Drinking Water Options in the Context of Arsenic Contamination in the Vietnamese Mekong Delta

Vo Thanh Danh, Huynh Viet Khai, Nguyen My Hoa, and Nguyen Van Cong

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January, 2017

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All opinions, findings, conclusions, and recommendations expressed in this report are those of the authors and do not necessarily reflect the views of EEPSEA. The authors are solely responsible for any errors in this paper.

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DRINKING WATER OPTIONS IN THE CONTEXT OF ARSENIC CONTAMINATION IN THE VIETNAMESE MEKONG DELTA

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EXECUTIVE SUMMARY

This study aims to assess households' choices regarding safe drinking water and safe water treatment technology in the context of arsenic (*As*) contamination in the Vietnamese Mekong Delta (VMD). Based on the Protection Motivation Theory, the study designed a predictive model of *As*-poison-related health protective behavior via a cognitive mediating process with threat and coping appraisals of intention action choice in safe drinking water by household. Quantitatively, the study used methods of cost-effectiveness analysis (CEA) and multi-criteria analysis (MCA) to rank household preference of *As*-mitigation technologies. Additionally, descriptive statistics analyses were used to test households' knowledge of arsenic and its health impacts. The choice of sampled areas was based on a previous secondary *As*-contamination well testing program.

A total of 404 households, consisting of both tested and untested households, were interviewed in the survey. The results showed that unsafe groundwater was still being used for drinking water. The borax method and treatment equipment were the preferred choices for water decontamination, respectively. Household knowledge of *As* contamination was extremely bad and differed depending on a household's socioeconomic and demographic factors and on *As* contaminated area.

Five factors affected a household's decision to use *As*-treatment technology: educational status, duration of residence, family size, knowledge of *As*, and ethnicity. In terms of cost-effectiveness, at a discount rate of 3% and a timeline of 10 years, the results showed that the costs per death averted or the costs per disability-adjusted life years avoided saved by using sand filter and treatment equipment were USD 1.29 and USD 1.13, respectively. This suggests that using the treatment equipment method is the best choice for preventing *As*-related diseases.

Finally, household preferences regarding water treatment methods are different depending on what criteria are given top priority. The study proposes policy recommendations to improve safe water use and water provision in arsenic-contaminated areas, such as launching a public awareness campaign, speeding up the existing rural piped water program, promoting safe water treatment or arsenic treatment equipment, providing the public with up-to-date and accurate information on the state of *As* contamination, and seeking additional safe water sources such as rainwater and treated groundwater.

1.0 INTRODUCTION

1.1 Background and Rationale

Access to a supply of safe drinking water should always be one of the top priorities in developing countries, including Vietnam. The Vietnamese Mekong Delta (VMD) is a home to about 18 million people. Almost 70% of the VMD population lives in rural areas, where access to clean water is a problem. There is pressure to meet the ever-increasing demands for water due to Vietnam's high economic growth and growing population.

This study examines arsenic (referred to throughout this research report as "*As*") contamination in the VMD. Arsenic is a toxic metalloid that has adverse effects on human health (Ratnaike 2003). All major chronic *As* poisonings have stemmed from water, and this is usually the predominant exposure route. Various clinical symptoms (e.g., hyperpigmentation, symptoms of keratosis) and different cancers (e.g., cancer of the skin, internal organs, lungs etc.) have proven links to *As* consumption. Since 2003, the United Nations' Children's Fund (UNICEF) has examined groundwater at tube wells in the VMD. It has found that groundwater extracted from tube wells in Long An, Kien Giang, An Giang, and Dong Thap provinces is seriously contaminated with *As*. Stanger et al. (2005) provide an overview of *As* pollution in groundwater across scattered anomalous areas where contamination of 10–30 µg/l is quite common, although most aquifers contain groundwater of no more than 10 µg/l. High *As* groundwater was found at a depth of between 100–120 m in water tables. Most *As*-contaminated areas are located along the Hau and Tien rivers and in the Long Xuyen quadrangle.

1.2 Water Supply in the Mekong Delta

Circumstances surrounding safe water use and supply in the VMD are complicated. Choosing safe water sources mainly depends on the availability of water sources, their quality, and the economic condition of households. Table 1 shows the opportunities and constraints inherent in these options. There are three main water supplies: surface water, groundwater, and rainwater. Table 2 shows safe water-use options in the rural areas of the VMD. The proportion of safe water users is quite low. A large proportion of the populations of Bac Lieu, Soc Trang, Hau Giang, and Tra Vinh provinces use groundwater from tube wells. A large proportion of the populations of Dong Thap, Kien Giang, An Giang, Hau Giang, and Long An provinces access river water for domestic use. Residents used safe water from Groundwater Supply Unit (GSU)[1] water, rainwater, and surface water at 34%, 4.2%, and 4% respectively. Some 24% of rural residents use unsafe untreated groundwater and surface water.

A survey by Danh (2008) on the demand for clean water amongst users of groundwater in the Mekong Delta showed that groundwater was the preferred water source. Rainwater ranked second, while river water was not preferred at all. The serious pollution of rivers in recent years has discouraged people from using river water. Meanwhile, rainwater presents problems of air pollution, reliability, and storage. People in the VMD prefer to use groundwater for domestic uses. However, they still use other water sources such as rainwater and river water for daily activities. Households believe that using groundwater will allow them to avoid health hazards. The reliability of groundwater sources is also appreciated by households. With regard to rainwater and river water sources, availability and reliability were cited as the most important reasons for continued domestic use.

[1] A GSU user stands for those who are using the clean water from a Groundwater Supply Unit (or public water).

Table 1. Techniques, advantages, and constraints of different water sources in the Mekong Delta

Water Sources	Type of Pollution	Water Storage/ Extraction Options	Water Treatment Techniques	Advantages	Constraints
Rainwater	Acidity Air dust Other pollutants deposited on house roofs	Small-scale terra-cotta jars or cement-brick tanks	Porous porcelain filter equipment Drying Boiling	Very cheap water source Covers a wide area Easily available in the rainy season Easy to collect Suitable for the majority, especially the poor	Unreliable in the dry season Time-consuming to treat
		Large-scale containers	Porous porcelain filter equipment Drying Boiling	Very cheap water source High quality Covers a wide area Easily available in the rainy season Easy to collect	Unreliable in the dry season Low affordability (due to buying the containers) Time-consuming to treat
Surface water (water from rivers, lakes, etc.)	Suspended solids/particles Salinity Chemical toxins High acidity Other pollutants	Cement or brick containers	Treatment with aluminum sulphate Slow sand filtration Chloric disinfectant	Cheap water source Easily available Preferred by households	Time consuming to collect High pollution in the dry season No full removal of bacterial contamination
		Groundwater Supply Unit (GSU) plants	Advanced treatment techniques	Cheap water source Widely available	High cost to remove pollutants
Groundwater	Salinity High iron content High acidity Arsenic contamination Other contamination	Private tube wells	Sand and/or carbonate filtration	Suitable for remote areas Reasonable cost	Household's economic constraints; poverty High density wells could lead to subsidence of land No full removal of pollutants
		GSU plants	Rapid/slow filtration Aeration by water diffusing tray Other advanced treatment techniques	Helps to manage groundwater resources Use controlled by market prices	Household's economic constraints High cost to remove pollutants

Source: Danh (2008)

Table 2. Safe water-use options in the Mekong Delta

Province	Rural Population (1,000 persons)	Proportion of Safe Water Use					Comply with Vietnamese Standard
		Total	GSU	Tube Well	Rainwater	River Water	
Long An	1,197	89.80	63.24	17.13	–	9.21	11.60
Tien Giang	1,435	84.55	74.93	6.35	2.63	0.64	55.05
Ben Tre	1,081	76.00	–	–	–	–	32.00
Tra Vinh	947	66.00	26.26	39.94	6.42	–	40.00
Vinh Long	869	73.00	37.00	–	–	–	37.00
Đong Thap	1,483	63.44	43.82	3.30	–	16.32	43.82
Can Tho	779	71.46	39.00	27.50	2.40	3.70	57.76
Hau Giang	579	82.57	15.21	50.10	7.82	9.44	44.96
Soc Trang	1,173	87.20	28.88	56.41	1.92	–	28.51
Bac Lieu	697	74.36	7.70	60.18	–	–	52.00
Ca Mau	989	78.00	7.80	–	–	–	n/a
Kien Giang	1,372	74.66	14.94	47.15	–	12.57	27.51
An Giang	1,567	57.02	42.70	4.56	0.67	9.82	48.82
Total	14,167	75.82	–	–	–	–	36.52

Source: Provincial statistics, 2012

Table 3 presents the main reasons for a household's choice of water sources for domestic use. There is a marked difference in the behavior of the two water-user groups in terms of the purpose of the water use. Non-GSU households used groundwater, rainwater, and river water mainly for drinking, cooking, bathing, and washing, while GSU households did not use river water for drinking and cooking. This was the biggest difference in the pattern of water use of the two water user groups in the study. The GSU households used groundwater for cooking and drinking, the most important reasons for obtaining a clean and sanitary water supply.

Groundwater was also the most important source of water used by GSU users and non-GSU users for other activities such as bathing, washing, gardening, and so on. Table 4 ranks water sources used for different purposes. Groundwater is used for drinking in the VMD, especially in remote rural areas. *As* contamination in groundwater sources certainly affects a part of the population in the VMD. There are already studies on the issue of *As* contamination in the VMD but most of them examine population coverage and the geochemical distribution of high *As* concentrations, etc.

