Combining Water Resources, Socioenvironmental, and Psychological Factors in Assessing Willingness to Conserve Groundwater in the Vietnamese Mekong Delta

Klessens, Tycho M.A.; Daniel, D.; Jiang, Yong; Van Breukelen, Boris M.; Scholten, Lisa; Pande, Saket

DOI
10.1061/(ASCE)WR.1943-5452.0001516

Publication date
2022

Document Version
Final published version

Published in
Journal of Water Resources Planning and Management

Citation (APA)
Klessens, T. M. A., Daniel, D., Jiang, Y., Van Breukelen, B. M., Scholten, L., & Pande, S. (2022). Combining Water Resources, Socioenvironmental, and Psychological Factors in Assessing Willingness to Conserve Groundwater in the Vietnamese Mekong Delta. *Journal of Water Resources Planning and Management*, *148*(3), Article 05021034. https://doi.org/10.1061/(ASCE)WR.1943-5452.0001516

Case Study

Combining Water Resources, Socioenvironmental, and Psychological Factors in Assessing Willingness to Conserve Groundwater in the Vietnamese Mekong Delta

Tycho M. A. Klessens[1]; D. Daniel[2]; Yong Jiang[3]; Boris M. Van Breukelen[4]; Lisa Scholten[5]; and Saket Pande[6]

Abstract: Freshwater resources in coastal areas are under intense pressure from excessive groundwater extraction, which amplifies saltwater intrusion (SWI) into coastal freshwater aquifers, such as in the Mekong Delta. Studies that combine socioenvironmental data and households' psychological factors next to salinity measurement data to design groundwater conservation strategies are rare. In this study, these aspects are combined to explore their influence on the public willingness to conserve groundwater using a Bayesian belief network model. We analyzed 313 household survey data spread over three districts in the coastal province of Tra Vinh, located in the Vietnamese Mekong Delta. The level of salinity is significantly correlated with the willingness to conserve groundwater. The top three socioenvironmental characteristics that influence willingness are the level of salinity, type of employment—i.e., being a farmer—and frequency of being exposed to groundwater or SWI promotional activities. Social norm, i.e., perceived social pressure, is the most influential psychological factor that determines willingness. This study reveals an urgency for the local government to intervene and create social pressure regarding the issue. **DOI: 10.1061/(ASCE)WR.1943-5452.0001516.** © *2021 American Society of Civil Engineers.*

Author keywords: Groundwater conservation; Bayesian belief networks; Mekong Delta; Behavioral model; Saltwater intrusion (SWI).

Introduction

Human population growth and climate change are expected to have substantial impacts on global water resources throughout the 21st century (McDonald et al. 2011). While freshwater availability is predicted to remain constant in the future, the water demand is increasing globally, by about six times in the last century (Wada et al. 2016).

Groundwater has a vital role in supplying freshwater to human activities. For example, it was estimated that almost 40% of the irrigation worldwide relied on groundwater (Siebert et al. 2010) and 2.5 billion people rely on groundwater as their daily drinking water source (Grönwall and Danert 2020). However, extensive extraction results in groundwater depletion and leads to undesirable consequences, such as reducing the food production, land subsidence, and saltwater intrusion (SWI) (Alfarrah and Walraevens 2018; Minderhoud et al. 2017; Mukherjee et al. 2018).

The negative impact of excessive groundwater extraction is more evident in coastal areas because groundwater depletion contributes to the sea-level rise (Wada et al. 2010). People living in coastal regions also face SWI, which can be worsened by the groundwater abstraction (Klassen and Allen 2017). Yet, with 70% of the world's population residing in these areas, they are among the most densely populated regions in the world (Webb and Howard 2011), often with enormous socioenvironmental importance.

Located at the mouth of the Mekong River, the Vietnamese Mekong Delta (VMD) is one of the most densely populated coastal areas in the world (Tuan et al. 2007). Similar to other coastal areas, it is subject to severe groundwater depletion and SWI while heavily relying on groundwater to augment water supply. An estimated average abstraction rate of 1,924,000 m^3 every day from 550,000 exploitation wells for drinking water, irrigation, and industry purposes is the leading cause for groundwater depletion and SWI in the VMD (Shrestha et al. 2016). Extreme SWI has affected more than 50% of the area in the VMD and caused an economic loss of more than $300 million (Mai et al. 2019). This situation has also led to on average 18 cm of land subsidence between 1990 and 2015 in the area (Minderhoud et al. 2017).

Lack of groundwater information, lack of knowledge and awareness among inhabitants, and a lack of regulations and guidelines for a groundwater permit system and management aggravate

[1]Master Student, Dept. of Water Management, Faculty of Civil Engineering and Geosciences, Delft Univ. of Technology, 2628 CN Delft, Netherlands. ORCID: https://orcid.org/0000-0001-6881-3567

[2]Doctoral Candidate, Dept. of Water Management, Faculty of Civil Engineering and Geosciences, Delft Univ. of Technology, 2628 CN Delft, Netherlands; Assistant Professor, Dept. of Health Behavior, Environment, and Social Medicine, Faculty of Medicine, Public Health and Nursing, Universitas Gadjah Mada, 55281 Depok, Indonesia (corresponding author). ORCID: https://orcid.org/0000-0002-2664-2517. Email: d.daniel@tudelft.nl; daniel01@ugm.ac.id

[3]Senior Lecturer, Dept. of Land and Water Management, IHE Delft Institute for Water Education, 2611 AX Delft, Netherlands.

[4]Associate Professor, Dept. of Water Management, Faculty of Civil Engineering and Geosciences, Delft Univ. of Technology, 2628 CN Delft, Netherlands.

[5]Assistant Professor, Dept. of Multi-actor System, Faculty of Technology, Policy and Management, Delft Univ. of Technology, 2628 BX Delft, Netherlands.

[6]Assistant Professor, Dept. of Water Management, Faculty of Civil Engineering and Geosciences, Delft Univ. of Technology, 2628 CN Delft, Netherland.

Note. This manuscript was submitted on December 1, 2020; approved on October 25, 2021; published online on December 23, 2021. Discussion period open until May 23, 2022; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Water Resources Planning and Management***, © ASCE, ISSN 0733-9496.

the risk of groundwater overexploitation and SWI (Klassen and Allen 2017). Groundwater conservation is essential for alleviating the impact of the SWI on freshwater and also on the daily life of the inhabitants. The possible measures can be categorized into hard and soft solutions (Wutich et al. 2014), also called as hardware or software (Peal et al. 2010). The hard path relies almost exclusively on providing equipment or infrastructure, such as piped water supply. The soft approach is mainly related to human behavior and requires the involvement of local communities in prevention and adaptation activities such as good hygiene practice and water-saving (Smajgl et al. 2015; Sonego et al. 2013). While hard paths are commonly used, they are very cost-intensive and often do not lead to sustained adoption. A combination of hard and soft measures are expected to result in a better solution in the long run (Pagano et al. 2018). Water managers are increasingly embracing behavioral approaches to meet water demand (Wutich et al. 2014).

A previous review by Koop et al. (2019) found that most of the water conservation behavioral studies focus on socioenvironmental factors and lack the understanding of psychological factors that influence the water conservation behavior. Furthermore, they also stated that most of these studies were conducted in developed countries, indicating the need to understand the situation in low- and middle-income countries. Therefore, this study fills the gap by combining socioenvironmental and psychological predictors with an interpolated salinity data to assess the willingness of households in the Tra Vinh province to conserve groundwater. Tra Vinh ranked among the five provinces most affected by climate change in Vietnam (Tran et al. 2018), highlighting the importance of conserving groundwater in this area. A probabilistic Bayesian belief network (BBN) and statistical analysis are used to attribute the households' variability in willingness to change to socioenvironmental and psychological characteristics. Moreover, by adding salinity measurement as one of the socioenvironmental characteristics (SECs), we could contrast the water quality with the willingness of people to conserve groundwater.

Materials and Methods

Study Setting

The study mainly focuses on nine communes in three different districts within the Tra Vinh province: Duyên Hải, Càng Long, and Trà Cú (Fig. 1). The Tra Vinh province is located in the coastal lowlands of the VMD, about 150 km from Ho Chi Minh City, and is important for agri- and aquaculture. About 80% of the total area in Tra Vinh is used for agriculture (Van and Koontanakulvong 2019). Groundwater is the primary water source for the 1.3 million inhabitants living in the province and is used for household, industry, and irrigation purposes (Hai 1999). In 2007, the average daily groundwater abstraction in Tra Vinh was about 187,685 m^3/d by an estimated 84,600 wells, of which only 121 were licensed (Sanh 2010). In 2016, the groundwater abstraction in the dry season was estimated to be 346,279 m^3/d, which indicates that total groundwater abstraction has increased about twofold in the last 10 years (Van and Koontanakulvong 2019).

