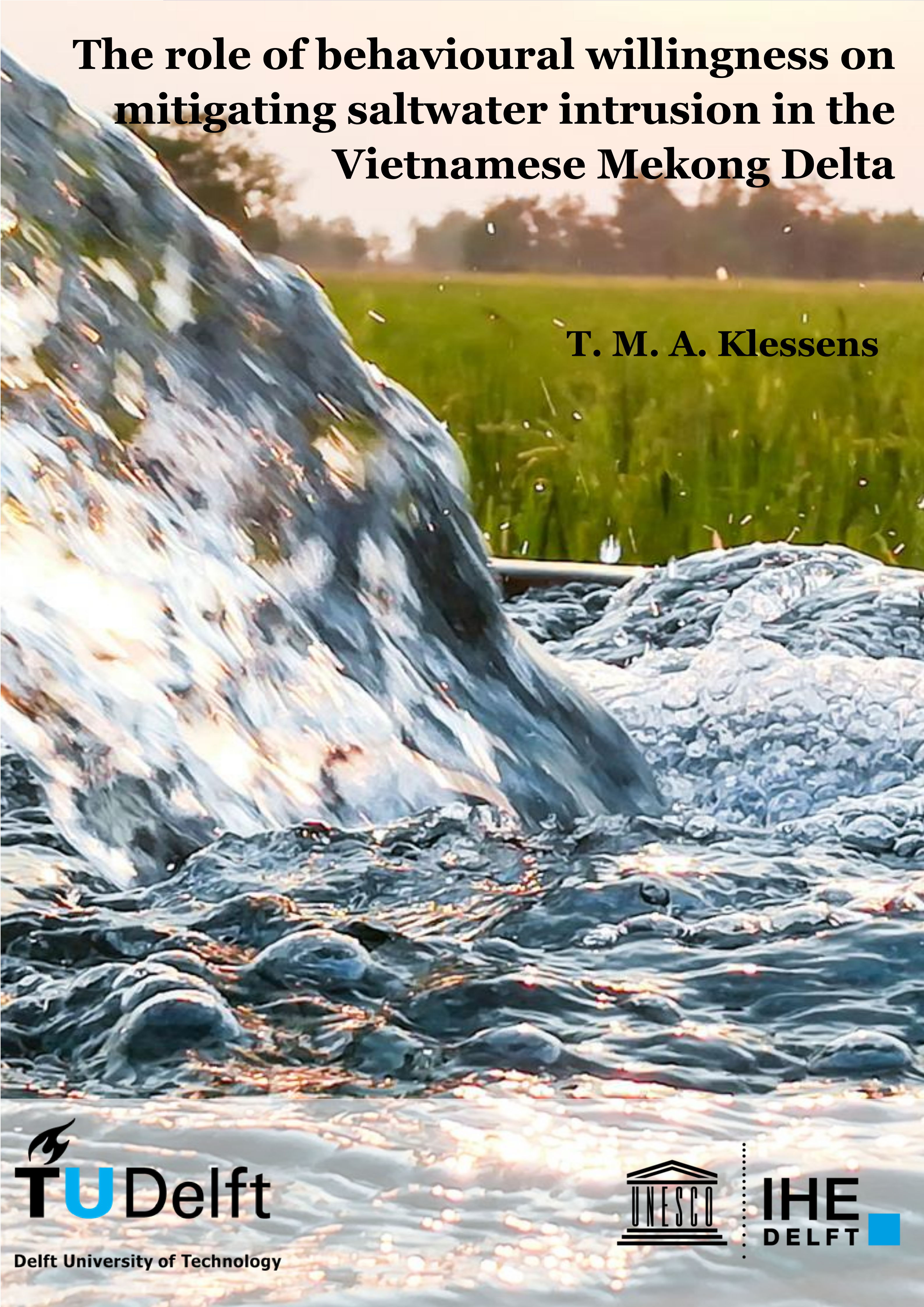
The role of behavioural willingness on mitigating saltwater intrusion in the Vietnamese Mekong Delta