Table 3. Reasons for choice of water sources for domestic use (in percent)

Reasons for Choice	Sources of Water		
	Groundwater	Rainwater	River Water
Reliability	67.4	16.9	41.2
Availability	27.9	62.8	71.9
Convenience	15.9	25.0	–
Health concerns	63.9	35.8	1.8
Other water source/s polluted	78.1	20.3	–
Low cost	36.9	25.0	36.8

Source: Danh (2008)

Table 4. Ranking of water source by purpose (in percent)

Water Sources	Purpose of Use					
	Drinking	Cooking	Bathing	Washing	Gardening	Other
Non-GSU users						
Groundwater	61.8	90.4	97.9	93.6	39.3	24.5
Rainwater	57.7	24.4	3.4	3.0	–	–
River water	6.7	9.8	8.5	25.2	–	6.4
GSU users						
Groundwater	74.8	100.0	100.0	77.2	3.1	4.7
Rainwater	41.7	18.9	–	–	–	–
River water	–	–	11.0	37.8	34.6	7.9

Source: Danh (2008)

1.3 Research Questions

This study highlights the following questions:

1. What do people know about the risk of using *As*-contaminated drinking water?
2. Why do people continue to consume *As*-contaminated drinking water?
3. What factors make people respond to *As*-related health impacts?
4. Which proposed *As*-treatment technologies are preferred or not preferred by households?

5. What factors affect household decisions regarding drinking water choices?
6. What roles do information and government policy play in water-usage behavior by households and communities?
7. What are the practical policies for safe drinking water in the areas contaminated by *As* in the VMD?

1.4 Objectives of the Study

The main objective of the study was to assess household constraints and choices in the context of *As* contamination and to propose policy recommendations for safe drinking water use in the VMD. The specific objectives were

1. to assess household behavior with regard to choices around drinking water given the *As* contamination situation;
2. to find out what *As*-treatment technologies are preferred or not preferred by households;
3. to rank proposed *As*-mitigation options;
4. to analyze factors that determine household awareness and preferences for safe drinking water in the context of *As* contamination; and
5. to make policy recommendations for safe drinking water use in the areas contaminated by *As* in the VMD.

2.0 REVIEW OF LITERATURE

Arsenic is a toxic metalloid that has adverse effects on human health (Ratnaike 2003). *As*-contaminated groundwater has become a critical water quality problem in many parts of the world, particularly in East Asia (Nordstrom 2002). Kapaj et al. (2006) showed that the ill effects of human exposure to *As* have recently been reevaluated by government agencies around the world as *As* has caused deleterious effects at lower concentrations than previously thought possible. For example, increases in fetal loss and premature delivery and decreased birth weights of infants can occur even at low (<10 µg/L) exposure levels.

All major chronic *As* poisonings have stemmed from water, which is usually the predominant exposure route. These poisonings have various clinical symptoms such as hyperpigmentation and keratosis. Different cancers (e.g., cancer of the skin, internal organs, and lungs) have proven links to *As* consumption. Kapaj et al. (2006) concluded that "communities with water *As* levels greater than 5 µg/L should consider a program to document *As* levels in the population." It is estimated that groundwater extraction serves about 4.5 million people out of the VMD's total population of 14 million (Ghassemi and Brennan 2000). Most planned water plants depend on groundwater extraction, but high levels of *As* contamination are found in groundwater (Shinkhai et al. 2007). Consequently, *As* pollution in groundwater has raised more and more concerns about the health risks for the people who consume it.

With regard to the VMD, Stanger et al. (2005) provided an overview of *As* pollution in groundwater and stated that scattered anomalous areas of 10–30 µg/l were quite common, although most aquifers contain groundwater of no more than 10 µg/l. High *As* groundwater was found in both shallow water tables and in deeper water tables of between 100–120 m depth.

The fact that people use moderate to high *As* groundwater for chicken farming, aquaculture, and livestock poses risks for low-level *As* ingestion.

This study suggested continuing caution in water resources development throughout the Lower Mekong (including Cambodia) and the VMD. Be and Tuyen (2007) conducted a survey to evaluate shallow groundwater in sand dunes in the coastal areas of Tra Vinh province. A total of 90 households were interviewed and 18 water samples were taken from six research sites. The results indicated that shallow groundwater in sand dunes is currently overexploited, with no agency monitoring. Local people do not fully know about the impact of poor water quality on human health. *As* concentrations in shallow wells on and near sand dunes at Truong Long Hoa commune (one of the six research sites) was very high in all of the sampling cycles. Also, Berg et al. (2007) showed that *As* concentrations ranged from 1–845 µg/l in Southern Vietnam (39 µg/l on average). A subset of hair samples collected in Vietnam from residents drinking groundwater with *As* levels >50 µg/l had a significantly higher *As* content than that of the control groups. Consequently, the population at risk of chronic *As* poisoning was estimated to be 0.5–1 million in the VMD.

Similarly, Buschmann et al. (2008) presented a transnational groundwater survey of the 62,000 km^2 of the Mekong delta floodplain (Southern Vietnam and bordering Cambodia). Groundwater, which is used as the drinking water supply, had *As* concentrations ranging from 0.1–1,340 µg/l, with 37% of the studied wells exceeding the 10 µg/l standard of the World Health Organization (WHO). Chronic *As* poisoning was the most serious health risk for around 2 million people in the Mekong delta floodplain, who drink this groundwater without treatment. Although no cases of *As*-related health problems have been reported in the VMD (Stanger et al. 2005) compared to Bangladesh and West Bengal (Berg et al. 2007), this is probably due to the fact that *As*-contaminated groundwater has only been used in Vietnam for around 7–10 years; it takes more than 10 years for the symptoms of chronic *As* poisoning to develop (Berg et al. 2007). Given this fact, the number of cases of *As*-related health problems is likely to increase (Berg et al. 2007). Buschmann et al. (2008) confirmed that *As* contamination is serious, and that government agencies, water specialists, and scientists must become more aware of the situation. Also, mitigation measures are urgently needed to protect people who are unaware of the health problems associated with *As* contamination.

Hutton (2001) described instruments to assess water and sanitation interventions. The author argued that an important economic decision with regard to sanitation intervention is how to spend a limited budget and yet have the biggest positive impact on health. Analyses of the costs and benefits of alternative interventions can provide appropriate information for decision makers. However, water and sanitation interventions aimed at improving or sustaining health have their own challenges:

1. They need to be regulatory in nature (e.g., they must meet quality criteria).
2. They should involve cross-sector collaboration and be financed by non-health agencies.
3. They should have large non-health benefits (e.g., they should save time, increase amenities, etc.).
4. They should be less amenable to controlled trials as a way of evaluating effectiveness.
5. They should have a range of effects.

In addition, water and sanitation interventions in developing countries are faced with difficulties in determining the expenditure patterns required to meet the current WHO guidelines and standards. The authors reviewed the economic evaluation framework used by Drummond and Jefferson (1996) with three main stages, namely, study design, data collection, data analysis, and interpretation of results. The authors also reviewed some past CEA (cost effective analysis) studies that evaluated sanitation interventions. It was determined that none of the studies estimated the cost effectiveness of water and sanitation interventions using primary data from a single setting. Only a few studies considered both the costs and the consequences of at least two alternatives, thus meeting the criteria for a full economic evaluation.

For CEA studies, Varley, Tarvid, and Chao (1998) used the CEA for water and sanitation interventions in a hypothetical city in a developing country using secondary data from a variety of sources under a number of assumptions. Phillips, Mills, and Dye (1993) discussed the CEA of hand washing to prevent diarrhea, and used published studies of effectiveness data to model a picture of procedures and resource use in CEA. Briscoe (1984) discussed methodological issues in evaluating the cost effectiveness of water and sanitation interventions and supported the hypothesis that water and sanitation interventions can compete with oral rehydration in terms of cost-effectiveness in reducing the incidence of diarrheal diseases.

However, very few studies have measured the actual costs of water and sanitation services, and those studies generally used available data transferred from other countries. Cook et al. (2008) used CEA to evaluate the cost effectiveness of Vi vaccination against typhoid across sites in four Asian cities: Kolkata (India), Karachi (Pakistan), North Jakarta (Indonesia), and Hue (Vietnam) from both a societal and a public sector finance perspective. The study used the results of a recent research of the Diseases of the Most Impoverished program, consisting of a number of parallel activities including epidemiological studies, economic studies, and an investigation of the feasibility of vaccine technology transfer. The study provided a unique set of site-specific economic and epidemiological data. The authors used CEA to assess the burden of disease (BOD) in terms of cases, deaths, and disability-adjusted life years (DALYs) avoided for selected urban sites. The study primarily used the uniform age-weights that apply the same value to an extra year of life regardless of the age of its recipient, and then explored the effects of non-uniform age-weights by doing a sensitivity analysis. Using the DALYs as the health outcome measure, the authors used measures of reductions in morbidity from vaccination and reductions in typhoid mortality by using country-specific life expectancies from the WHO life tables and discount life years of a 3% real discount rate. Three types of typhoid Vi vaccination program were examined, namely,

1. a school-based option that targets only children of 5–14 years old who are actually enrolled in school;
2. a school-based option that targets all children older than two but younger than 15; and
3. school-aged children not attending school and adults as well as eligible children within a community-based vaccination campaign.