In May and June 2019, we conducted a cross-sectional study in nine communes and interviewed 313 households (Fig. 1) to represent the communes. This study is the continuation of a previous groundwater study in the same area (Van and Koontanakulvong 2019).

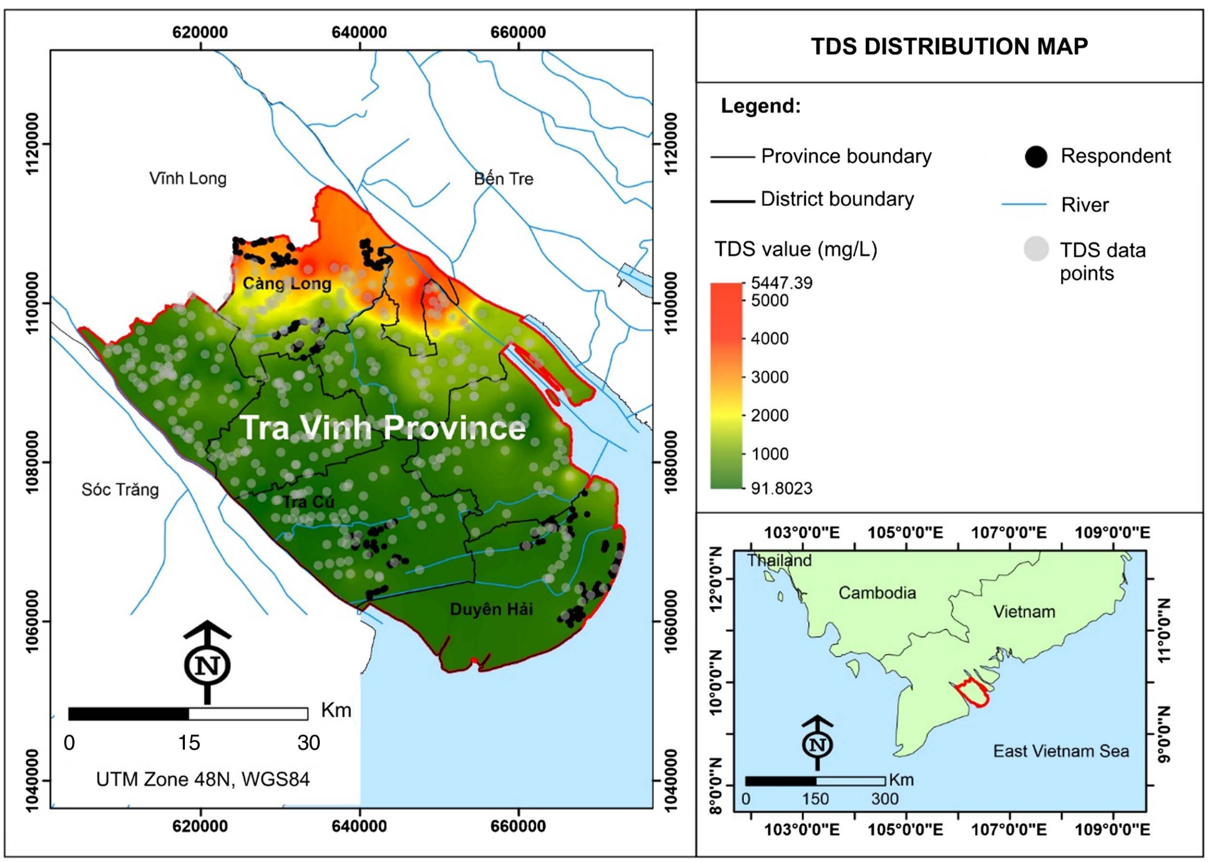

Fig. 1. The TDS distribution map of the study location in Tra Vinh province, including 313 households surveyed (solid dots) and 417 TDS measurements (transparent dots). (Map data from GADM.)

J. Water Resour. Plann. Manage., 2022, 148(3): 05021034

However, not all communes visited in 2018 were able to be revisited in 2019 due to the difficulties to get a permit from the local districts. Every commune consists of six to eight villages and in every village eight households were randomly selected. For each selected household, the survey was conducted by interviewing the oldest member present at the time.

The survey covered: (1) sociodemographic information of the household; (2) psychological information related to knowledge and perception on groundwater abstraction and SWI; (3) expectations on future water availability; and (4) water use practice and patterns. Structured interviews were used to facilitate quantitative assessment and statistical analysis.

The questionnaire of the survey was translated from English into Vietnamese in collaboration with Ho Chi Minh City University of Technology, back-translated into English, and reviewed for accuracy and possible interpretation errors by the first author. We used the Open Data Kit (ODK) platform on a smartphone for the interview, and the data was digitized to allow analysis. All interviewers were trained and a pilot test was performed among students from the Ho Chi Minh City University of Technology prior the survey. Moreover, informed consent was obtained from all participants prior to the interview, and ethical approval was given by the Human Research Ethics Committee of Delft University of Technology (ref. no. 753).

Groundwater Salinity Distribution

From January to March 2017, water quality measurements were performed at 417 points in Tra Vinh by a local technical team from the SALINEPROVE project. The measured variables included the salinity level measured by electrical conductivity (EC), which then was converted to total dissolved solid (TDS) by multiplying the EC values by 0.65 (Rusydi 2018), assuming that the groundwater temperature of all sampling points is at around 25°C of the third aquifer (Upper–Middle Pleistocene aquifer) at a depth of 70−140 m, i.e., EC was measured at 25°C. This aquifer is mostly used for groundwater abstraction. We then created the TDS distribution map using ArcGIS 10.6 (ESRI, Redlands, California) (Fig. 1). TDS (mg/L) was used as a proxy of salinity in water. The TDS concentrations at each of the 313 households was obtained based on the household's coordinates in this interpolated TDS field. We further categorized the salinity level into nonsaline (<500 mg/L), slightly saline (500−1,500 mg/L), and moderately saline (1,500−7,000 mg/L) based on ranges recommended by Rhoades et al. (1992).

SECs

We identified six SECs that influence the willingness of households to conserve groundwater from water conservation and other water-related behavioral studies:

1. Presence of children under the age of 18, indicated by the number (a continuous scale) of children under 18 years old (Clark and Finley 2007; Davies et al. 2014; Gamma et al. 2017);
2. Level of education (Daniel et al. 2019; Syme et al. 2000);
3. Type of employment, e.g., agribusiness and service (Irwin et al. 2016), measured on a nominal scale;
4. Age of the respondent (Mosler et al. 2010);
5. Promotion activities (Daniel et al. 2019; George et al. 2016; Mosler et al. 2013); and
6. Wealth as measured by the household assets, e.g., presence of TV, radio, and the house's types of roof and floor (Russell and Fielding 2010; Willis et al. 2013).

We used the frequency of having heard the SWI information to represent the promotional activities related to SWI mitigation or adaptation. The frequency was measured on a five-point scale (1 = never to 5 = all the time). Finally, a variable level of saline water, quantifying salinity at household levels, was included to see its relationship with the psychology and willingness of people with regard to groundwater conservation.

RANAS Psychological Framework

The risk, attitude, norm, ability, and self-regulation (RANAS) framework was adopted to elicit psychological information from the households (Mosler 2012). The framework enables one to measure key psychological factors underlying behavior so as to design and evaluate behavioral change strategies that target a specific behavior in a specific population. Moreover, RANAS can be used to measure the willingness or intention, habit, and behavior of the respondents (Mosler and Contzen 2016). The risk factor reflects a person's awareness and understanding of a threat, here unsustainable groundwater usage and using saline water at home. Attitude captures a person's emotions that arise when thinking of a particular practice, e.g., the convenience of using groundwater compared to other sources of water. Norm represents a person's perceived social pressure towards the behavior or practice, e.g., of sustainable ground water use. Ability measures a person's own confidence in his or her ability to perform the behavior, e.g., personal confidence to get and use a nongroundwater source. Self-regulation represents a person's attempts to plan and self-monitor behavior and manage conflicting goals, i.e., person's self-management. The RANAS framework inquires psychological information at the subfactor level (Table 1). The scale used in the questionnaire followed the recommendations of the RANAS practice guide, which recommends the use of a five-point Likert scale (Mosler and Contzen 2016).

