact matrix

The impact matrix for the analysis was formed by using both quantitative and qualitative (linguistic) variables. Under the economic group, the implementation cost was calculated by the estimation of 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 PSF. This difference can be explained by the prohibition of commercial fish cultivation in ponds using PSF, which limits owners' income generation options.

In the technical group, the water availability criterion was determined by using both survey data and technical analysis results. To define the criterion of water quality both user perception and data from the relevant literature was 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; TWDB 2011; Harun & Kabir 2013) and the users were also satisfied with the quality. Because the water from DTW is bacteriologically safe, this water option scored higher than the STW, which are at risk of bacterial contamination from the nearby pit latrines, but lower than PSF and RWHS 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 feasibility 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 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 the PSF 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. And users of pond water said they do not want to drink it because it is not safe and requires further treatment.

Qualitative data in the impact matrix are presented using five different linguistic variables: very good (VG), good (G), moderate (M), bad (B) and very bad (VB).

A scale of 1 to 5 was used to define the scores from VB to VG. The monetary values for the first two criteria were scored in Tk (currency of Bangladesh). Table 2 shows the score of alternatives with respect to the criteria.

During the survey respondents were also asked to prioritize the evaluating criteria. The economic and technical criteria were considered higher priority than the social. So economic and technical were weighted at 1.5 (except the implementation cost) and the social criterion was weighted at 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 2011). So the weight of the implementation cost was determined to be 1. Table 3 illustrates the standardized scores of the alternatives and the weights. For instance, the score of implementation cost of DTW (Table 3) was determined through the following steps: (i) the numerator was calculated by subtracting the worst (maximum) value from the actual value, i.e. 70,000–95,000; (ii) the denominator was determined by subtracting the worst value form the best (minimum), i.e. 25,000–95,000; and (iii) the score was obtained by dividing the nominator by the denominator and multiplying the result with the weight for the criterion, i.e. $(-25{,}000/-70{,}000)\times 1 = 0.36$.

Equity issues

Users were asked to identify sustainable solutions to equity issues that were identified during the survey. Discussions focused on five main concerns: (i) distribution of maintenance cost among the users; (ii) ensuring options for women and adolescent girls that take into account easy access, harassment and dignity; (iii) obstruction by the

Table 2 | Scores of alternatives with respect to criteria

		Alternatives				
Groups	**Criteria**	**DTW**	**STW**	**PSF**	**RWHS**	**Pond**
Economic	Implementation cost (Tk)[a]	70,000	30,000	95,000	55,000	25,000
	Operation cost (Tk)[a]	3,875	1,880	2,478	3,329	1,655
	Economic impact	G	G	M	G	G
Technical	Water availability	G	M	G	M	M
	Water quality	M	B	G	G	VB
	Cyclone resistance	M	M	B	G	VB
Social	Social acceptance	G	B	G	G	B

G: good (score 4); M: moderate (score 3); B: bad (score 2); VB: very bad (score 1); DTW: deep tubewell; STW: shallow tubewell; PSF: pond sand filter; RWHS: rainwater harvesting system.
[a]77.64 Tk = 1 US$.

Table 3 | Standardized scores of the alternatives

			Alternatives				
Groups	**Criteria**	**Weights**	**DTW**	**STW**	**PSF**	**RWHS**	**Pond**
Economic	Implementation cost	1.0	0.36	0.93	0.00	0.57	1.00
	Operation cost	1.5	0.00	1.35	0.94	0.37	1.50
	Economic impact	1.5	1.50	1.50	0.00	1.50	1.50
Technical	Water availability	1.5	1.50	0.00	1.50	0.00	0.00
	Water quality	1.5	1.00	0.50	1.50	1.50	0.00
	Cyclone resistance	1.5	1.00	1.00	0.50	1.50	0.00
Social	Social acceptance	1.0	1.00	0.00	1.00	1.00	0.00
Total			6.36	5.28	5.44	6.44	4.00

land owner during water collection; (iv) discrimination of rich and poor in decision-making; and (v) the influence of the rich in site selection of the facility. Some of the users felt that maintenance costs should only be borne by the affluent to ensure the smooth functioning of the facility. Most of the users felt that women, as the primary handlers of water, must be ensured free access to options. Some respondents complained that land owners obstructed access to water. On the other hand, households that had their own facility worried that if they allow everyone to collect water, their facility will become damaged through misuse and not last long. Criticism also surfaced about discrimination of rich and poor during site selection of a new facility and about the formation of caretaker committees, which are responsible for function and maintenance of water sources. Seemingly, if only the local elite are involved in the caretaker committee, it may not function as expected and the users may encounter difficulties in compelling the committee to take the necessary steps to fix the problem.

A focus group discussion (FGD) with 24 users of different options was conducted in the community to clarify the equity issues. The users were asked to evaluate the alternatives with respect to the above-mentioned equity criteria. The equity evaluation reflected the qualitative assessment of alternatives by the stakeholders. Also the ranking of the alternatives based on the impact matrix was shared with the users.