The study considered the costs of the vaccination program options from both a public sector finance and a societal perspective. Vaccine manufacturing/acquisition costs and delivery costs were calculated as public costs. The cost of illness (COI) was also categorized as "public COI" if the vaccination program had not been implemented; otherwise "private COI." The authors used the terms "cost-effective" (for a cost-effectiveness ratio less than three times per capita of gross national income [GNI]) and "very cost-effective" (for a cost-effectiveness ratio less than per capita GNI). The steps of the study included

1. Calculate the cost-effectiveness ratios of the three program options from both a societal and a public sector finance perspective as the base case;
2. Examine the effect of using non-uniform age-weights on the cost-effectiveness calculations;
3. Investigate the impact of uncertainty in the parameters under sensitivity analysis and probabilistic Monte Carlo framework.

The results showed the BOD estimates in the four selected areas to be

1. 750 cases per year in two Kolkata neighborhoods (population 185,000);
2. 84 cases per year in the city of Hue (population 280,000);
3. 298 cases per year in two subdistricts of North Jakarta (population 161,000), and
4. 538 cases per year in three squatter settlements in Karachi (population 102,000).

The results also showed that a vaccination program targeting all children (2–14.9 years old) would prevent 456, 158, and 258 typhoid cases (and 4.6, 1.6, and 2.6 deaths); and avert 126, 44, and 72 DALYs over three years in Kolkata, North Jakarta, and Karachi, respectively. The net social costs would be USD 160 and USD 549 per DALY averted in Kolkata and North Jakarta, respectively.

Generally, these programs were considered "very cost effective." However, the program targeting school-aged children in Hue, Vietnam was considered not cost effective. In this study, the authors concluded that the usefulness of the CEA is not only in comparing ratios with an absolute threshold, such as per capita GNI, but also in the ability to compare various policy interventions using a common metric. In addition, given the limitations of the study, the assumption that the marginal delivery cost per dose in calculating the CEA is the same for the three options would not be the case in reality. However, the difference is not strong enough to warrant the use of different delivery costs for the CEA in this study.

Regarding studies on perception and the behavior of water-choice decisions, Sarah, Paschal, and Sheina (2000) reviewed the Protection Motivation Theory (PMT) predictive model of health-related intention and behavior. They used meta-analysis and vote-count procedures to evaluate the success of each of the model's components in predicting intention (threat and coping appraisal variables). They also assessed behavior (all components of the model) to identify those best to target in health-education interventions. Meta-analysis was used to determine the average correlation between each PMT variable and intention and behavior, and a vote count was used to see how often these associations were significant across studies. Results modestly supported for the threat and coping appraisal components of the model in predicting health-related intentions. However, coping appraisal components of the model had stronger associations with intention than did the threat appraisal cognitions. Results also showed that the processes of threat and coping appraisal have modest utility in predicting intentions to protect oneself against a health threat. Coping appraisal variables had greater utility in the prediction of intention and behavior than threat appraisal variables.

Meanwhile, Baghianimoghadam et al. (2011) conducted a PMT study on educational intervention in reducing the rise in skin cancer risk in Pakistan. Using PMT variables of threat appraisal and coping appraisal, the study compared the health behaviors between experiment and control groups after educational intervention. In the data analyses, ANOVA, t-test, Wilcoxon, and Pearson's correlation and coefficient were used. Results supported the effectiveness of educational intervention to change the attitudes and behaviors associated with skin cancer risks.

Similarly, Kien and Ross (2009) conducted an assessment of the knowledge of residents living in Hanoi's *As*-contaminated areas to determine the relationship between knowledge about arsenic and a household's socioeconomic and demographic characteristics. Using the score ranking technique, an *As*-related questionnaire with a three-level scale (from 0 to 3), where a higher level presenting better knowledge, was designed to measure the understanding of respondents of *As* issues. The basis of the scaling was derived from scientific evidence to show the facts and examine whether the respondent's answer was right or wrong. The authors used descriptive statistical analyses techniques to measure a household's *As* knowledge.
The relationships between a household's *As* knowledge and its socioeconomic and demographic characteristics were analyzed by bivariate analysis techniques such as t-test, ANOVA, and the

Tukey HSD test (testing for relationship within group), etc. Results showed that household awareness of *As* was low. Factors such as location, gender, occupation, annual household income, and level of education significantly influenced a respondent's knowledge of arsenic contamination. Men with low income and low level of education, and women had the lowest levels of awareness.

In summary, reviews of methods for assessing water options and sanitation intervention policies showed that cost-benefit analysis and cost-effectiveness analysis are recommended if the monetary values of costs and benefits (in the case of CBA) or costs (in cases of CEA) are to be measured. Hutton (2001) made a literature review of the economic evaluation framework used by other authors. He found that none of the CEA studies that estimated the cost effectiveness of water and sanitation interventions used primary data from a single setting. Only a few studies considered both the costs and consequences of at least two alternatives, and thus meet the criteria for a full economic evaluation. If monetary values are not able to be measured, then an alternative to CBA or CEA is a multi-criteria analysis (MCA), where the ranking of policy options can be based on different measurement scales (including the combination of quantitative and qualitative variables). The advantage of MCA over CBA and CEA is to consider different criteria, which can be estimated in different ways due to their multi-dimensional nature.

3.0 METHODOLOGY AND ANALYTICAL TOOLS

This section presents the research approaches and analytical methods used to tackle the objectives of the study. First, a PMT framework stimulated the *As*-poison-related health protective behavior via a cognitive mediating process, including threat appraisal and coping appraisal of protection motivation or intention action. Second, the CEA method was applied to rank the efficiency of *As*-treatment technologies. Third, the MCA method was used to capture both qualitative and quantitative impacts on a household's preference for *As*-mitigation technologies. The hypothesis was that a household's choice was dependent on technology options (surface water, groundwater, rainwater), the effectiveness of *As* mitigation technologies, the cost of investment and operation, the availability of *As* removal materials, convenience of use and maintenance, educational status, ethnicity, the water supply situation in the community, size of family, household income, etc.

3.1 Descriptive Statistics Analysis

Applying the approach taken by Kien and Ross (2009) when scoring a household's knowledge of *As*, each answer in this study was weighted from 0 to 3 points. It was dependent on a respondent's understanding and knowledge of a certain issue related to the context of *As* contamination. According to this approach, if his/her answer duplicated announced scientific evidence, he/she got the highest score for that issue; otherwise the lowest score (0 score) was obtained. Then, the authors tested for relationships between socioeconomic, demographic, and other factors and *As* knowledge. To ask people about their preferred method of *As*-treatment, the stated preference modeling-based scenarios were described in the questionnaire. The study uses scientific evidence from professional literature to describe scenarios and hypotheses of *As*-treatment options and efficient levels of *As* removal. Based on this approach, the study elicits preferences from the respondents.

3.2 PMT Framework

Rogers (1975) developed the PMT to predict and understand health-related behavior in order to formulate intervention policies or measures. Based on a fear-appeal approach, which was an informative communication about a threat to an individual's well-being, the model suggests measures that can be taken to avoid it or to reduce its impacts. A PMT was designed to specify and operationalize the components of a fear appeal in order to determine the common variables that produce attitude change. The structure of PMT was derived from expectancy-value theory, a social cognition behavioral model, where the tendency to adopt a given behavior was a function of expectancies regarding the consequences of the behavior and the value of those consequences. Rogers (1983) then revised the theory into a more general theory of cognitive change.

In a PMT's cognitive mediational process framework, the magnitude of noxiousness initiates a perceived severity, the probability of occurrence initiates a perceived vulnerability, and the efficacy of the recommended response initiates a perceived response efficacy. PMT is organized along two cognitive mediating processes: the threat appraisal process and the coping appraisal process. Threat appraisal evaluates maladaptive behavior. The PMT variables comprising the threat appraisal process are maladaptive response rewards (intrinsic and extrinsic), perception of threat (severity and vulnerability), and fear arousal. Rewards increase the probability of selecting the maladaptive response (not to protect the self or others), whereas threat decreases the probability of selecting the maladaptive response. Perceived vulnerability assesses how personally susceptible an individual feels to the communicated threat. Perceived severity assesses how serious the individual believes that the threat would be to his or her own life. Fear arousal assesses how much fear the threat evokes for the individual. Fear is considered an intervening variable. The more vulnerable an individual feels to a threat and the more serious he or she believes it to be, the more fear will be aroused and the greater the appraised threat will be. The greater the perceived threat, the more likely the individual is to be motivated to protect himself or herself; that is, the more likely a behavioral intention to adopt a protective behavior would be formed.

Coping appraisal process evaluates the ability to cope with and avert the threatened danger. The PMT variables that comprise the coping appraisal process are efficacy variables (both response efficacy and self-efficacy) and response costs. Response efficacy is the belief that the adaptive response will work, that taking the protective action will be effective in protecting the self or others. Self-efficacy is the perceived ability of the person to actually carry out the adaptive response. Response costs are any costs (e.g., monetary, personal, time, effort) associated with taking the adaptive coping response. Response efficacy and self-efficacy increase the probability of selecting the adaptive response, whereas response costs decrease the probability of selecting the adaptive response.

The output of these appraisal-mediating processes is the decision (or intention) to initiate, continue, or inhibit the applicable adaptive responses via the protection motivation behavior. In other words, protection motivation is a key mediator of the relationship between behavior and threat and coping appraisal. Protection motivation is synonymous with the intention to perform a behavior and is a positive linear function of the beliefs that (1) the threat is severe, 2) the individual is personally vulnerable to the threat, (3) the recommended response is effective, (4) the individual is able to perform the recommended response and is a negative linear function of the belief that (5) the perceived costs of the recommended coping response will be high.