RANAS offers some advantages compared to other psychological frameworks whose constructs have proven validity regarding water-related behaviors, such as the health belief model (Rainey and Harding 2005) or Integrated Behavioural Model for Water, Sanitation, and Hygiene (IBM-WASH) (Dreibelbis et al. 2013). These include: (1) standardized questionnaire structure and clear guidelines for applying the method, (2) easy adaptation to any kind of water-related behavior, (3) clearly defined behavior change techniques (BCTs), and (4) amenability to testing of causal structures. The RANAS framework has been used in many water-related behavioral studies (Daniel et al. 2019; Inauen et al. 2013; Lilje et al. 2015), including handwashing behavior (Seimetz et al. 2016) and even Ebola prevention (Gamma et al. 2017).

Outcome Variable: Willingness to Conserve Groundwater

Intention or willingness can be defined as a person's readiness to practice a behavior. To measure the willingness of people to conserve groundwater, we combined the answer of two questions: "Are you willing to change your daily water source (from groundwater to another water source)?" and "How much do you expect you can reduce your groundwater usage and change this with another water source?". Both questions were answered using a five-point Likert scale, from 1 = no groundwater reduction expected to 5 = large reduction expected. We named the outcome variable as *willingness to conserve groundwater.*

We then created a simple index by summing those two answers; the range of possible scores is 2–10. For the BBN analysis, the index was divided into *yes*, i.e., willing to conserve groundwater

J. Water Resour. Plann. Manage., 2022, 148(3): 05021034

Table 1. Description of RANAS psychological subfactors and corresponding questions

Psychological factors		Question	Scale	Median
Risk	Perceived vulnerability	Do you think the risk of you not having enough freshwater will increase in the future?	1–5	3
	Perceived severity	How big is the impact of saltwater intrusion in groundwater on your daily life?	1–5	2
	Factual knowledge	Four true/false questions to test the general knowledge of saltwater intrusion and groundwater depletion.	1–5[a]	1
Attitude	Belief about quality	Have you experienced a decrease in quality over the past years?	1–5	3
	Belief about convenience	Is GW the most convenient water source?	0–1[b]	1
	Belief about cost	Is cost the main reason for you to use this type of water source?	0–1[b]	0
	Belief about visual	Is visual appeal the main reason for you to use this type of water source?	0–1[b]	0
Norm	Descriptive	How many of your neighbors/friends have already changed their water source due to saltwater intrusion?	1–5	2
	Injunctive	People who are important to you, how much do they approve of you to adapt/change?	1–5	5
	Personal	Is it important to look for alternatives water sources?	1–5	5
Ability	Confidence in continuation–1	How confident are you to always get unsalted water, if you have many things to do?	1–5	4
	Confidence in continuation–2	How confident are you to get unsalted water for your daily purpose if your primary water source is prohibited by the government or if you found that your water source is salty?	1–5	4
	Confidence in performance	How difficult would it be to get unsalted water every day?	1–5	5
Self-regulation	Action control–1	How much attention do you pay to the level of saltiness of water when using for drinking water?	1–5	2
	Action control–2	How much do you pay attention to the level of saltiness of water when using for irrigation purposes?	1–5	2
	Commitment	With your knowledge about the impact that saltwater intrusion and/or groundwater depletion can have on the Tra Vinh province, how strong of an obligation do you feel to change your household water consumption?	1–5	3

[a]1 means respondents could not answer all four questions correctly.
[b]Answer options: *yes* or *no*. Median was calculated based on all the respondents' answers to that question.

(score ≥ threshold that identifies upper half of the possible scores), and *no*, i.e., not willing to conserve groundwater (score < threshold). We used a score of 6 as a threshold for yes and no because we assume that households with higher scores communicated their much stronger willingness to conserve groundwater than those with a score less than six. This is similar to converting a real valued outcome variable to a binary outcome variable (Pande et al. 2009).

Statistical Analysis

A principal component analysis (PCA) was first performed to reduce the dimensionality of the variables by creating new variables along the dominant axes of their respective variations, i.e., the principal component, before being used in the BBN model (Ringnér 2008). The first principal component of the household data on assets, such as a car, fridge, and air conditioning, was used to create a relative wealth level among the participants. It is called *wealth* in the analysis. The households were divided into three categories based on the PCA scores: poor (40% of the lowest scores), middle (the next 40% of the scores), and rich (20% of the highest scores) (Vyas and Kumaranayake 2006).

Using all RANAS subfactors in the BBN structure to predict the outcome variable would make the BBN model very complex and therefore was avoided (Cain 2001). Instead, we summarized the subfactors into one variable to represent each RANAS factor using PCA. For example, the principal component of behavioral factor *risk* was constructed using three questions: perceived vulnerability, perceived severity, and factual knowledge (see Table 1). The PCA scores were discretized (transformed into the categorical values) and the households were divided into three categories with equal width based on their PCA scores: low, moderate, and high (Daniel et al. 2019). For example, the PCA scores range from 1 to 6. Households who have scores of 1 and 2 are categorized as low, 3 and 4 as moderate, and 5 and 6 as high. The scoring was done similarly for the other four psychological groups (attitude, norm, ability, and self-regulation).

Finally, Chi-square tests were applied to assess potential relationships between the SECs and the psychological factors and also between other categorical-typed variables. We also performed nonparametric tests to assess the correlation between two variables, e.g., the correlation between the level of salinity with the willingness to conserve groundwater (Spearman rank-order correlation r_s) or the significance of difference in medians between groups, e.g., the differences of median willingness to conserve groundwater between the three districts (Kruskal-Wallis H). All statistical analysis used IBM SPSS Statistics 25 (IBM, Armonk, New York).

BBN Analysis

BBN is a directed acyclic graph representing a hypothetical causal relationship between variables (Pearl 1988). The strength of a relationship between a cause variable (where the arrow starts, called a parent node in BBN) and an affected variable (called a child node) is depicted by the values in its corresponding conditional probability table (CPT). CPT can be determined by expert judgement, empirical data, other model outcomes, or a combination of these (Cain 2001). In our case, we used empirical data, i.e., household interviews, and salinity observations.

J. Water Resour. Plann. Manage., 2022, 148(3): 05021034

BBN was considered over other methods, such as structural equations modeling and regression analysis, because BBN analysis enables one not only to proceed from hypothesized causes to effects, but also to deduce the probabilities of different hypothesized causes given the effect (Laura 2007). Moreover, BBN models conveniently illustrate and model possible interrelationships between variables (Cain 2001).

The BBN model designed in this study consisted of three levels of hierarchy: Level 1 (the outer layer) is the level of SECs such as education and age, Level 2 (intermediate layer) is the level of five RANAS psychological factors, and Level 3 is the measured outcome variable *willingness to conserve groundwater*. The main assumption is that SECs influence behavior via psychological factors (Daniel et al. 2020). The BBN structure was created based on statistical relationships between the SEC and the RANAS variables and linking the latter to the outcome variable. For example, we found a statistically significant relationship between the variable *level of saline water* and all RANAS factors except *norm*. Therefore, we linked them in the BBN structure.

We used the software GeNIe 2.2 (BayesFusion, Pittsburgh) to visualize and perform the BBN analysis. The software uses the expectation-maximization (EM) algorithm to estimate the CPT values from the data (Do and Batzoglou 2008). Tenfold cross-validation was used in the same software to assess the model's performance (Rodriguez et al. 2009). A total of 90% of the data are randomly selected for learning the parameters (CPT) and 10% for evaluation. The model's performance was assessed by the area under the curve (AUC) value of the receiver operating characteristics (ROC) curve (Greiner et al. 2000) and also the percentage to accurately predict the outcome variable of 313 respondents.

We performed Bayesian inference to see the effect of each category in each node on the outcome variable. This was performed by setting the category in each node to 100% and observing the effect on the outcome node. For example, we set the node *employment* to 100% agribusiness and assessed the updated probability of the outcome node. We performed a similar approach to other categories in node *employment* as well as in other SEC and psychological nodes.

In addition, the diagnostic inference was performed to set the desired condition in the outcome node and infer the distribution of states in SEC and psychological factors that could lead to the desired outcome (Zabinski et al. 2018).

In order to assess regional and household variation in the willingness to conserve groundwater, the BBN model was used to simulate the willingness of the 313 households individually. This was done by inputting the seven SECs data of households (nodes in the outer layer) in the model and record the prediction of the probability of that household conserving the groundwater. The predicted willingness was plotted on the interpolated salinity in one map to visualize the variation of predicted willingness to conserve groundwater with regard to its salinity level.

Results

SECs of the Respondents and Relevant Information

The median age of the respondents was 47 years ($M = 48$, $SD = 13$). Most of the respondents were male (66.8%), and most of them had children below the age of 18 (69.3%). Of the respondents, 13.1% reported having no education, 51.1% reported having completed primary school, 26.5% finished secondary school, and 9.3% attended college. The majority of the respondents followed a Vietnamese folk religion (60.7%) or Buddhism (32.6%). About 59.4% of the respondents worked in the agribusiness sector, followed by 19.5% as a daily laborer and 11.8% as working in business.