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Combining socioeconomic data with groundwater simulations using Bayesian Belief Networks

By

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The role of behavioural willingness on mitigating saltwater intrusion in the Vietnamese Mekong Delta

Combining socioeconomic data with groundwater simulations using Bayesian Belief Networks

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Fresh water resources in coastal areas are under intense pressure from groundwater consuming activities, sea level rise and extreme weather events, which effectively amplify salt water intrusion (SWI) into coastal freshwater aquifers. Literature on SWI describe the effects of SWI, model SWI scenarios and explain possible SWI mitigation strategies. To our knowledge there are, however, no studies that combine socioeconomic data with groundwater simulations to estimate SWI mitigation prevalence within an area. In this study, we demonstrate how a socioeconomic model can be combined with groundwater simulations to explore the possible role of behaviour willingness in finding suitable SWI adaptation/ mitigation strategies. The coastal province of Tra Vinh, located in the populated Vietnamese Mekong Delta, is an area affected by SWI and was used as case study area. Data collected from 313 households spread over nine communes, within the province, was used to construct a Bayesian Belief Network (BBN) model. The model integrates both socioeconomic (e.g. education, age) and psychosocial (behavioural) characteristics, to predict the willingness to change of the population; *willingness to change from groundwater to a different source of water*. The validated BBN model showed good model performances. The research found amongst others, using three model analysis, how the BBN model could be used on both regional (province) and local (commune) scale. The two different scales can help in defining both target groups and suitable locations for SWI mitigation/ adaptation interventions. Moreover, this study did not focus on finding suitable alternative water sources, that can serve as a substitute for groundwater abstraction. Though, the model analysis can help to more effectively define the possibilities of alternative sources and/ or water-saving interventions.

Keywords: Saltwater intrusion, Groundwater abstraction, Bayesian Belief networks, Behavioural model

1. INTRODUCTION

A. Research motivation

Fresh water is a precious natural resource for human life, essential in our daily lives. Human population growth and climate change are expected to have substantial impacts on global water resources throughout the twenty-first century [1]. Freshwater resources (mainly groundwater) in coastal areas are under pressure from water consuming activities, salt water intrusion and extreme weather events [2] [3]. These coastal areas are a nexus of the world's oceanic and hydrologic ecosystems [4] and with 70 % of the world's population residing in these areas they are among the most densely populated areas in the world [5], often with enormous socioeconomic importance. It is therefore imperative to understand the available water resources in these densely pop-

ulated areas. The large Vietnamese Mekong Delta, located at the end of the second richest river basin (the Mekong river basin), in terms of biodiversity in the world, is one of these densely populated coastal areas [6]. The 21 million inhabitants living in this part of the river basin already experience the burden of climate change, groundwater depletion and saltwater intrusion [7]. Moreover, Vietnam has been ranked among top five countries where climate change is expected to have a devastating impact, in particular its Tra Vinh province [8]. Further increase in extreme climate events (periods of extreme droughts and floods) are expected to result in depletion of the freshwater availability and with it a drop of the water levels in the aquifers [9] [10]. Dropping water levels in these fresh water aquifers and a rising sea level, due to climate change, are expected to have an increasing influence over the saltwater intrusion (SWI) phenomena, a common phenomenon in coastal aquifers, in which saltwater intrudes the fresh water aquifers, polluting the fresh water intended for drinking, irrigation and/ or industry purposes [11]. SWI is the movement of saltwater into fresh water bodies like rivers or aquifers, due to natural processes which can be influenced by human activities. Uncontrolled fresh-groundwater extraction by (large) water users is one of these human activities, which leads to degrading the quality of the fresh-water to brackish water, directly affect domestic supply and crop productivity (S5) [12] [13]. Lack of groundwater information, knowledge and awareness amongst inhabitants and a lack of regulations and guidelines for groundwater permit system and management, aggravates the risk of salt water intrusion and leads to over exploitation in certain areas [2].
Vietnam's strong economic growth and demographic transition, in which a higher water demand is expected, will create both opportunities and challenges [14]. Figure 1 gives an illustration of the various factors which play a role in the increasing demand for water and the factors that result in freshwater scarcity in the Vietnamese Mekong Delta.
Several countries have already faced the problems of climate change and the race of minimizing the gap between what's needed and what's the feasible water supply. The in 2018, *Day Zero* status of Cape Town (South Africa), in which the local authorities referred to the day when Cape Town would become the first major city in the world to run out of water, as reservoirs tend to dip too low to deliver a potable supply [15], is one of these examples. Moreover, Massachusetts Institute of Technology (MIT) published an article in April 2019, which states:"Sea-level rise threatens to deluge villages and mega-cities, and poison the water tables, along the subcontinent's 7,500 kilometers coastline. The Southern Indian city of Chennai already experienced acute water shortage (June - July, 2019), some 21 other cities in India could follow Chennai and run out of and/ or lose its "most" valuable resource of groundwater as early as next year" [16].