Thus, the typical dependent variables in a PMT study are measures of behavioral intentions. Figure 1 presents the PMT framework used in this study to determine household behavior in dealing with *As* contamination of groundwater.

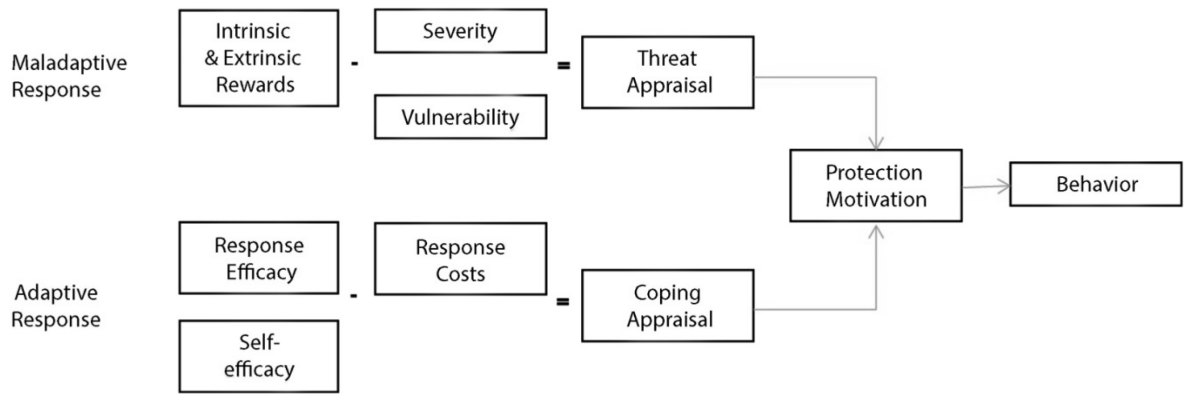

Figure 1. Schematic representation of protection motivation theory

Source: Adapted from Rogers (1983)

Based on the general PMT framework, this study created PMT variables in order to capture the main components of the PMT theory in the case of *As*-contamination-related health behavior study. Table 5 presents the variables and the PMT variables associated with intention (or protection motivation) behavior and protection behavior.

The PMT model was composed of a five-point Likert scale. For the purpose of statistical descriptive analyses, ANOVA and t-test were used with a level of confidence interval at 95%. To assess the intention (or protection motivation) behavior of the *As* risk-related water user, the study used variables (1) knowledge of *As* risk-related health impacts, (2) perceived vulnerability to *As*-contamination-related diseases, (3) perceived severity of *As*-contamination-related diseases, (4) fear arousal of *As*-contamination-related diseases, (5) self-efficacy with respect to participation in the examination of *As* contamination, (6) response efficacy of examination of *As* contamination, (7) response costs of *As*-contamination-related diseases, (8) intention to participate in the examination of *As* contamination, and (9) demographic variables. For interval data, depending on the number of questions or items describing the subjects (e.g., knowledge of *As*-related health risks, threat appraisal, coping appraisal, etc.), either the test of Cronbach's alpha or correlation coefficient was used in the analysis.[2] The study made comparative analyses on water-usage decisions between convenience and inconvenience groups in water supply to detect differences in protective behavior so that recommended policy would be applicable in reality.

To predict the intention to participate from the main and interaction effects of protection motivation variables, knowledge, and fear of *As*-related diseases, the method of within-subject regression analysis was used to determine the relationship between the components of the PMT theory and the level of protection motivation. That is, using measures of existing cognition makes it possible to test the predicted interactions directly. By using interaction terms or variables in the regression analyses, it was possible to determine whether a linear additive model was sufficient or whether a combination of an additive model and a multiplicative model would be necessary to predict individual differences in level of protection motivation or intention behavior. However, because interaction variables were not statistically significant, the assumption of a linear additive model was accepted in this study.

[2] If the numbers of questioning items are larger than 2, then the Cronbach's alpha is used. If the numbers of questioning items are 2, then correlation coefficient is used.

Table 5. PMT variables in arsenic contamination-related health behavior study

PMT Variable	Meaning of Cognitive Process
Threat appraisal	
Rewards	Beliefs about adopting the recommended coping response. The higher the reward of not adopting the coping response, the less likely the individual would adopt it.
Vulnerability	How personally susceptible an individual feels to the communicated threat
Severity	How serious the individual believes the threat would be to his or her own life
Fear	How much fear the threat evokes for the individual
Coping appraisal	
Self-efficacy	An individual's beliefs about whether he or she is able to perform the recommended coping response
Response efficacy	Beliefs about whether the recommended coping response will be effective in reducing the threat to the individual
Response costs	Beliefs about how costly performing the recommended response will be to the individual
Intention motivation	The intention to perform a behavior

3.3 CEA Framework

The CEA measure of household drinking water options dealing with the context of *As* contamination is dependent on the DALYs saved. The DALY value of each technology option depends on the effectiveness of *As* removal. It shows that there is a relationship between an *As*-removal-related drinking water option and health impacts. The more effective the technology is, the lower the DALY value would be. This is the measure of the health impact of having a safe water supply. The DALY method is recommended by the WHO and the World Bank as a means of combining information about mortality and morbidity within a single index. The DALY is defined as the lost year of "healthy" life. The sum of DALYs across the population is a measurement of the gap between current health status and an ideal health situation, where the entire population lives to an advanced age, free of disease and disability.

Figure 2 shows the conceptual framework of the CEA study. For each water treatment option, the costs, including government costs and private costs, were investigated to determine the cost structure. The cost-effectiveness measurements of household water treatment options were calculated by dividing the total costs incurred by DALYs corresponding to drinking-water-related diseases saved by these water treatment options. The cost-effectiveness ratios were then calculated by comparing to the per capita household income in order to conclude whether the drinking water treatment options were cost effective.

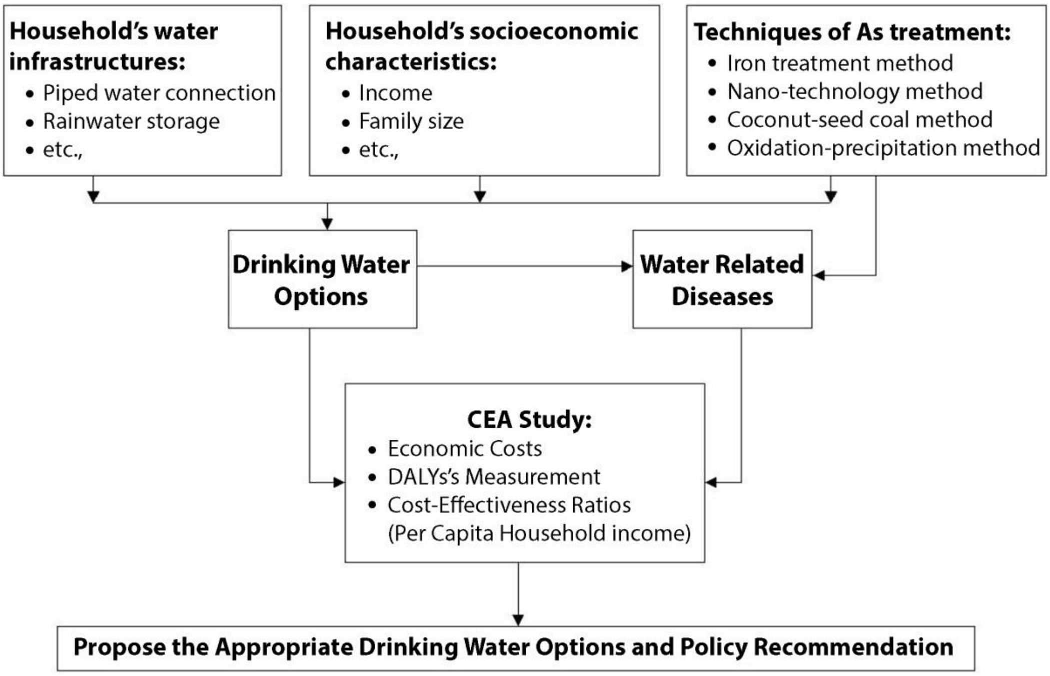

Figure 2. Conceptual framework of the CEA study

3.4 Multi-criteria Analysis

To assess household choice regarding *As*-mitigation technology options in the complex context of impact factors, MCA was used in the study. MCA established preferences between *As*-treatment technology options by reference to a suitable solution for drinking water use in rural areas via qualitative and quantitative criteria reflecting historical factors, culture, ethnicity, etc. Establishing a performance matrix helps to capture the main impact factors affecting household decisions regarding their choice of *As*-treatment technology. By using MCA, qualitative assessment (with check, ranking, opinion, etc.) at the beginning stage was transferred into quantitative assessment with scores and interval values for the criteria's evaluation.

A comparison was then made for ranking *As*-mitigation options in the analysis. In addition, the analyses of different groups of location (near vs. far from river areas), ethnicity group (Khmer vs. Kinh), water supply condition (convenience vs. inconvenience), and household income (poor vs. non-poor) were included. Applying the expected value method, a simple procedure was used to derive the weights and the scores achieved by alternatives based on pairwise comparisons between criteria and between options in ranking criteria. The following steps were conducted:

1. Complete the performance table (or effects matrix).
2. Standardize the scores in the performance table using the ratio method.
3. Calculate the criteria weights using the expected value method.
4. Multiply the standardized performance scores by the corresponding criteria weights.
5. Sum the resulting scores and obtain a total score for each technology.
6. Rank the technologies according to their total scores.