Among the 313 surveyed respondents, 99% had access to groundwater either directly or indirectly and the remaining used rainwater stored during the rainy season. While only 59% made direct use of groundwater and used it as a primary water source, e.g., using private wells (median of the well depth is 90 m, i.e., the third aquifer), the remaining 40% had access to or used piped water supply that also originated from groundwater abstraction. The majority of the respondents (64.9%) were never or rarely informed on anything related to groundwater or SWI, suggesting a lack of information and promotion, while 20.1% said that they sometimes heard about the topic, and only 15% had often encountered promotion or information regarding the topic.

The TDS values among respondents' groundwater ranged from 423 to 3,647 mg/L (median = 598 mg/L). The median value is categorized as slightly saline (500−1,500 mg/L) (Rhoades et al. 1992). Moreover, there was a significant difference in salinity between the three districts [$H(2) = 256.7$, $p < 0.001$ with degrees of freedom = 2]. The medians of salinity in districts Càng Long, Trà Cú, and Duyên Hải were 2,886, 454, and 560 mg/L, respectively. In addition, there was a significant difference in median willingness to conserve groundwater between three districts [$H(2) = 23.67$, $p < 0.001$]. The median score of willingness to conserve groundwater in district Càng Long, Trà Cú, and Duyên Hải were 6, 5.5, and 6 (in a range of 1–10), respectively. Moreover, we found that the level of salinity has a significant, but weak, correlation with the willingness to conserve groundwater [$r_s(313) = 0.143$, $p = 0.01$]. This indicates that people who suffer from saline water were more willing to conserve groundwater.

When we asked the respondents about who is responsible for supplying nonsaline water, 57.8% of them answered district government, followed by 28.1% answering central or provincial government, and 14.1% responded that it is their own responsibility. Furthermore, the relationship between this variable and the psychological factor *ability* is also significant [$\chi^2(4) = 40.62$, $p < 0.001$], in which respondents who said that the responsibility is on the government perceived a much higher level of ability.

Almost all of the respondents (91.4%) were willing to pay a higher fee for water. Among these respondents, more than half of them (54.5%) want to pay more for higher quality water, while 32.8% want to have a more constant supply, indicating that most of the respondents were not satisfied with the quality and/or supply of their water sources. The remaining respondents answered that they want to pay a higher fee to have a better taste of water (2.4%) and comply with the social norms, i.e., follow what others practice (10.1%).

Relationship Analysis between SEC and Psychological Factors

The results of the Chi-square tests to assess potential relationships between the SECs and psychological factors are shown in Fig. 2. Variables *employment*, *level of saline water*, and *SWI or Groundwater (GW) promotion* had a significant relationship with four psychological factors, while *wealth* only had a significant relationship with *risk*. Psychological factor *self-regulation* had the most significant relationship with SECs; six out of seven SECs were significantly linked to *self-regulation*.

BBN Analysis

The BBN model in Fig. 3 illustrates the final structure of the BBN model inspired by the relationship tests between SECs and

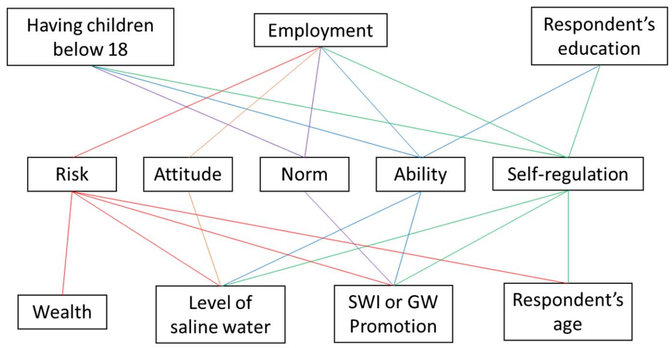

Fig. 2. Significant relationships between SEC and RANAS psychological factors ($p \leq 0.05$).

psychological factors. The BBN structure portrays the respondents' characteristics (Fig. 3, the nodes in the top layer), i.e., the percentage in each node indicates the percentage of respondents having certain characteristics. The BBN model predicted that the response *yes* to the willingness to conserve groundwater was 57% and *no* was 43%, indicating that more than half of the respondents are willing to conserve groundwater. The overall model accuracy in predicting the outcome variable of 313 respondents was 76.99%. Moreover, the AUC value was 0.74, which classifies the model as moderately accurate (Greiner et al. 2000). The model shows that the perceived levels of norm and ability being high were 55% and 50%, respectively. In addition, almost half of the respondents (41%) perceived a low level of self-regulation, and the distributions of risk and attitude perceptions were relatively similar.

Table 2 gives the results of the predictive inference of each node on the willingness to conserve groundwater. The most influential SEC node was the level of saline water and employment ($\Delta P = 7\%$), followed by SWI information ($\Delta P = 3\%$), where ΔP indicates a corresponding change in outcome probability of willing to conserve groundwater. From the psychological factors, norm ($\Delta P = 18\%$) was the most important psychological factor, followed by risk ($\Delta P = 12\%$) and attitude ($\Delta P = 11\%$).

The diagnostic inference does not reveal a significant difference in the distributions of all SECs, i.e., the changes in the distribution of SEC nodes from Figs. 3 and 4 was only 0%–2%. The difference in the distributions of psychological factors was bigger than SECs, especially in the node norm. The maximum change in the distribution was 6%. This was in line with the results of predictive inference that norm was the most influential psychological factor.

The results of the predicted willingness to conserve groundwater by the SECs of households are visualized in Fig. 5. The map shows that there is a variation of the household's willingness considering all the seven SECs, especially between the Càng Long and Duyên Hải districts.

Discussion

To the best of our knowledge, this is the first study that combines the results of salinity measurements, SECs, and psychological factors of respondents in examining the public's behavioral willingness for groundwater conservation, especially in the Mekong Delta. The salinity measurements show that people in the Tra Vinh province suffer from (slightly) saline water (median = 598 mg/L). Sea-level regression and transgression phases over the last few millennia resulted in trapped seawater in inland areas, i.e., Càng Long, which is the main reason why the salinity levels inland are higher than on the coastline (Duyên Hải) (An et al. 2014; Van Pham et al. 2019). However, anthropogenic activities, e.g., through groundwater extraction, worsen SWI (Shrestha et al. 2016). This study then focuses on the behavioral aspect of groundwater extraction in order to alleviate the anthropogenic effect on SWI.

Furthermore, results show that water being saline is an important driver of household willingness to conserve groundwater. This has also been reported by another study in India that found that the level of groundwater contamination by nitrates positively influences the willingness to protect groundwater (Mukherjee 2008). This implies that households are often late in realizing the negative

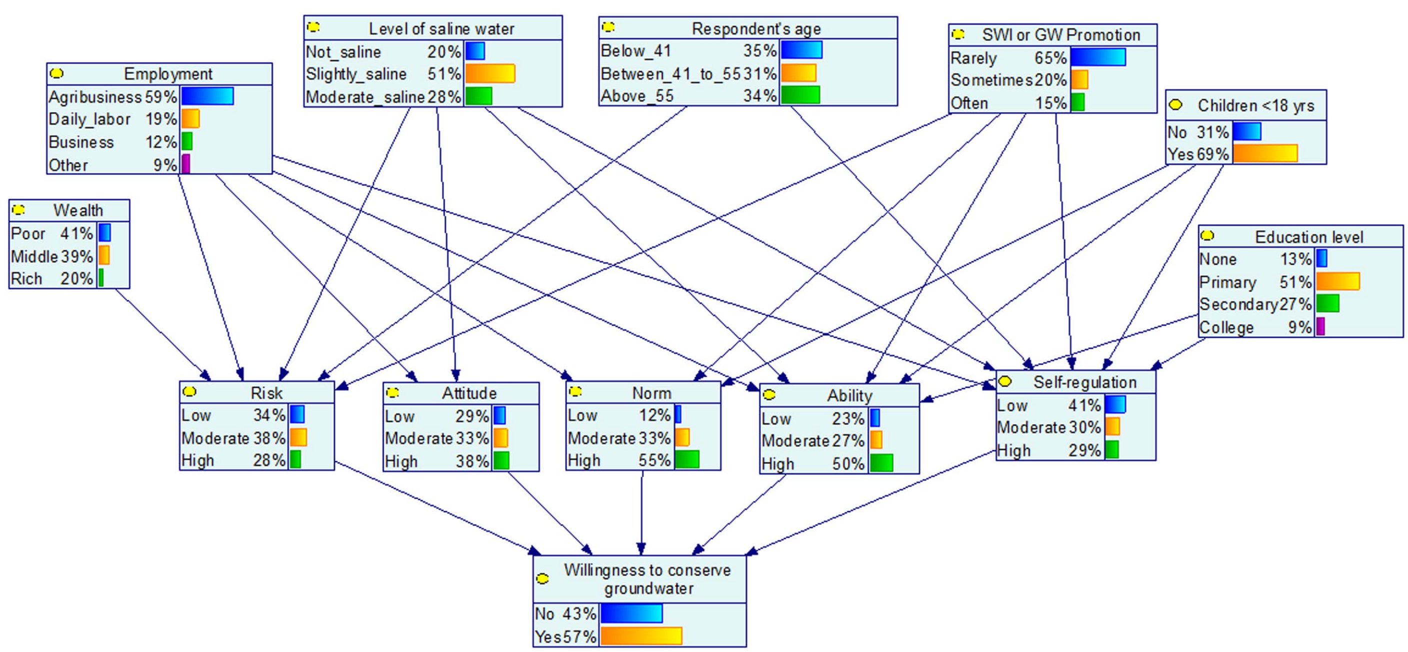

Fig. 3. The final structure of the compiled BBN model. The percentages in each node indicate the probability of a node being in a certain state.