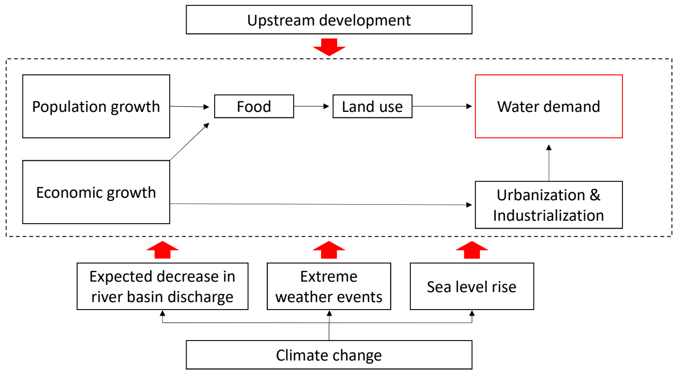


Figure. 1. Influence factors, expected to increase the demand for water (partially derived from the Mekong Delta Plan I www.mekongdeltaplan.com/)

The estimated volume of 1,924,000 m^3 abstracted every day from 550,000 exploitation wells for drinking water, irrigation and industry purposes, is the main cause for groundwater depletion and saltwater intrusion in the Vietnamese Mekong Delta [13]. For future development of the area it is important to have a better understanding of one of the most abundant, but at the same time poorly understood water sources, fresh groundwater reservoirs [8].
Saltwater intrusion mitigation and adaptation measures are essential for protecting the quality of the remaining water. These possible measures could be categorised by 'hard' and 'soft' solutions [18]. Soft measures always require the involvement of local communities and seeks to improve the way water is used (e.g. via efficient technologies, education and/ or training), rather than to find new sources of supply [7]. Whereas, the hard path relies almost exclusively on centralised infrastructure to capture, treat and deliver (new) water supplies. To date this hard path is mainly used, however, a combination of 'hard' and 'soft' measures is expected to result in a better solution in the long run [19]. Water managers are increasingly embracing the "soft