4.0 STUDY LOCATION

The study was conducted in Dong Thap and An Giang provinces. Dong Thap is close to An Giang. Both provinces have borders with Cambodia. Since the 2000s, surveys that test *As* concentration (Gordon et al. 2005; Buschmann et al. 2008; Bang et al. 2008) have indicated that areas in the lower part of Cambodia and Dong Thap and An Giang provinces of Vietnam have high levels of *As*. According to a survey done by the UNICEF, in An Giang province, 40% of the 2,966 tube wells tested were contaminated with *As*. Samples were tested from An Phu, Phu Tan, Tan Chau, and Cho Moi districts. Most tested groundwater samples had *As* concentrations 12–83 times more than accepted/standard levels. In Dong Thap province, 67% of tube wells out of the 2,960 wells tested were contaminated with *As*. In Thanh Binh district, 85% of wells were found to harbor *As* contamination.

Households in *As*-contaminated areas were selected for interview. A total of 404 households, consisting of both tested and untested households, were interviewed via the study's questionnaire. Samples were selected from Thanh Binh and Tam Nong districts of Dong Thap province and Phu Tan and Cho Moi districts of An Giang province. All these districts run along the Mekong River. Sample sites included areas within 10 km of the riverbank and more than 10 km of the riverbank. The condition of the water supply or the convenience of the water supply in the communities in each area were considered during the sampling process—an equal proportion of households located in convenient water supply areas and in inconvenient water supply areas were selected for interview. In the same way, a relatively equal sample was collected with ethnicity as the main consideration.

5.0 RESULTS AND DISCUSSION

5.1 Description of Sampled Households

Table 6 shows the socioeconomic and demographic characteristics of the sampled households. An average four-person household in the study had a household head of 47 years of age who had been educated to secondary standard, had lived in the area for about 30 years, and had an annual income of VND 72 million (USD 3,200). Although some households are far from the river, accessing water for domestic uses is not difficult. Some 44% of households currently apply safe water treatment methods.

Table 6. Characteristics of sample households

Variable	Freq	Minimum	Maximum	Mean	SD
Head's sex (1: male; 0: female)	404	0	1	0.45	0.498
Head's age (year)	403	17	94	47.20	13.710
Head's education (grade)	398	0	15	6.37	3.783
Minority (1: Kinh; 0: other)	404	0	1	0.96	0.201
Duration of residence (year)	404	1	86	30.60	20.612
Household size (person)	404	2	11	4.33	1.522
Distance to the river (km)	389	0	25	1.03	2.595
Access to water in the dry season (1 = easy, 0 = difficult)	404	0	1	0.85	0.356
Household's income per year (million VND)	367	11	840	71.82	74.350

5.2 Water-Use Situation

Household water-use options were not different in the dry and the rainy seasons, excepting the rainwater option. Some 68% of households use bottled water for daily drinking use. Nearly half and more than one-third of the households use piped water and river water, respectively (Table 7).

Most households use piped water for cooking, bathing, and washing clothing at 91%, 84%, and 81% respectively. For river water, 31% and 36% of households use it for bathing and washing clothing, respectively. Using rainwater is another water-use option in the rural areas, especially in the rainy season when 15% of households use rainwater.

Table 7. Seasonal water-use options (in percent)

Water-use option	Dry Season	Rainy Season
Bottled water	67.70	67.57
Piped water	48.51	48.51
River water	38.12	37.62
Tube well	10.15	10.15
Rainwater	0.99	15.10

Bottled water is the most preferred water-use option, and tube well water was the least preferred option (Figure 3). Piped surface water and piped groundwater were ranked second and third, respectively. River water was preferred to rainwater. Most choices regarding water options depended on household knowledge of health issues. Some 78% of users of bottled water said that it was good for their health, while 18% of users interpreted that other water sources were polluted so bottled water was the reasonable choice. Some 46% and 38% of piped surface water and piped groundwater users, respectively, believed that these types of water are good for their health. Some 36% and 21% of river water users revealed that either no other safe water was available and that the availability of river water, respectively, are the main reasons for their choice. Some 30% and 14% of rainwater and river water users, respectively, indicated that the low cost of these water sources was an advantage.

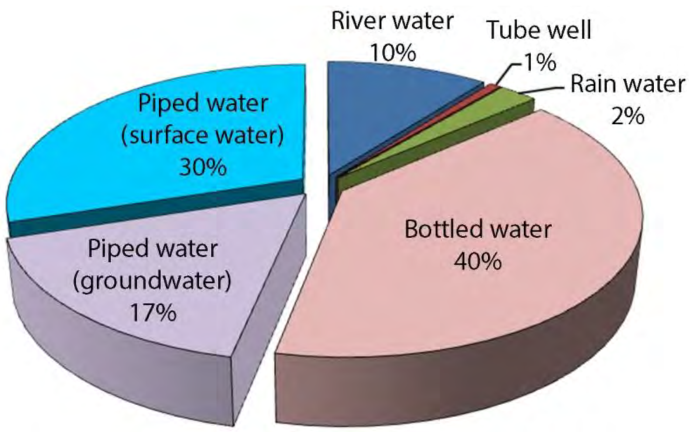

Figure 3. Household water preferences (in percent)

5.3 Household-Based Safe Water Treatment Methods

There were some methods of household-based safe water treatment, namely, the borax method, using treatment equipment, using chemical materials, boiling or heating the drawn water, and using sand filtering. The borax method and using safe water treatment equipment were the most preferred methods, used by 77% and 27% of households, respectively. The borax method was mostly applied because it incurs the lowest cost and is easy to use. The survey revealed that the higher the household income, the more treatment equipment it had. For example, 24% of households with an annual income higher than VND 100 million owned treatment equipment, but only 8% of households with an annual income lower than VND 100 million owned treatment equipment. Figure 4 shows safe water treatment methods used by households.

There were reasons why people were not willing to use *As*-treatment technology. Some 46% of households did not believe that *As*-treatment technology is reliable and 18% of households stated that they thought water treatment equipment is difficult to use. Around 19% of households said that there were financial constraints to owning *As*-treatment technology. A few households said that they did not know about *As*-treatment technology. Figure 5 presents reasons that households were not willing to use arsenic treatment technology.

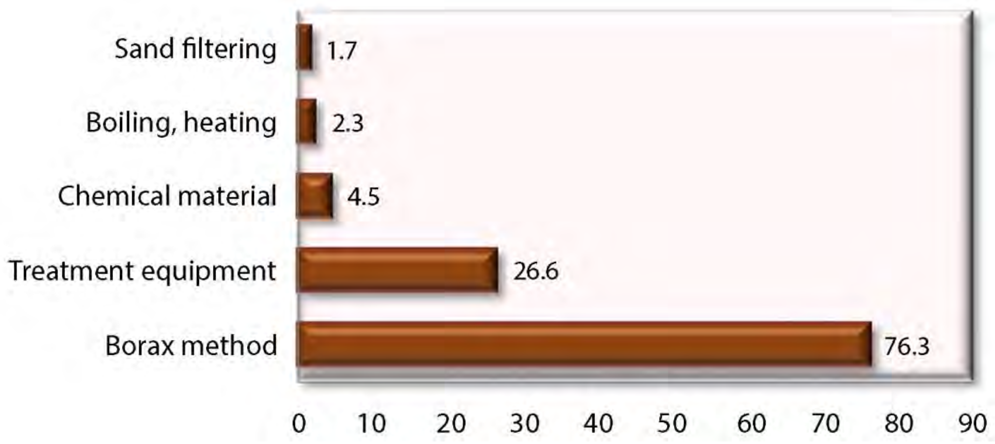

Figure 4. Household safe water treatment methods (in percent)

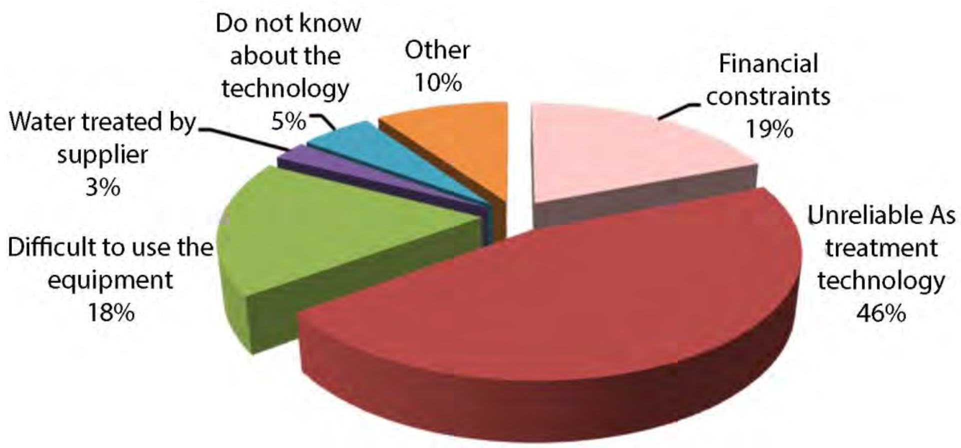

Figure 5. Reasons households were unwilling to use arsenic treatment technology

5.4 Knowledge and Concerns Regarding Arsenic Contamination

Knowledge of arsenic contamination was very bad among the sampled households. Nearly 69% and 1% of respondents did not know anything about arsenic contamination or knew only a little about arsenic contamination and its health effects respectively (Table 1 in the Appendix). Compared to a total score of 27, which was the best *As* knowledge score, the mean score was only 1.76. However, knowledge regarding arsenic contamination differed depending on a household's socioeconomic and demographic characteristics. Households where the occupants work in offices, have had access to higher education, or have a high income, had better knowledge of *As* contamination. Households that were home to laborers, small traders, or were poorly educated had only a little knowledge of *As* contamination. Table 8 presents the *As* knowledge scores of groups of people, who are classified by their different socioeconomic and demographic characteristics.