Table 2. Bayesian inference of the probability of willingness to conserve groundwater. The value of each category in each node was individually set to 100% one at a time, and the updated probability, P_{Willing} = Yes (%), of the outcome node being yes is reported[a]

Nodes		Updated P_{Willing} = yes (%)				$\Delta P_{\mathrm{Willing}}$ = yes (%)[b]
Socioenvironmental (SEC) nodes	Children <18	No		Yes		2
		55		57		
	Age (in years)	<41	41–55	>55		1
		56	56	57		
	Level of saline water	Not saline	Slightly saline	Moderate saline		7
		53	56	60		
	Education level	None	Secondary	High school	College	1
		56	57	57	56	
	Employment	Agribusiness	Daily labor	Business	Other	7
		57	54	60	53	
	Wealth	Poor	Middle	Rich		1
		57	56	57		
	SWI/GW promotion	Rarely	Sometimes	Often		3
		56	58	59		
Psychological nodes	Risk	Low	Moderate	High		12
		52	56	64		
	Attitude	Low	Moderate	High		11
		51	55	62		
	Norm	Low	Moderate	High		18
		45	51	63		
	Ability	Low	Moderate	High		6
		53	54	59		
	Self-regulation	Low	Moderate	High		4
		54	59	58		

[a]For example, by setting the value of *not saline* in node *Level of saline water* to 100%, the updated probability of outcome node *Willingness to conserve groundwater* was 53%, while the baseline situation was 57% (Fig. 3).
[b]ΔP is the difference between the lowest and highest value of the updated probability of outcome node being *yes*.

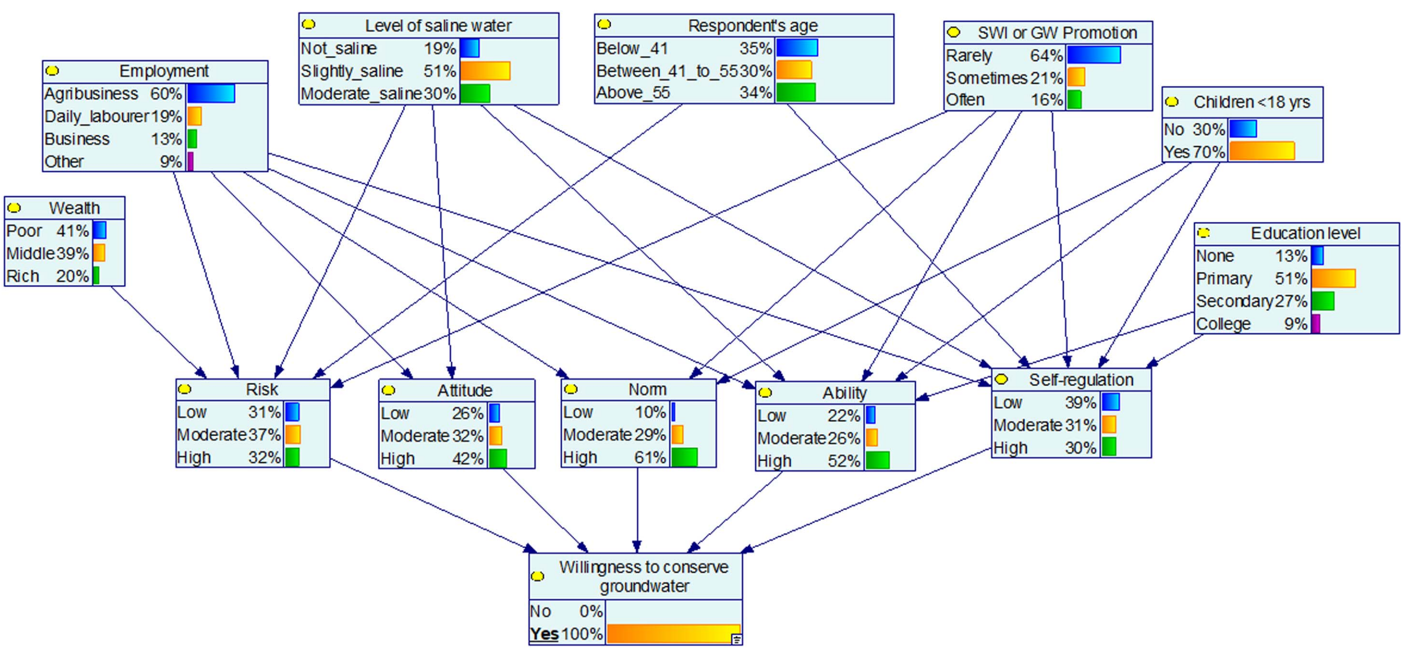

Fig. 4. Diagnostic inference: most probable states of all SEC and psychological factors that lead to the probability of willingness to conserve groundwater to 100%. The percentages in each node indicate the probability of a node being in a certain state and the arrows indicate the assumed cause and effect variables.

consequences of excessive ground water use, i.e., people are more willing to conserve groundwater only after they have saline water at home. Households may extract groundwater without realizing that the groundwater capacity is limited and that the source can run dry (Richey et al. 2015). One of the possible reasons for this is infrequent groundwater or SWI awareness campaigns or information sharing activities, i.e., 65% of the respondents have never or rarely heard anything regarding groundwater abstraction and its potential

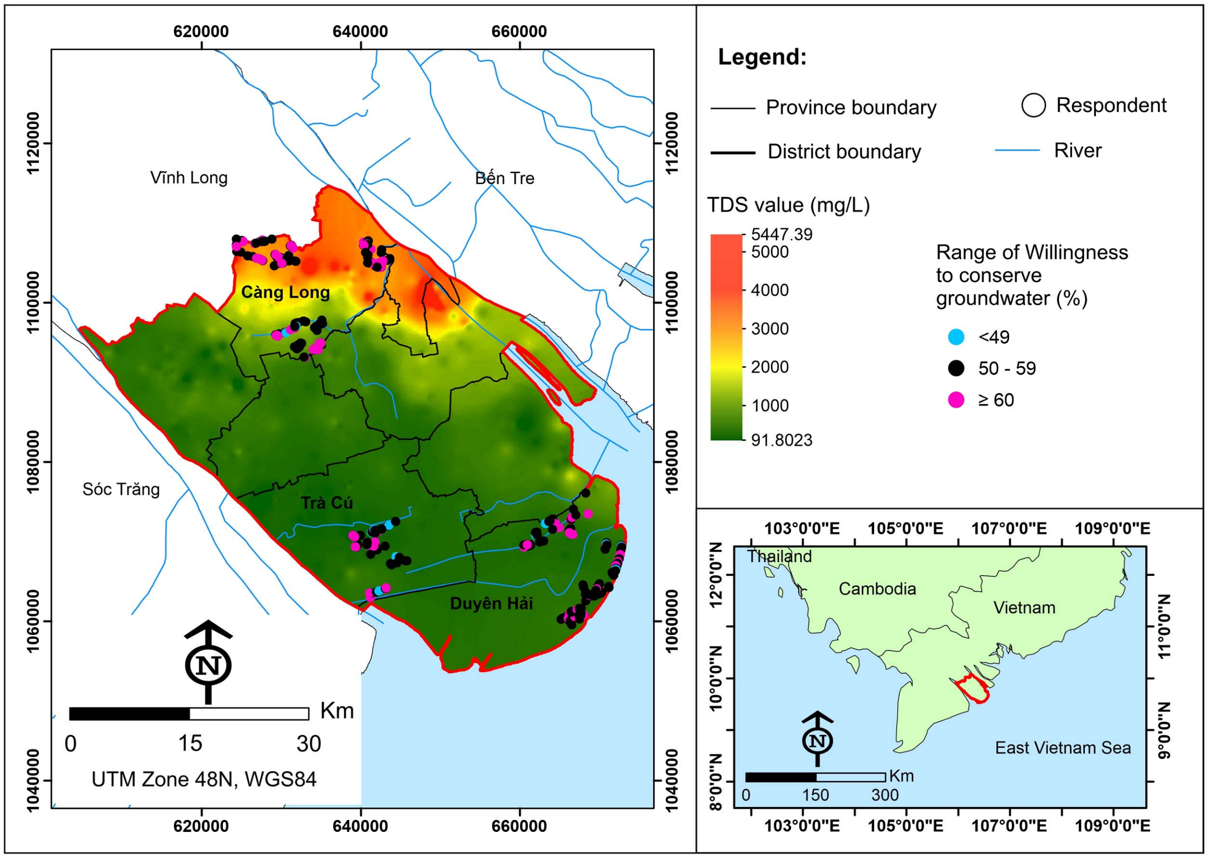

Fig. 5. The predicted BBN model of the willingness to conserve groundwater by the SECs of the respondents in Tra Vinh. (Map data from GADM.)