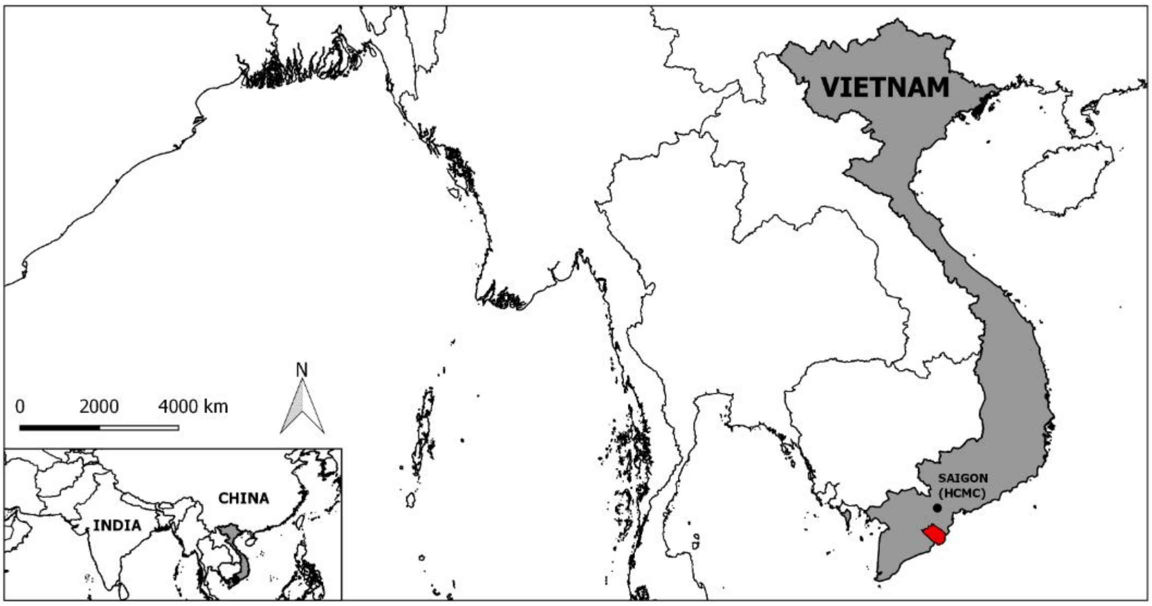


Figure. 2. Study location, Tra Vinh province (red) and the surrounding environment, drawn using QGIS [17]

path" approaches to ensure that people have the water they need in the future [18]. Water solutions that rely on social engineering (in addition to hydrologic engineering) will require a more nuanced understanding of public awareness, participation, beliefs, and behaviour change [20] [21]. This study will focus on designing a model, to find suitable locations to effectively implement both 'hard' and 'soft' solutions and try to use the nuance as described above to come to conclusions.

Research into saltwater intrusion; monitoring, mitigating the possible socioeconomic impact and/ or designing adaption strategies is nothing new. However, to our knowledge there is no study that investigates the possibilities of using psychosocial and socioeconomic data in combination with groundwater simulations to design effective saltwater intrusion mitigation strategies, which the local population would be willing to accept and use. We belief that it is essential to include behavioural aspects of the local inhabitants, to effectively implement (large and capital intense) mitigation/ adaptation strategies to overcome the possible (negative) impact of SWI. After all, an investment solely based on data simulations (i.e. the groundwater model), without consultation or proper analysis of the end-user (i.e. local inhabitants) is doomed to be unsuccessful.

The main objective of this research is to combine socioeconomic data and groundwater model simulations within a probabilistic graphical model (PGM), which addresses the behaviour willingness (i.e. the willingness of the local inhabitants to change/ adapt towards a different water source as a result of the increasing problems that come with saltwater intrusion). This combination of data is expected to help to identify suitable locations for implementing SWI mitigation/ adaptation strategies i.e. identify locations in which people are likely to encounter the SWI effect and are willing to change from groundwater to a different source of water.
With this research we expect to answer the following question:

> *Does the local population expect and experience the same risk of saltwater intrusion as can be seen from the groundwater model simulations? If so, how willing (or not) are the inhabitants to adapt to these effects, and how could their behaviour be influenced?*

We will first present a cross-sectional survey preformed in the Tra Vinh province, Vietnam. Followed by a brief explanation on the design of the groundwater model used. After which we present a Bayesian Belief Network (BBN) model, which uses the analysis of the interactions between socioeconomic and psychosocial characteristics to find the impact of these interactions on the willingness to change (behavioural willingness), using the RANAS approach. And finally we will present and discuss three different model analyses.