Table 8. Descriptive statistics of arsenic score ranking classified by socioeconomic and demographic characteristics

Variable	Percent	Frequency	Mean	SD
Total	**100.0**	**404**	**1.76**	**3.530**
Household size				
1–3 persons	28.2	114	1.68	3.392
4–5 persons	51.5	208	1.75	3.339
>5 persons	20.3	82	1.90	3.452
Total	100			
Gender				
Male	45.0	182	1.77	3.398
Female	55.0	222	1.76	3.643
Total	100.0			
Age				
18–40 years old	36.0	145	1.68	3.329
41–50 years old	25.5	103	1.82	3.839
>50 years old	38.5	155	1.78	3.507
Total	100.0			
Occupation				
Farmer	30.4	123	1.86	3.498
Small trader	15.8	64	1.25	3.399
Officer	7.9	32	4.31	4.291
Laborer	26.2	106	1.19	2.935
Other	19.6	79	1.77	3.697
Total	100.0			
Level of education				
Primary	48.0	191	1.38	3.148
Secondary	31.4	207	2.16	3.856
High school	17.6	82	3.09	4.598
>high school	3.0	12	3.50	3.705
Total	100.0			
Household annual income				
≤ 30 million VND	28.9	106	1.68	3.325
> 30–50 million VND	21.0	77	1.42	2.988
> 50–100 million VND	27.8	102	1.59	2.946
>100 million VND	22.3	82	2.71	4.888
Total	100.0			
Area under *As* contamination				
Contaminated	44.0	137	1.96	4.153
Not contaminated	46.0	267	1.67	3.168
Total	100.0			
Distance to the river (km)				
Near (≤ 0.1 km)	52.0	210	1.56	3.130
Far (> 0.1 km)	48.0	194	1.99	3.914
Total	100.0			

It was found that apart from household size and distance to the river, other socioeconomic and demographic factors such as gender, age, occupation, educational attainment, income, and *As*-contaminated area correlated to a household's knowledge of *As* contamination (Table 2 in the Appendix).

Some 10% of sampled households use tube wells. Among these households, 29% of them did not know whether their tube well was *As*-contaminated or not and 39% of them were not sure about *As* contamination. Most sampled households were not concerned about *As* contamination. Figure 6 shows levels of household concern regarding arsenic contamination.

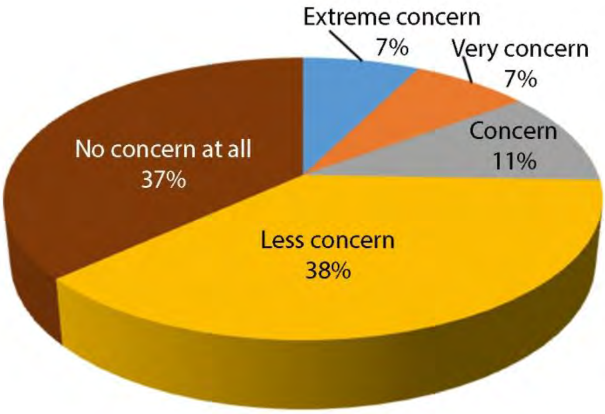

Figure 6. Levels of household concern regarding arsenic contamination

Regarding the relationship between household characteristics and levels of concern about *As* contamination, the survey indicated that those who were more educated were more than twice as concerned as those who were less educated. Those who owned safe water treatment equipment were 50% more concerned about *As* contamination than those who did not own safe water treatment equipment. Those who lived in an area with easy access to water were 46% more concerned about *As* contamination than those who lived in areas with a constrained water supply. Households from the Kinh ethnic group were 48% more concerned than households from the Khmer ethnic group. Table 9 presents the relationship between household characteristics and levels of concern regarding *As* contamination.

Three factors affected a household's concerns regarding *As* contamination. The results of the probit model, shown in Table 10, indicate that the more educated the household head, the more concerned he/she was about *As* contamination; the more knowledge of *As* contamination he or she had, the more concerned they were. Female household heads had more concerns about *As* contamination than male household heads.

Five factors affected a household's decision to use *As*-treatment technology to cope with the possibility of *As* contamination. The results of the probit model in Table 11 indicate that the more educated the head of the household, the higher the probability of intention to use *As*-treatment technology. The older the household head, the higher the probability of intention to use *As*-treatment technology. The greater the number of people in a household, the higher the probability of intention to use *As*-treatment technology. The more knowledge of *As* contamination the household head had, the higher the probability of the intention to use *As*-treatment technology. People from the Khmer ethnic group had a higher probability of the intention to use *As*-treatment technology.

Table 9. Relationship between household characteristics and levels of concern regarding arsenic contamination (in percent)

Variable	Measurement	Concern Regarding Arsenic Contamination		Total
		Concerned	Not Concerned	
Educational status	Secondary or below	28.9	71.1	100.0
	Above secondary	13.4	86.6	100.0
Total		25.7	74.3	100.0
Arsenic contamination status	Not contaminated	26.6	73.4	100.0
	Contaminated	24.1	75.9	100.0
Total		25.7	74.3	100.0
Area under arsenic testing	Not tested	25.8	74.2	100.0
	Tested	22.2	77.8	100.0
Total		25.7	74.3	100.0
Water access status	Easy	31.7	68.3	100.0
	Difficult	24.7	75.3	100.0
Total		25.7	74.3	100.0
Minority	Other	17.6	82.4	100.0
	Kinh	26.1	73.9	100.0
Total		25.7	74.3	100.0
Own safe water treatment equipment?	No	30.0	70.0	100.0
	Yes	20.3	79.7	100.0
Total		25.7	74.3	100.0

Table 10. Results of probit model, household concern regarding arsenic contamination

Variable	Coefficient	t-value	Marginal Effect dp/dx
Constant	0.722	1.560	
Household head's gender (1 = male, 0 = female)	–0.421***	–2.750	–0.126
Head's education status (1 = above secondary, 0 = otherwise)	0.089***	4.040	0.026
Minority (1 = Kinh, 0 = otherwise)	–0.516	–1.360	–0.124
Residence time (year)	0.001	0.320	0.000
Family size (person)	–0.071	–1.440	–0.021
Distance to the river (km)	–0.017	–0.640	–0.005
Water access ability during dry season (1 = easy, 0 = otherwise)	0.230	1.160	0.072
Household annual income (million VND)	0.001	0.900	0.000
As knowlege (interval scale: 0–27)	0.113***	3.620	0.034
χ^2 value	49.090		
Sig. value	0.000		

Note: *** refers to values that are significant at 1% level.

Table 11. Results of probit model, intention to use arsenic treatment technology

Variable	Coefficient	t–value	Marginal Effect dp/dx
Constant	–0.931	–2.310	
Household head's gender (1 = male; 0 = female)	0.194	1.440	0.076
Household head's educational status (1 = > the secondary, 0 = otherwise)	0.035*	1.860	0.014
Minority (1= Kinh, 0 = otherwise)	–0.570*	–1.770	–0.223
Residence time (year)	0.015***	4.400	0.006
Family size (person)	0.078*	1.760	0.031
Distance to the river (km)	–0.040	–1.560	–0.016
Ability to access water during dry season (1 = easy, 0 = otherwise)	0.234	1.240	0.090
Household's annual income (million VND)	–0.001	–0.350	–0.000
Knowlege of Arsenic (interval scale = 0–27)	0.048**	2.510	0.019
χ^2 value	50.180		
Sig. value	0.000		

Note: *, **, *** refer to values that are significant at 10%, 5%, and 1% levels, respectively.

5.5 Protection Motivation Behavior

The results from crosstab analysis, shown in Table 12, outline a relationship between household characteristics and the intention motivation for *As* testing. In general, people had more intention to do *As* testing. Households with a higher level of education were more likely to test for *As* in their tube wells—those who had been through high school or beyond were 21% more likely to test for *As* than those who had only been through secondary level education or below. Households in *As*-contaminated areas tended to do *As* testing more than those who lived in areas not contaminated with *As*. Almost all the households in areas that had been previously tested for *As* (89%) intended to test for *As* in their tube wells in the future. It would seem that whatever the distance to the river, a proxy variable for an abundant water supply, it was not an important factor in differentiating a household's *As* testing decision. Some 45% of households from the Kinh ethnic group were more likely to test for *As* than Khmer households.

In order to examine the factors affecting a household's intention-motivation behavior regarding *As* testing, the Within-regression model was applied to the PMT model with interval variables. As described, in the PMT model explanatory variables included knowledge of *As*-risk-related health impacts, perceived vulnerability to *As*-contamination-related diseases, perceived severity of *As*-contamination-related diseases, fear arousal of *As*-contamination-related diseases, self-efficacy with respect to participation in the examination of *As* contamination, response efficacy of examination of *As* contamination, response costs of *As*-contamination-related diseases, and demographic variables.

However, based on the Cronbach's alpha test, statistically, only the threat appraisal factor had an influence on protection-motivation behavior in this study (Tables A3 and A4 in the Appendix). The results in Table 13 show that the fear arousal factor affected a household's decision regarding intention to conduct *As* testing. Besides, households with more concerns about *As* contamination would statistically have more intent to do *As* testing. Statistically, males tend to conduct *As* testing more than females.