consequences. This is also inferred by the BBN model that the level of risk perception is positively correlated with the frequency of people being exposed to groundwater information or SWI awareness campaigns (Fig. 2).

The type of employment is the most important socioenvironmental characteristic. People working in agribusiness, e.g., farmers, can serve as potential targets for groundwater conservation programs and need to be involved in a groundwater conservation intervention in this area (Smith et al. 2016). Furthermore, 80% of the area of Tra Vinh is used for agribusiness (Van and Koontanakulvong 2019). Agribusiness is also the most dominant occupation among the respondents (59%), and it heavily depends on water availability, being the sector that is most vulnerable to groundwater depletion and SWI.

We also found that people entrust the solution of excessive groundwater abstraction and saline water to the local government. This suggests that the respondent's ability to get nonsaline water relies on the performance of the government to solve the issue, e.g., managing and reducing demand, or providing alternative water sources besides private groundwater wells. The study therefore emphasizes the need for local governments to urgently find solutions. A positive finding is that almost all of the respondents are willing to pay extra for better water quality and more reliable supply. Next to providing a reliable piped water supply, introducing groundwater charges could reduce the overuse of groundwater, i.e., make it more efficient, as also suggested by Danh and Khai (2015). These solutions, however, are technology-focused, costly, and difficult to implement.

Since norm was found to be the most influential psychological factor, implementers could leverage social norms to create a favorable social pressure to conserve groundwater among the community. The normative message, i.e., promotional activities that target social norms, have been found effective in inducing water conservation programs (Ferraro et al. 2011; Landon et al. 2018; Schultz et al. 2014). Reinforcing favorable social norms within communities can be done by regulating the use of groundwater, informing the respondents about their peers' behavior, raising certain expectations, or by making a public commitment to reduce groundwater usage (Bernedo et al. 2014; Ferraro et al. 2011; Koop et al. 2019). In the case of the VMD, Hamer et al. (2020) argue that the current groundwater regulation and governance are weak, i.e., water resource usage is not clear, and there is neither monitoring nor long-term vision regarding groundwater resources. Therefore, we emphasize to improve the current groundwater regulations and then positively influence social norms among groundwater users.

Our results can inspire intervention strategies for Tra Vinh. For example, an intervention strategy for an area with high salinity and high willingness, e.g., the Càng Long district, can be to enforce restrictions to groundwater use or to introduce fees to reduce demand, alongside increasing the use of water from alternative water sources. At the same time, in areas with low willingness, e.g., the Trà Cú district, soft interventions can be used to increase the awareness and improve the willingness to conserve groundwater. For example, providing information about one's water use and saving performance as compared to the average of one's neighbors has proven to lead to significant water savings by invoking social norms (OECD 2017). In combination with information about the importance of water-saving, this can facilitate conservation behavior among the population. Next to soft interventions to balance groundwater extraction and recharge, these could be complemented with hard interventions in the area as well, e.g., introducing water-saving appliances to storage and provision of water from alternative sources (Sønderlund et al. 2016). Pumping strategies should also be introduced to prevent excessive groundwater extraction (Sreekanth and Datta 2014).

Our model performance (AUC = 0.74 or moderately accurate) is slightly lower than that in the study by Daniel et al. (2019), who investigated the use of household water treatment in rural Nepal. Daniel et al. (2019) reported an AUC of 0.85, but also classified it as moderately accurate. One possible reason behind moderate accuracy could be that the model doesn't account for still-unknown important SEC variables that influence the RANAS psychological factors.

The BBN model structure relies on statistical correlations and hence should be cautiously used in inferring the hypothesized causal relationships between variables. Daniel et al. (2019) suggested to design a BBN structure that conforms with the literature and balances the statistical relationships with model complexity and model performance. Nonetheless, the BBN model is only a parsimonious representation of complex relationships between socioenvironmental, psychological, and water use–related intentions in the area. The findings should therefore be interpreted with caution.

Future studies could include other SECs that may influence the willingness to change water sources. Moreover, a better understanding of (ground) water usage patterns of households is needed, e.g., when and for what do they use which type of water source, how many liters of groundwater do people use per day, and for what purpose. In addition, future research could focus on improving access to alternative water sources that can substitute groundwater abstraction. Furthermore, our study is a cross-sectional study that aims to capture the perceptions at one given point in time. Salinization is a slow process and the perceptions of people with regard to it may also change slowly. A longitudinal study assessing people's perceptions should be conducted to see how the perceptions change following the increased level of salinity. Lastly, we used interpolated TDS values at the household locations, and the accuracy of the interpolated field depends on the density of TDS measurement points in the neighborhood of the households and the interpolation scheme used. We suggest measuring TDS at location of the household's water source to get more accurate TDS values rather than relying on the interpolated TDS values.

Conclusions

Groundwater conservation is challenging and requires more than just hard solutions. A synergetic implementation of hard and soft solutions, which entails the involvement of local communities, is expected to have a long-term impact. In this study, we used a BBN model to combine salinity measurements with socioenvironmental and psychological information of households collected from an extensive survey in the Tra Vinh province to understand the drivers of willingness to conserve groundwater. We found that the respondents in Tra Vinh are willing to conserve groundwater. One of the main reasons for that is that they are facing the issue of saline water. Additionally, the type of employment and the exposure to groundwater information or awareness campaigns were found to be important SECs that distinguish households who are willing to change. The psychological factor norm was found to be most important and needs addressing, for example by regulating the groundwater usage and by initiating public commitments to reduce the groundwater usage. Finally, this research emphasizes the urgency for the local government in the Mekong Delta, especially the Tra Vinh province, to act now, especially because most of the respondents rely on the capabilities of the local government to solve the issue of excessive groundwater extraction in the region.

Data Availability Statement

The following data, models, or code generated or used during the study are available from the corresponding author by request (data sets used and the BBN model).

Acknowledgments

We thank the SALINPROVE team for their collaboration and sharing the groundwater simulations analysis. We thank the Lamminga fund and IHE Delft Institute for Water Education for their financial support. A special thanks to Hai Dao Hong, Truyen Phu Nhat, Huy Nguyen Quoc, and Anh Vuong Tuan (VNUHCM-University of Technology) for their assistance during the fieldwork in the Tra Vinh province, May–June 2019, and A. Arifin for helping with the GIS modeling.

References

Alfarrah, N., and K. Walraevens. 2018. "Groundwater overexploitation and seawater intrusion in coastal areas of arid and semi-arid regions." *Water (Switzerland)* 10 (2): 143. https://doi.org/10.3390/w10020143.

An, T. D., M. Tsujimura, V. Le Phu, A. Kawachi, and D. T. Ha. 2014. "Chemical characteristics of surface water and groundwater in coastal watershed, Mekong Delta, Vietnam." *Procedia Environ. Sci.* 20: 712–721. https://doi.org/10.1016/j.proenv.2014.03.085.

Bernedo, M., P. J. Ferraro, and M. Price. 2014. "The persistent impacts of norm-based messaging and their implications for water conservation." *J. Consum. Policy* 37 (3): 437–452. https://doi.org/10.1007/s10603-014-9266-0.

Cain, J. 2001. *Planning improvements in natural resources management*. Wallingford, UK: UK Centre for Ecology & Hydrology.

Clark, W. A., and J. C. Finley. 2007. "Determinants of water conservation intention in Blagoevgrad, Bulgaria." *Soc. Nat. Resour.* 20 (7): 613–627. https://doi.org/10.1080/08941920701216552.