2. METHODOLOGY

A. Study location

The economic potential of the Vietnamese Mekong River Delta is the result of its strategic position in socioeconomic development, relative young and abundant labour force and the favourable climate conditions [22]. With over 20 % of Vietnam's population living in the Mekong Delta area, it generates nearly 25 % of Vietnam's national GDP and 90 % of the total rice exported [23], as a result the area is a key player to Vietnam's food production and economic development. The province of Tra Vinh is located in the coastal lowlands of the Vietnamese Mekong Delta. Located only ±150 kilometres from Vietnam's most populated city and economic center, Ho Chi Minh City (8.64 million inhabitants), Tra Vinh province is primarily important in agri- and aqua- cultural production [24]. Groundwater abstraction is seen as primary water source for the 1.3 million inhabitants living in the province and is used for both household, industry and irrigation purposes. A research report from Can Tho University [25] reported an average daily groundwater abstraction in 2007 of ±187,685 m^3, abstracted by an estimated 84,600 wells of which only 121 are licensed. Moreover, in 2016 annual groundwater abstraction was estimated to be 347,793 m^3/d. Resulting in a total groundwater abstraction increase of two to three times in the last 10 years.

B. Data collection

B.1. Socioeconomic data collection

In May and June 2019, a cross-sectional study in the Tra Vinh province was conducted, during which 313 households were surveyed (S6). The households were divided over nine communes (third-level and lowest level of Vietnam's administrative units system). The communes were located in three different districts (Duyên Hi, Càng Long and Trà Cú) within the Tra Vinh province (figure 2). During the cross-sectional study the local SALINPROVE project partner, Ho Chi Minh City University of Technology (HCMUT), assisted in arranging collaboration of the commune based government (Tra Vinh Provincial Youth Union). The questionnaire was translated from English into Vietnamese, back-translated into English, and reviewed for definition accuracy and possible interpretation errors. A pilot test was performed amongst students from HCMUT. Moreover, informed consent was obtained from all participants prior to the interview and ethical approval was given by HREC Delft University of Technology (Human Research Ethics Committee).

Survey households were selected based on a previous survey study conducted in March 2018. During the study in 2018, IHE made a selection of the nine communes based on water resources conditions and commune level income analysis. In 2018 the target was to collect data on groundwater use [25]. Every commune consists of 6 - 8 villages and in every village 8 households were randomly selected. In 2018 a total of 419 households were interviewed. During the survey study in May - June 2019 in 2018 collected GPS-coordinates were used to interview the (same) households. The limited resolution of the in 2018 gathered gps-coordinates, and to retain random selection of household, led to using a constant "household-selection" approach. The interviewee had to select the household nearest to the location indicated by the gps-coordinates on google.maps. If there was nobody home or if the inhabitants were not willing to take part in the interview the survey conductor had the possibility to address the direct neighbours (i.e. the household on the right or left side of the first chosen household). If these neighbours didn't consent to partake the gps-coordinate was disregarded. Data collected in 2018 was not used and/ or compared for purposes other than the household sampling in this study.
The target audience for this study was chosen to be the "oldest" household member present at that moment; respect for the elderly and their say over the household are the primary reasons. The questionnaire designed for the survey study (2019), include the following themes; 1. socio-demographic information of the household; 2. knowledge and perceptions on groundwater abstraction and saltwater intrusion; 3. future expectations on water availability; and 4. water related habits (S6). Behaviour determinant factor questions i.e. questions related to the RANAS approach (C.2), were measured using a five-item *Likert scale*. Furthermore, a *nominal scale* was used to measure socioeconomic characteristics. And the number of open questions was kept to a minimum, since they are not considered suitable for statistical analysis and are considered to serve as source of additional information. Moreover, water quality measurements were performed, measuring the electrical conductivity (EC) and parts per million (ppm) of the various water sources present at the households.