5.6 Arsenic Treatment Technology

The calculation of the cost-effectiveness of drinking water treatment technologies using the cost per death averted or the cost per DALY saved as the outcome measure was based on the assumption that all deaths due to *As* contamination can be averted using *As*-treatment methods. Under this assumption, the calculation started to estimate the proportion of all possible *As*-poisoning-related deaths, i.e., the number of deaths that can be averted by using *As*-treatment methods. The population risk due to *As* contamination was calculated from the proportion of those people in the survey who had symptoms of suspected *As* poisoning, such as keratosis, gangrenous ulcers, skin cancer, lung cancer, liver cancer, and bladder cancer. There were 38 cases out of 1,750 persons across 404 households in the survey that were suspected to be infected with *As*-poison-related symptoms. Hence, the probability of death due to *As* contamination was 0.0217.

Table 12. Relationship between household characteristics and the intention motivation to conduct arsenic testing (in percent)

Variable	Measurement	Intention to Arsenic Testing		Total
		Likely	Unlikely	
Educational status	Secondary or below	56.5	43.5	100.0
	High school or above	68.3	31.7	100.0
Total		58.9	41.1	100.0
Arsenic contamination status	Not contaminated	55.1	44.9	100.0
	Contaminated	66.4	33.6	100.0
Total		58.9	41.1	100.0
Area under arsenic testing	Not tested	58.2	41.8	100.0
	Tested	88.9	11.1	100.0
Total		58.9	41.1	100.0
Distance to the river	Near	57.6	42.4	100.0
	Far	60.3	39.7	100.0
Total		58.9	41.1	100.0
Water access status	Easy	68.3	31.7	100.0
	Difficult	57.3	42.7	100.0
Total		58.9	41.1	100.0
Minority	Other	41.2	58.8	100.0
	Kinh	59.7	40.3	100.0
Total		58.9	41.1	100.0
Own safe water treatment equipment?	No	61.2	38.8	100.0
	Yes	55.9	44.1	100.0
Total		58.9	41.1	100.0

Table 13. Results of within-regression model of intention motivation to test for arsenic (dependent variable: intention to do *As* testing)

Variable	Initial Model		Model with Cronbach's Alpha Testing	
	Estimate	p-values	Estimate	p-values
Constant	0.171	0.882	0.958	0.240
Rewards (1 = completely sure, 5 = completely not sure)	–0.183	0.141	–	
Perceived vulnerability (Likert scale) (1 = completely sure, 5 = completely not sure)	0.140	0.292	0.194	0.130
Perceived severity (Likert scale) (1 = extremely serious, 5 = not serious at all)	–0.148	0.346	–0.107	0.507
Fear arousal (Likert scale) (1 = extremely anxious, 5 = not anxious at all)	0.232**	0.024	0.274***	0.009
Self-efficacy (Likert scale) (1 = strongly agree, 5 = strongly disagree)	–0.024	0.745	–	
Response efficacy (Likert scale) (1 = strongly agree, 5 = strongly disagree)	0.494***	0.001	–	
Response costs (Likert scale) (1 = most likely, 5 = most unlikely)	0.001	0.998	–	
Distance to the river (km)	–0.125	0.618	–0.132	0.605
Tube well tested (1 = tested, 0 = not tested)	0.409	0.643	0.522	0.564
Minority (1 = Kinh, 0 = Khmer)	0.451	0.370	0.579	0.263
Gender (1 = male, 0 = female)	0.332	0.150	0.427*	0.068
Education level (grade)	–0.011	0.823	0.021	0.671
Water supply status (1 = easy, 0 = difficult)	–0.371	0.241	–0.406	0.210
Household annual income (million VND)	0.002	0.327	0.002	0.459
Arsenic contamination status (1 = yes, 0 = no)	0.110	0.659	0.154	
Concerns about arsenic contamination (1 = yes, 0 = no)	0.531*	0.057	0.566**	0.048
F-test	2.859	0.000	2.472	0.003
R^2	0.261		0.190	

Note: *, **, *** significant levels at 10%, 5%, 1% respectively.

Among the three drinking water treatment methods used by residents at the study sites, there were only two methods—using a sand filter and using treatment equipment—that were effective in eliminating arsenic. According to environmental scientists at Cantho University, the rate of effectiveness in eliminating *As* using sand filtering was 20%, and the rate for treatment equipment was 98–100%. Meanwhile, it was found that the borax method was unable to eliminate arsenic in water. Table 14 presents the measures of calculation of DALYs and the results of the CEA. In this study, DALY saved or *As*-related death averted was a function of the effectiveness of an arsenic treatment method. It also implies the rate of infection of *As*-related diseases, and the population. Based on that, DALYs of sand filter and treatment equipment methods were sequentially 7.60 and 37.22. To calculate the values of the total DALYs, a discount rate of 3% and a timeline of 10 years were applied in the analysis. As a result, the total values of DALYs of the sand filter and treatment equipment methods were 64.79 and 317.45 respectively.

By using a discount rate of 3% and a timeline of 10 years, the present values of costs (including investment and treatment materials) under the two *As*-treatment methods were sequentially VND 1,866,670 (USD 83.71) and VND 8,020,760 (USD 359.68). Therefore, the costs per death averted or the costs per DALY saved of sand filter and treatment equipment were VND 28,810 (USD 1.29) and VND 25,270 (USD 1.13), respectively. It shows that the costs per death averted for the latter were significantly smaller, which suggests that the treatment equipment method would be a very cost-effective intervention for preventing *As*-related diseases.

Table 14. Calculations of costs per DALY saved with different arsenic treatment methods

Item	Water Treatment Method	
	Sand filter	Treatment Equipment
Rate of effectiveness of arsenic treatment	0.20	0.98
Rate of arsenic-related disease infection	0.02017	0.02017
Number of people in the sampled area	1,750	1,750
DALY	7.60	37.22
Total DALYs (t = 10 years, r = 3%)	64.79	317.45
Investment (‘000 VND)	1,866.67	1,572.08
Treatment materials per year (‘000 VND)	–	756.00
Present value of costs in ‘000 VND (t = 10 years, r = 3%)	1,866.67	8,020.76
Cost per DALY saved (‘000 VND)	28.81	25.27

5.7 Water-Use Preference

In evaluating a household’s water use preference, interval or ranking variables of availability, continuity, convenience, health impacts, substitution competence to other polluted water sources, and ratio of variable of costs of water access were used in the MCA model. In the calculation, these qualitative and quantitative assessments were transferred into quantitative assessment with scores and interval values for criteria evaluation. Using the expected value method, the weights and the scores were calculated based on pairwise comparisons between the criteria and the options in ranking criteria. If a household ranked the cost of water provision as being their most important criterion,[3] the results of the MCA calculation in Table 15 show that the household’s water-use preferences sequentially were piped water, bottled water, groundwater, rainwater, and surface water.

[3] Based on the following ranking: cost of water provision, health impacts, pollution levels of other water sources, availability, continuity, and convenience.

Table 15. Results of multi-criteria analysis on water supply options

Criteria	Measurement	Surface water	Ground water	Rain water	Piped water	Bottled water
Availability	5-scale Likert	80	17	19	103	39
Continuity	5-scale Likert	17	7	0	61	6
Convenience	5-scale Likert	0	2	0	17	28
Other polluted water sources	5-scale Likert	5	4	3	158	94
Health impacts	5-scale Likert	9	5	7	147	242
Costs	million VND	–408	–197	–211	–155	–84
Total scores		–297	–163	–183	331	324
Ranking		5	3	4	1	2

Note: 1 = for not important at all, 5 = extremely important

The water preference did not change if the household thought that pollution in other water sources was the most important reason for their water supply decision. However, if health issues were their top priority, bottled water was their first choice, with piped water their second choice. These preferences show that at the household level, apart from piped water, groundwater is still a preference in spite of the other criteria that choice of water supply. Table 16 presents sensitivity analyses of household water options.

Table 16. Sensitivity analyses of ranking of water preferences

Scenario	Ranking of water option				
	Surface water	Ground–water	Rain water	Piped water	Bottled water
Base case (cost of water provision is the greatest concern)	5	3	4	1	2
Health impacts are the greatest concern	5	3	4	2	1
Finding an alternative source of water is the greatest concern	5	3	4	1	2

5.8 Safe Water Treatment Technology Preference

In order to rank a household's safe water treatment technology preference, interval and ranking variables of ease of use, ease of equipment maintenance, effectiveness of the *As*-treatment technology, ease of finding *As*-treatment materials, and ratio variables of initial investment capital and the *As*-treatment material costs were used in the MCA model. Where a household ranked the cost of investment capital or treatment materials as the most important criteria, results of the MCA calculation in Table 17 show that the household's safe water treatment technology preferences were treatment equipment, sand filtering, and then the borax method.

Table 18 presents the results of sensitivity analyses that rank arsenic treatment technology. Interestingly, even though households paid more attention to operating factors such as ease of use, ease of maintenance of equipment, the effectiveness of *As*-treatment, and getting treatment materials easily, his or her *As*-treatment technology preference was not changed.