Danh, V. T., and H. V. Khai. 2015. "Household demand and supply for clean groundwater in the Mekong Delta, Vietnam." *Renewables: Wind Water Solar* 2 (1): 1–12. https://doi.org/10.1186/s40807-014-0004-7.

Daniel, D., A. Diener, S. Pande, S. Jansen, S. Marks, R. Meierhofer, M. Bhatta, and L. Rietveld. 2019. "Understanding the effect of socio-economic characteristics and psychosocial factors on household water treatment practices in rural Nepal using Bayesian Belief Networks." *Int. J. Hyg. Environ. Health* 222 (5): 847–855. https://doi.org/10.1016/j.ijheh.2019.04.005.

Daniel, D., S. Pande, and L. Rietveld. 2020. "The effect of socio-economic characteristics on the use of household water treatment via psychosocial factors: A mediation analysis." *Hydrol. Sci. J.* 65 (14): 2350–2358. https://doi.org/10.1080/02626667.2020.1807553.

Davies, K., C. Doolan, R. Van Den Honert, and R. Shi. 2014. "Water-saving impacts of smart meter technology: An empirical 5 year, whole-of-community study in Sydney, Australia." *Water Resour. Res.* 50 (9): 7348–7358. https://doi.org/10.1002/2014WR015812.

Do, C. B., and S. Batzoglou. 2008. "What is the expectation maximization algorithm?" *Nat. Biotechnol.* 26 (8): 897–899. https://doi.org/10.1038/nbt1406.

Dreibelbis, R., P. J. Winch, E. Leontsini, K. R. Hulland, P. K. Ram, L. Unicomb, and S. P. Luby. 2013. "The integrated behavioural model for water, sanitation, and hygiene: A systematic review of behavioural models and a framework for designing and evaluating behaviour change interventions in infrastructure-restricted settings." *BMC Public Health* 13 (1): 1015. https://doi.org/10.1186/1471-2458-13-1015.

Ferraro, P. J., J. J. Miranda, and M. K. Price. 2011. "The persistence of treatment effects with norm-based policy instruments: Evidence from a randomized environmental policy experiment." *Am. Econ. Rev.* 101 (3): 318–322. https://doi.org/10.1257/aer.101.3.318.

Gamma, A. E., J. Slekiene, G. von Medeazza, F. Asplund, P. Cardoso, and H.-J. Mosler. 2017. "Contextual and psychosocial factors predicting Ebola prevention behaviours using the RANAS approach to behaviour change in Guinea-Bissau." *BMC Public Health* 17 (1): 446. https://doi.org/10.1186/s12889-017-4360-2.

George, C. M., et al. 2016. "Sustained uptake of a hospital-based handwashing with soap and water treatment intervention (cholera-hospital-based intervention for 7 days [CHoBI7]): A randomized controlled trial." *Am. J. Trop. Med. Hyg.* 94 (2): 428–436. https://doi.org/10.4269/ajtmh.15-0502.

Greiner, M., D. Pfeiffer, and R. D. Smith. 2000. "Principles and practical application of the receiver-operating characteristic analysis for diagnostic tests." *Prev. Vet. Med.* 45 (1–2): 23–41. https://doi.org/10.1016/S0167-5877(00)00115-X.

Grönwall, J., and K. Danert. 2020. "Regarding groundwater and drinking water access through a human rights lens: Self-supply as a norm." *Water (Switzerland)* 12 (2): 419. https://doi.org/10.3390/w12020419.

Hai, D. 1999. *Participatory poverty assessment*. Tra Vinh Province, Vietnam: World Bank Resident Mission.

Hamer, T., C. Dieperink, V. P. D. Tri, H. S. Otter, and P. Hoekstra. 2020. "The rationality of groundwater governance in the Vietnamese Mekong Delta's coastal zone." *Int. J. Water Resour. Dev.* 36 (1): 127–148. https://doi.org/10.1080/07900627.2019.1618247.

Inauen, J., M. M. Hossain, R. B. Johnston, and H. J. Mosler. 2013. "Acceptance and use of eight arsenic-safe drinking water options in Bangladesh." *PLoS One* 8 (1): e53640. https://doi.org/10.1371/journal.pone.0053640.

Irwin, A., O. Solar, and J. Vega. 2016. "Social determinants of health, the United Nations Commission of." *Int. Encycl. Public Heal.* 557–561. https://doi.org/10.1016/B978-0-12-803678-5.00415-X.

Klassen, J., and D. M. Allen. 2017. "Assessing the risk of saltwater intrusion in coastal aquifers." *J. Hydrol.* 551 (Aug): 730–745. https://doi.org/10.1016/j.jhydrol.2017.02.044.

Koop, S. H. A., A. J. Van Dorssen, and S. Brouwer. 2019. "Enhancing domestic water conservation behaviour: A review of empirical studies on influencing tactics." *J. Environ. Manage.* 247 (Oct): 867–876. https://doi.org/10.1016/j.jenvman.2019.06.126.

Landon, A. C., R. T. Woodward, G. T. Kyle, and R. A. Kaiser. 2018. "Evaluating the efficacy of an information-based residential outdoor water conservation program." *J. Cleaner Prod.* 195 (Sep): 56–65. https://doi.org/10.1016/j.jclepro.2018.05.196.

Laura, U. 2007. "Advantages and challenges of Bayesian networks in environmental modeling." *Ecol. Modell.* 203 (3–4): 312–318. https://doi.org/10.1016/j.ecolmodel.2006.11.033.

Lilje, J., H. Kessely, and H. J. Mosler. 2015. "Factors determining water treatment behavior for the prevention of cholera in Chad." *Am. J. Trop. Med. Hyg.* 93 (1): 57–65. https://doi.org/10.4269/ajtmh.14-0613.

Mai, N. P., T. D. Thang, S. Kantoush, T. Sumi, and D. Van Binh. 2019. "The processes of saltwater intrusion into Hau River." In *Proc., Int. Conf. on Asian and Pacific Coasts*, 1477–1483. Singapore: Springer. https://doi.org/10.1007/978-981-15-0291-0_199.

McDonald, R. I., P. Green, D. Balk, B. M. Fekete, C. Revenga, M. Todd, and M. Montgomery. 2011. "Urban growth, climate change, and freshwater availability." *Proc. Natl. Acad. Sci. U.S.A.* 108 (15): 6312–6317. https://doi.org/10.1073/pnas.1011615108.

Minderhoud, P. S. J., G. Erkens, V. H. Pham, V. T. Bui, L. Erban, H. Kooi, and E. Stouthamer. 2017. "Impacts of 25 years of groundwater extraction on subsidence in the Mekong delta, Vietnam." *Environ. Res. Lett.* 12 (6): 064006. https://doi.org/10.1088/1748-9326/aa7146.

Mosler, H., and N. Contzen. 2016. *Systematic behavior change in water sanitation and hygiene a practical guide using the RANAS approach, version 1.1*. Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology.

Mosler, H. J., O. R. Blöchliger, and J. Inauen. 2010. "Personal, social, and situational factors influencing the consumption of drinking water from arsenic-safe deep tubewells in Bangladesh." *J. Environ. Manage.* 91 (6): 1316–1323. https://doi.org/10.1016/j.jenvman.2010.02.012.

Mosler, H. J., S. M. Kraemer, and R. B. Johnston. 2013. "Achieving long-term use of solar water disinfection in Zimbabwe." *Public Health* 127 (1): 92–98. https://doi.org/10.1016/j.puhe.2012.09.001.

Mosler, H.-J. 2012. "A systematic approach to behavior change interventions for the water and sanitation sector in developing countries: A conceptual model, a review, and a guideline." *Int. J. Environ. Health Res.* 22 (5): 431–449. https://doi.org/10.1080/09603123.2011.650156.

Mukherjee, A., S. N. Bhanja, and Y. Wada. 2018. "Groundwater depletion causing reduction of baseflow triggering Ganges River summer drying." *Sci. Rep.* 8 (1): 1–9. https://doi.org/10.1038/s41598-018-30246-7.

Mukherjee, S. 2008. *Factors influencing farmers' willingness to protect groundwater from nonpoint sources of pollution in the lower Bhavani River basin, Tamil Nadu, in: Managing water in the face of growing scarcity, inequity and declining returns: Exploring fresh approaches.* Adelaide, Australia: International Water Management Institute.

OECD (Organisation for Economic Co-operation and Development). 2017. *Behavioral insights and public policy: Lessons from around the world, behavioural insights and public policy.* Paris: OECD.

Pagano, A., I. Pluchinotta, R. Giordano, and U. Fratino. 2018. "Integrating 'hard' and 'soft' infrastructural resilience assessment for water distribution systems." *Complexity* 2018: 1–16. https://doi.org/10.1155/2018/3074791.