The major suggestions of the FGD were:

- Individual options such as household RWHS function better and require less maintenance than communal options because no one takes the responsibility to fix communal facilities if something is broken or stolen. Though some newly constructed facilities have caretaker committees in place, most committees are inactive.
- It was strongly recommended that during site selections the interests of women should take priority as they are prime users of water options. Sites should be selected in places where women feel comfortable, with no threat of physical harassment, and their privacy is ensured.
- Training needs to be enhanced to maintain new technologies such as PSF and RWHS, which are more sophisticated and require more technical expertise.
- During site selection and formation of caretaker committees, all users should be considered equally. A memorandum between the users and the land owner should be put into place for communal options. Priority should be given to ensure maximum coverage.
- The users emphasized the need to establish ownership of the options to ensure sustainability, which requires much more social mobilization and community participation.

MAJOR FINDINGS AND RECOMMENDATIONS

The scores of the alternatives based on the impact matrix are presented in Table 3. The scores for DTW, STW, PSF, RWHS and natural ponds are 6.36, 5.28, 5.44, 6.44 and 4.00, respectively, when calculating the weighted sum. It is clear that RWHS secured the highest score at 6.44. The ranking from highest to lowest based on the scores of alternatives is: RWHS, DTW, PSF, STW and natural ponds. During the FGD, the ranking was discussed with the community. Participants also agreed that RWHS is the best option as a source of drinking water supply for the study area. As the groundwater is saline and PSF requires sophisticated maintenance such as changing the filter materials and replacing them after a certain period, RWHS was viewed as the best choice. The equity issues were evaluated by the qualitative assessment of the stakeholders. Some suggestions also came up during the user discussion regarding the sustainability and smooth functioning of facilities. A major portion of the participants complained of discrimination between rich and poor during the site selection process and formation of the caretaker committees. They also suggested considering the gender issue during site selection and design of facilities. For instances, women are not comfortable to fetch water from facilities located in public places with a high male assemblage. Similarly, the staircases of raised platforms and the height of the collection tap should be designed considering easy access for women and children. The necessity of developing ownership and the importance of proper operation and maintenance of the facilities also came up during the discussion. Participants also made strong recommendations regarding the installation of individual facilities.

Considering the criteria to evaluate the existing options, RWHS were found to be the most suitable alternative in the area. It is important to consider the value judgments of the users during the selection of a water supply option. This will ensure the sustainability of the facility. During the design of a facility, user suggestions should be given high priority. Discrimination among the rich and poor should be eliminated from the process. Instead of selecting affluent households, sites should be selected based on specific criteria such as number of users covered, distance from the target households and not inside someone's private residence. This will ensure easy access of all the users as well as longevity of the facility. During site selection the gender perspective should be given significant weight and water options should be installed where women and children have easy and safe access. By providing necessary training and developing awareness, the regular maintenance of a facility can be ensured. Independent options for each household could address many of these issues as the users will no longer have to collect water from a distance and others will not be able to restrict access. However, this will require huge financial support. Participation of both beneficiary and implementer (government or other stakeholders) in the initial cost can reduce this burden. Discussion with the stakeholders should be open, and the decision-maker should address all the issues raised.

Feasibility analysis of technical and economic criteria along with social perspectives will ensure the sustainability of a water supply facility. Since rainwater harvesting was chosen as the most preferred option, special attention should be given to facility design. The storage tank should be designed to preserve water for the dry season. The operation and maintenance of the facility should be simplified to ensure smooth functioning and longevity. Thus use of low-cost, long-lasting and locally available material that would ensure easy water collection, tank cleaning and flow diversion may popularize the system to the users. Additionally, as participants mentioned, the operation cost of RWHS is relatively high compared with other options; while designing the facility this should be taken into account and components that are more durable and do not require annual repair or replacement should be used. RWHS received the highest score in the cyclone resistance criterion. While all the other water sources are contaminated by saline surge water, RWHS can serve as a source of safe water due to the accompanying rain of the cyclone. This unique feature of the technology makes it a suitable option for water supply in the cyclone-prone areas of Bangladesh.

Drinking water supply in the coastal area of Bangladesh is a major challenge. Drinking water is the most critical issue especially in the rural areas closer to the sea where groundwater is saline. The government is trying to promote small-scale alternative water supply sources. But the sustainability of these facilities depends on the users to a great extent. So the determination of the user's perception about a facility is essential. If an option is selected based only on the technical feasibility, it might not be sustained if the users are reluctant to receive the technology. To ensure the predicted performance of any water supply facility, all the criteria related to the water supply should be considered properly. This study was an attempt to perform a participatory assessment of water supply facilities in the cyclone-prone coastal area and develop a ranking of the options. RWHS emerged as the most preferred option for the study area.

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First received 1 August 2013; accepted in revised form 21 November 2013. Available online 27 January 2014