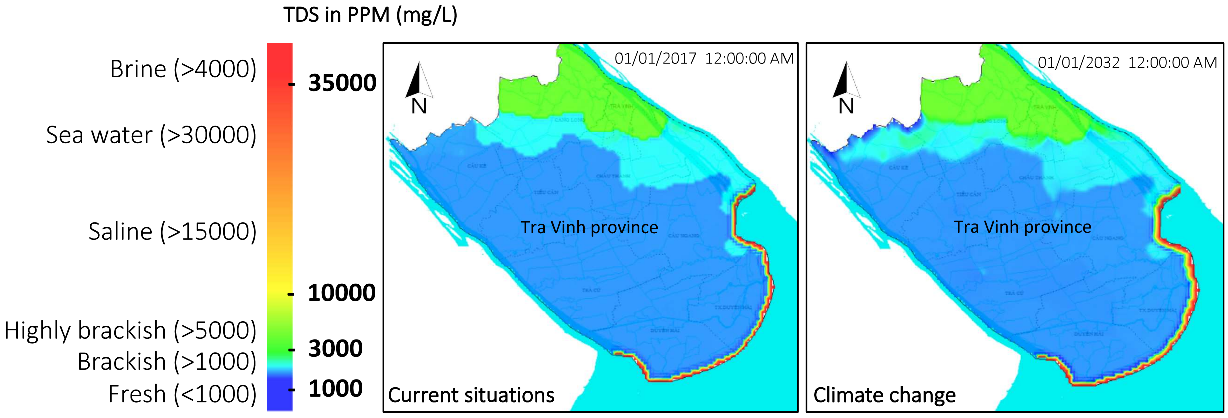


Figure. 3. Two maps of groundwater simulations scenarios of the upper-middle Pleistocene aquifer (qp2-3)

B.2. The groundwater model

The groundwater model used in this research was developed by the SALINPROVE team. The software Groundwater Modelling System ("GMS") was used to create a three-dimensional (3D) groundwater flow and saltwater transport model. The model consists of 135 rows and 151 columns, and 13 model layers representing 7 aquifers and 6 aquitards. The model grid size was set at 500 meters x 500 meters. The model boundaries are determined by three natural boundaries (northeast and southwest boundary are two big rivers: Co Chien and Hau rivers respectively and the southeast boundary is the 65 km long coastline of the South China Sea) and one man-made boundary (northwest boundary: the Tra Vinh province border). Aquifer inflow/ recharge is considered from precipitation infiltration, river leakage and underground inflow from upstream (i.e. man-made boundary, northwest). Moreover, aquifer discharge/ outflow was considered to be the result of groundwater abstraction and discharge to the sea.
A MODFLOW model was used to simulate transient groundwater flows from January 2007 to December 2016. The model was compared and calibrated with data collected from six observation wells, which measured the groundwater levels on a monthly basis for a period of ten years (2007 - 2016), resulting in 120 groundwater measurements from every well. Furthermore, a SEAWAT model was used to simulate the saltwater transport/ intrusion. The model was compared and calibrated with groundwater measurement taken during a survey study conducted in 2018. From the salinity measurements collected a contour map was created, using Ordinary Kriging, which looks fairly similar to the groundwater model (S9). The final calibrated model was used to run four forecast scenarios illustrating the change in salinity levels in the province; 1. business as usual, 2. reduction of abstraction, 3. increase of recharge and 4. climate change. This research only considers the groundwater model output from the third aquifer (Upper - middle Pleistocene aquifer (qp2-3), depth: ±70 meters - ±140 meters). Mainly, since the aquifer is the most used aquifer for groundwater abstraction. Two model output maps (qp2-3, average salinity levels) are used as data input in the BBN model. Only the climate change scenario was considered for this study, this scenario showed the biggest change in salinity levels and is expected to illustrate the goal of the BBN model best. The two scenarios used in this research are:

1. Current situation (01/01/2017)

   Primary model calibrated with in situ data measurements, as explained.

2. Climate change effects (01/01/2032)

   The simulation was done using Representative Concentration Pathway (RCP) 4.5, which influenced model input parameters; rainfall, actual evapotranspiration (AET), and runoff [26] [27].

C. Data analysis

The procedure on collecting and analysing household data using the RANAS approach described by Daniel et al. (2019) [28], was used. The analysis of the groundwater model simulations was based on the coloured model output maps, indicating the salinity of the groundwater.