Pande, S., M. McKee, and L. A. Bastidas. 2009. "Complexity-based robust hydrologic prediction." *Water Resour. Res.* 45 (10): 1–18. https://doi.org/10.1029/2008WR007524.

Peal, A. J., B. E. Evans, and C. van der Voorden. 2010. *Hygiene and sanitation software: An overview of approaches*. Geneva, Switzerland: Water Supply & Sanitation Collaborative Council.

Pearl, J. 1988. *Probabilistic reasoning in intelligent systems: Networks of plausible inference*. San Francisco, CA: Morgan Kaufmann Publishers.

Rainey, R. C., and A. K. Harding. 2005. "Acceptability of solar disinfection of drinking water treatment in Kathmandu Valley, Nepal." *Int. J. Environ. Health Res.* 15 (5): 361–372. https://doi.org/10.1080/09603120500289168.

Rhoades, J., A. Kandiah, and A. Mashali. 1992. *The use of saline waters for crop production, FAO irrigation and drainage paper*. Rome: Food and Agriculture Organization of the United Nations.

Richey, A. S., B. F. Thomas, M. H. Lo, J. S. Famiglietti, S. Swenson, and M. Rodell. 2015. "Uncertainty in global groundwater storage estimates in a total groundwater stress framework." *Water Resour. Res.* 51 (7): 5198–5216. https://doi.org/10.1002/2015WR017351.

Ringnér, M. 2008. "What is principal component analysis?" *Nat. Biotechnol.* 26: 303–304. https://doi.org/10.1038/nbt0308-303.

Rodriguez, J. D., A. Perez, and J. A. Lozano. 2009. "Sensitivity analysis of k-fold cross validation in prediction error estimation." *IEEE Trans. Pattern Anal. Mach. Intell.* 32 (3): 569–575. https://doi.org/10.1109/TPAMI.2009.187.

Russell, S., and K. Fielding. 2010. "Water demand management research: A psychological perspective." *Water Resour. Res.* 46 (5): 1–12. https://doi.org/10.1029/2009WR008408.

Rusydi, A. F., 2018. "Correlation between conductivity and total dissolved solid in various type of water: A review." In *Proc., IOP Conf. Series: Earth and Environmental Science*. Bandung, Indonesia: LipiI. https://doi.org/10.1088/1755-1315/118/1/012019.

Sanh, N. V. 2010. *Research on water resources in Tra Vinh province: Water use and exploitation, solutions for using sustainable water resources and management*. Can Tho, Vietnam: Can Tho Univ.

Schultz, P. W., A. Messina, G. Tronu, E. F. Limas, R. Gupta, and M. Estrada. 2014. "Personalized normative feedback and the moderating role of personal norms: A field experiment to reduce residential water consumption." *Environ. Behav.* 48 (5): 686–710. https://doi.org/10.1177/0013916514553835.

Seimetz, E., A. M. Boyayo, and H. J. Mosler. 2016. "The influence of contextual and psychosocial factors on handwashing." *Am. J. Trop. Med. Hyg.* 94 (6): 1407–1417. https://doi.org/10.4269/ajtmh.15-0657.

Shrestha, S., T. V. Bach, and V. P. Pandey. 2016. "Climate change impacts on groundwater resources in Mekong Delta under representative concentration pathways (RCPs) scenarios." *Environ. Sci. Policy* 61 (Jul): 1–13. https://doi.org/10.1016/j.envsci.2016.03.010.

Siebert, S., J. Burke, J. M. Faures, K. Frenken, J. Hoogeveen, P. Döll, and F. T. Portmann. 2010. "Groundwater use for irrigation—A global inventory." *Hydrol. Earth Syst. Sci.* 14 (10): 1863–1880. https://doi.org/10.5194/hess-14-1863-2010.

Smajgl, A., T. Q. Toan, D. K. Nhan, J. Ward, N. H. Trung, L. Q. Tri, V. P. D. Tri, and P. T. Vu. 2015. "Responding to rising sea levels in the Mekong delta." *Nat. Clim. Change* 5 (2): 167–174. https://doi.org/10.1038/nclimate2469.

Smith, M., K. Cross, M. Paden, and P. Laban. 2016. *Spring: Managing groundwater sustainably.* Gland, Switzerland: International Union for Conservation of Nature and Natural Resources.

Sønderlund, A. L., J. R. Smith, C. J. Hutton, Z. Kapelan, and D. Savic. 2016. "Effectiveness of smart meter-based consumption feedback in curbing household water use: Knowns and unknowns." *J. Water Resour. Plann. Manage.* 142 (12): 04016060. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000703.

Sonego, I. L., A. C. Huber, and H. Mosler. 2013. "Does the implementation of hardware need software? A longitudinal study on fluoride-removal filter use in Ethiopia." *Environ. Sci. Technol.* 47 (22): 12661–12668. https://doi.org/10.1021/es402787s.

Sreekanth, J., and B. Datta. 2014. "Design of an optimal compliance monitoring network and feedback information for adaptive management of saltwater intrusion in coastal aquifers." *J. Water Resour. Plann. Manage.* 140 (10): 04014026. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000406.

Syme, G. J., B. E. Nancarrow, and C. Seligman. 2000. "The evaluation of information campaigns to promote voluntary household water conservation." *Eval. Rev.* 24 (6): 539–578. https://doi.org/10.1177/0193841X0002400601.

Tran, P. H., A. K. Nguyen, Y. Liou, P. P. Hoang, and H. Thanh. 2018. "Estimation of salinity intrusion by using Landsat 8 OLI data in the Mekong Delta, Vietnam." Preprint submitted August 17, 2018. https://doi.org/10.20944/preprints201808.0301.v1.

Tuan, L. A., C. T. Hoanh, F. Miller, and B. T. Sinh. 2007. *Flood and salinity management in the Mekong Delta, Vietnam*. Bangkok, Thailand: Sustainable Mekong Research Network (Sumernet).

Van, T. P., and S. Koontanakulvong. 2019. "Estimation of groundwater use pattern and distribution in the coastal Mekong Delta, Vietnam via socio-economical survey and groundwater modeling." *Eng. J.* 23 (6): 487–499. https://doi.org/10.4186/ej.2019.23.6.487.

Van Pham, H., F. C. Van Geer, V. Bui Tran, W. Dubelaar, and G. H. P. Oude Essink. 2019. "Paleo-hydrogeological reconstruction of the fresh-saline groundwater distribution in the Vietnamese Mekong Delta since the late Pleistocene." *J. Hydrol.: Reg. Stud.* 23 (Jun): 100594. https://doi.org/10.1016/j.ejrh.2019.100594.

Vyas, S., and L. Kumaranayake. 2006. "Constructing socio-economic status indices: How to use principal components analysis." *Health Policy Plann.* 21 (6): 459–468. https://doi.org/10.1093/heapol/czl029.

Wada, Y., et al. 2016. "Modeling global water use for the 21st century: The Water Futures and Solutions (WFaS) initiative and its approaches." *Geosci. Model Dev.* 9 (1): 175–222. https://doi.org/10.5194/gmd-9-175-2016.

Wada, Y., L. P. H. Van Beek, C. M. Van Kempen, J. W. T. M. Reckman, S. Vasak, and M. F. P. Bierkens. 2010. "Global depletion of groundwater resources." *Geophys. Res. Lett.* 37 (20): 1–5. https://doi.org/10.1029/2010GL044571.

Webb, M. D., and K. W. F. Howard. 2011. "Modeling the transient response of saline intrusion to rising sea-levels." *Ground Water* 49 (4): 560–569. https://doi.org/10.1111/j.1745-6584.2010.00758.x.

Willis, R. M., R. A. Stewart, D. P. Giurco, M. R. Talebpour, and A. Mousavinejad. 2013. "End use water consumption in households: Impact of socio-demographic factors and efficient devices." *J. Cleaner Prod.* 60 (Dec): 107–115. https://doi.org/10.1016/j.jclepro.2011.08.006.

Wutich, A., A. C. White, D. D. White, K. L. Larson, A. Brewis, and C. Roberts. 2014. "Hard paths, soft paths or no paths? Cross-cultural perceptions of water solutions." *Hydrol. Earth Syst. Sci.* 18 (1): 109–120. https://doi.org/10.5194/hess-18-109-2014.

Zabinski, J. W., K. J. Pieper, and J. M. Gibson. 2018. "A Bayesian belief network model assessing the risk to wastewater workers of contracting Ebola virus disease during an outbreak." *Risk Anal.* 38 (2): 376–391. https://doi.org/10.1111/risa.12827.