Table 17. Results of multi-criteria analysis of safe water treatment methods

Criteria	Measurement	Borax method	Sand filter	Treatment equipment
Initial investment capital	million VND	–84	–135	–158
Material costs	million VND	–52	–87	–103
Ease of use	5-scale Likert	39	57	61
Ease of equipment maintainance	5-scale Likert	18	25	28
Arsenic treated effectively	5-scale Likert	319	351	408
Easy to obtain *As*-treatment materials	5-scale Likert	160	196	242
Total scores		400	407	478
Ranking		3	2	1

Table 18. Sensitivity analyses ranking of arsenic treatment technology

Scenario	Ranking of Arsenic Treatment Technology		
	Borax method	Sand filtering	Treatment equipment
Base case (cost is the greatest concern)	3	2	1
Effectiveness of arsenic removal is of greatest concern	3	2	1
Ease of use of equipment is of the greatest concern	3	2	1

5.9 Reaction of Local Government

Since 2010, rural residents have tended to use groundwater for domestic use due to the polluted state of river water. Although the UNICEF and the Institute of Hygiene and Public Health have recommended that, in the study sites, exposed *As*-contaminated groundwater is very risky for domestic use, information on *As*-contaminated groundwater and *As*-related diseases has not been given to the public. As a result, the majority of households still use groundwater as their main water source for domestic use. For example, *As* testing found that groundwater at Khanh An, Vinh Loc, Phuoc Hung, Quoc Thai, and Khanh Binh hamlets, An Phu district, An Giang province, is very high risk (120–830 ppb), which exceeds between 12 and 83 times the standard safety value. However, limited information was given to the public on *As*-contaminated groundwater and on the possibility of exposure. The provincial authority stated that the problem was very serious and needed to be tackled in the development plans. They believe that while there is no safer water source for people to switch to, information on *As*-contaminated groundwater should be limited to avoid possible public confusion or panic. At the district level, it is recommended that groundwater should not be used for drinking and cooking but for gardening and for livestock farming instead. River water and rainwater were considered good choices in this situation. At present, investing in an *As*-treatment system is not affordable. In general, the current solutions regarding the *As* contamination problem take the form of public marketing campaigns on safe water use and the protection of water resources. This is a policy paradox because both river water and groundwater is contaminated.

According to the local authority, in order to tackle *As* contamination in the long run, several measures are recommended. Firstly, all new tube wells should exceed a depth of 60 meters. The well-screen technique is required to dig the tube well in order to prevent *As* contamination in the lower layers. Secondly, *As*-contaminated tube wells need to be eliminated from use. Thirdly, marketing campaigns need to be designed to ask farmers not to use groundwater for agricultural production purposes such as vegetable production and aquaculture. Finally, in areas with very high *As* contamination (> 200 ppb), other water supply options should be considered.

6.0 CONCLUSION AND POLICY RECOMMENDATIONS

6.1 Conclusion

The proportion of people who use safe water in the VMD is quite low (approximately 37%). Besides piped water, tube wells are a main water source for domestic use in rural areas. Some 24% of rural residents use unsafe water from unsafe underground and surface water. In the study sites where serious levels of *As* contamination have been detected, majority of the residents use bottled and piped water for drinking and cooking purposes respectively.

Among the 404 sampled households (equally split into two subsamples, one subsample for convenient water supply areas, and one subsample for inconvenient water supply areas), 44% of them used safe water treatment methods. The borax method is the most preferred, and the treatment equipment was the second most preferred choice. The borax method is selected because of its low cost and ease of use. A few people said that they did not know about *As*-treatment technology, and that it can work properly and effectively. Most sampled households did not know if their tube well was *As*-contaminated or not so they had no concerns about *As* contamination.

Household knowledge of *As* contamination was very bad, with a mean ranking score of 1.76, compared to the best total score of 27 with regard to knowledge of the consequences of *As* contamination. Household knowledge of *As* contamination depended on a household's socioeconomic and demographic factors, such as gender, age, occupation, educational status, income, and *As*-contaminated/non-*As* contaminated area. Regarding levels of concern about *As* contamination, our results showed that Kinh households that were more educated, with easy access to water and to safe water treatment equipment were more concerned than Khmer households that were less educated, with a constrained access to water supply, and with no safe water treatment equipment. Households with more knowledge about *As* had more concerns about *As* contamination.

Five factors affected a household's decision to use *As*-treatment technology to cope with the possibility of *As* contamination, namely, educational status, duration of residence, family size, knowledge of *As*, and ethnicity. Results also indicate the existence of a relationship between household characteristics and intention motivation to conduct *As* testing. In general, people intended to do *As* testing in the future. Households with a higher education level, living in *As*-contaminated areas or in areas that had already been tested for *As*, and Kinh people intended to do *As* testing in the future. In testing the factors affecting a household's protection motivation behavior, statistically, only the fear arousal factor of threat appraisal affected intention to do *As* testing, whereas, statistically, none of the coping appraisal factors were given. The results also revealed that men who were more concerned about *As* contamination statistically intended to do *As* testing in the future.

Technically, only the sand filter and treatment equipment methods are effective in eliminating arsenic—the borax method cannot eliminate arsenic in water. Using a discount rate of 3% and a timeline of 10 years in the CEA calculations, the results showed that the costs per death averted or the costs per DALY saved by the sand filter and treatment equipment were USD 1.29 and USD 1.13, respectively. This suggests that the treatment equipment method is a cost-effective intervention for preventing *As*-related diseases.

For household water-use preferences, where the cost of water provision or the replacement of alternative water sources was considered to be the most important criteria, the most favored choices were piped water, bottled water, groundwater, rainwater, and surface water. However, if health issues were the top priority, bottled water and piped water were the first choices. When considering household preferences with regard to *As*-treatment methods, people favored treatment equipment first, then sand filtering, and finally the borax method.

6.2 Policy Recommendations

To improve safe water use and provision in the VMD's rural areas, based on the results of the survey, the following recommendations are offered.

First, a campaign to raise awareness of safe water use should be implemented in rural areas. People should be advised to quit unsafe water sources for domestic uses such as drinking or cooking because of the possible health impacts. People currently have very little *As* knowledge, and this will be a big problem for the VMD in the long run if *As* hazards are not publicized. Raising public awareness of *As* issues and of ways in which to avoid them through applying traditional and modern *As*-treatment technologies should be placed front and center in safe water use campaigns. The analyses showed that fear of *As* could be treated as an intervening variable. Improved *As* knowledge, together with increased fear arousal of the vulnerability caused by *As* hazards could lead an individual be more motivated to adopt protective behavior, such as switching to a safer water source or applying an *As*-treatment method.

Second, the rural piped water program should be accelerated. Rural socioeconomic programs, such as the New Rural Program and the Rural Piped Water Program, should be given priority. Currently, the proportion of rural households using piped water is still low. In addition to GSU investments, privatization of piped water investment is needed to accelerate the rate of rural safe water provision. It is necessary to combine private investment in piped water with the rural safe water supply program in order to alleviate poverty as part of the rural development strategy and master plan.

Third, although the borax method is popular in rural areas, safe water treatment equipment, especially *As*-treatment equipment, should be recommended to water users. The borax method cannot effectively eliminate *As* in water for domestic use—only *As*-treatment equipment has the technical capability to provide water that is safe to use.

Fourth, in *As*-polluted areas, local authorities should announce the state of *As* contamination to the public and encourage tube well users to participate in the *As* testing program. Rural safe water centers should periodically examine the status of *As* contamination near people's homes and report the results to residences in a timely manner.

Finally, in the long-term, additional safe water sources such as rainwater and treated groundwater should be taken into account. The availability and reliability of rainwater and groundwater make them possible additional water supplies, as long as they are treated properly and economically.

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APPENDIX

Table A1. Descriptive statistics of score ranking of knowledge about arsenic

Value	Frequency	Percent	Cumulative Percent
0	277	68.6	68.6
1	26	6.4	75.0
2	14	3.5	78.5
3	12	3.0	81.4
4	8	2.0	83.4
5	8	2.0	85.4
6	12	3.0	88.4
7	7	1.7	90.1
8	12	3.0	93.1
9	6	1.5	94.6
10	6	1.5	96.0
11	1	0.2	96.3
12	6	1.5	97.8
13	3	0.7	98.5
14	2	0.5	99.0
15	2	0.5	99.5
20	2	0.5	100.0
Total	404	100.0	

Table A2. Results of bivariate analyses of knowledge of arsenic

Variable	Testing Method	Test Result	
		Estimate	p-value
Household size	ANOVA (F-test)	2.102	0.334
Gender	t-test	7.411	0.000
Age	t-test	–64.388	0.000
Occupation	ANOVA (F-test)	3.979	0.000
Level of education	Chi-square test (χ^2)	280.585	0.037
Household annual income	Chi-square test (χ^2)	2469.126	0.000
Arsenic contaminated area	t-test	8.087	0.000
Distance to the river	Chi-square test (χ^2)	17.829	0.334

Table A3. Results of Cronbach’s alpha testing for critical variables of PMT model: Threat appraisal variables

Threat Appraisal Variable	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item Total Correlation	Cronbach's Alpha if Item Deleted
Perceived vulnerability	7.32	4.217	0.408	0.664
Perceived severity	7.25	4.285	0.550	0.517
Fear arousal	7.35	3.043	0.524	0.529

Table A4. Results of Cronbach’s alpha testing for critical variables of PMT model: Coping appraisal variables

Coping Appraisal Variable	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item Total Correlation	Cronbach’s Alpha if Item Deleted
Self-efficacy	5.70	1.873	0.019	0.048
Response efficacy	5.05	3.284	0.018	0.019
Response costs	7.66	3.403	–0.021	0.065

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