Table 1. Descriptive statistics of behavioural determination factors i.e. example of RANAS psychosocial factor questions. M = mean, SD = Standard deviation.

	Determinant factors	Example question	Scale[1]	M(SD)
Risk	Perceived vulnerability	How confident are you that you can ALWAYS get unsalted water/fresh water every day?	1-5	3.66(1.41)
	Perceived severity	Do you think the risk of you not having enough fresh water will increase in the future?	1-5	2.88(1.46)
	Factual knowledge	10 true/false questions to test the factual knowledge on saltwater intrusion and groundwater depletion.	1-5	2.15(0.80)
Attitude	Instrumental beliefs	How often do you talk with your neighbours/friends/relatives about the environment, SWI, groundwater depletion and similar topics?	1-5	2.11(1.05)
	Affective belief *(Feelings)*	Have you experienced a decrease in quality over the past years?	1-5	2.94(1.54)
Norm	Descriptive norm *(Others' behaviour)*	How many of your neighbours/friends already changed their water source, due to saltwater intrusion?	1-5	2.56(1.41)
	Injunctive norm *(Others (dis)approval)*	People who are important to you, how much do they approve you to adapt/change?	1-5	3.94(1.27)
	Personal norm	How important is it for you to get water from unsalted water source?	1-5	4.48(1.05)
Ability	Self-efficacy	How much do you expect you can reduce your groundwater usage and change this with another water source?	1-5	2.63(1.62)
	Maintenance self-efficacy	How confident are you to always get unsalted water, if you have many things to do?	1-5	3.83(1.30)
Self-regulation	Action control	How much do you pay attention to the level of saltiness of your water when using for drinking water?	1-5	2.40(1.61)
	Action control	How much do you pay attention to the level of saltiness of your water when using for irrigation purposes?	1-5	2.54(1.59)
	Action planning	Do you think it is important to look for alternative household water sources?	1-5	4.08(1.23)
	Coping planning	Are you willing to change your daily water source?	1-5	3.58(1.49)
	Commitment	With your knowledge about the impact that saltwater intrusion and/or groundwater depletion can have on the Tra Vinh province, how strong do you feel an obligation to change your household water consumption?	1-5	3.09(1.53)

[1]Scale explanation: (1) = unwanted answer i.e. perceived severity; (1) indicates *very low risk (no)* and (5) = look for answer i.e. perceived severity; (5) indicates *very high risk (yes, I feel the risk)*

C.1. Statistical analysis, socioeconomic characteristics

Six socioeconomic characteristics were identified from literature that may influence the willingness to change: 1. presence of children under the age of 18 years old [29], 2. level of education [30], 3. employment status [31], 4. age [32], 5. saltwater intrusion information/ promotion activities [33], and 6. Wealth level [28]. To create the socioeconomic characteristic, *wealth level* we used principal component analysis (PCA). PCA combines the relevant data (questions) and converts the data into one component, whilst retaining most of the information [34]. The software IBM SPSS Statistics 25 was used for this analysis process. Household asset data was used as input in the PCA for creating the socioeconomic status (SES) (S8). We used the principal component, output from the PCA, and assigned an index (i.e. poor (40%), middle (40%) and rich (20%) [35] [36]) to complete the wealth level characteristic. PCA to create a *Wealth level* component works best when using assets that are more unequally distributed between households, these assets are given more weight in the PCA [37]. For example, 24-hours electricity and having a mobile phone are assets that almost all households in the Tra Vinh province have (i.e. zero standard deviation). The zero variation of these assets will have little use in differentiating SES. Finally, the socioeconomic factor *saltwater intrusion level*, which illustrates location specific risk, was determined using the groundwater model simulations. We used the model output maps (figure 3) and categorize them by their colours; low risk: dark blue ($\pm$0 - 1500 ppm), medium risk: light blue ($\pm$1500 - 2000 ppm), high risk: green ($\pm$2000 - 10000 ppm) and very high: yellow and red ($\geq$ 10000 ppm).

C.2. Statistical analysis, psychosocial factors

The *Risk*, *Attitude*, *Norm*, *Ability* and *Self-regulation* (RANAS) approach was used to collect psychosocial data. The approach enables one to measure observable behaviour, with which one can use the data to design and evaluate behavioural change strategies that target a specific behaviour in a specific population [38] [39]. The three main reasons why we considered this approach above others are; 1. the clear structure and guidelines for applying the method, 2. the framework of already defined behaviour change techniques (BCTs), and 3. the extensive number of studies for which RANAS is used. The RANAS framework inquires psychosocial information at sub-factor level [28], and focuses on five behavioural factors. Together, these five factors determine three behaviour outcomes; behaviour, intention and habit. This research focuses on behaviour outcome intention i.e. the willingness to change. The behaviour factors considered by the RANAS approach are [38]:

- *Risk*, representing a person's awareness and understanding
- *Attitude*, representing a person's emotions which arise when thinking of a particular behaviour
- *Norm*, representing a person's perceived social pressure towards a behaviour

- *Ability*, representing a person's confidence in his or her ability to practice a behaviour
- *Self-regulation*, representing a person's attempts to plan and self-monitor a behaviour and manage conflicting goals

The cross-sectional study collected data on the five behavioural factors consisting of multiple questions, based on the RANAS guidelines. Here PCA combined the relevant questions assigned to each factor and converted the data into one component for every behavioural factor. Some of the questions used in the analysis are illustrated in table 1. For example, the component on behavioural factor *Risk* was constructed using three questions: a question on perceived vulnerability (person's subjective perception of his or her risk) , a question on perceived severity (person's perception of the seriousness of the consequences) and a set of questions on a person's general understanding and knowledge on groundwater abstraction and SWI. The compressed three risk questions resulted in a new data string that covers the *Risk* component. The five newly created behavioural components are classified as psychosocial factors.

Three tests were performed to evaluate the quality of the principal components; 1. Kaiser-Meyer-Olkin (*KMO*, measures the suitability of the data used for factor analysis), 2. Cronbach's alpha (α, measures the reliability, internal consistency of the data) and 3. total variance (*Var* %, used to measure the spread between numbers in a data set, helps to assess how individual numbers relate to each other within a data set) [28] [40].

D. BBN model compilation and validation

To visualise and assess the interaction between the defined socioeconomic and simplified RANAS psychosocial characteristics, a Bayesian belief network (BBN) framework was considered. Bayesian belief networks (also named causal probabilistic networks) can model the interaction between variables that are causally linked (or theorized to be so) in a probabilistic manner [28]. The BBN model designed in this study is a direct acyclic graph (DAG), consisting of three levels of hierarchy, illustrating the dependencies between variables (called "nodes") [41]. Level 1 socioeconomic characteristics (education, age, etc.), level 2 psychosocial characteristics (RANAS behaviour factors) and level 3 the expected outcome variable (willingness to change from groundwater to a different source of water). The outcome variable (level 3) gives a prediction of the *behaviour willingness* in the area. "Behavioural willingness is defined as what an individual is willing to do under certain circumstances" [29].
BBN was considered over other methods, like regression analysis, since it offers multiple advantages. The two main advantages for using BBN over other methods in this research are: 1. BBN enables one to not only proceed from causes to consequences, but also gives the opportunity to deduce the probabilities of different causes given the consequences [42] and 2. BBN offers a clear visualisation of the causal interpretation of a complex system [28]. The visualisation and analysis of the probabilistic graphical model (PGM) was performed using the software GeNIe 2.4 [1]. To assess potential statistical relationship between two categorical variables, we performed the chi-square tests. The chi-square test can determine whether their is a statistical relation between each of the households' socioeconomic characteristics and the psychosocial factors. Moreover, we used 1o-fold cross-validation[2] to validate the BBN model, which was compiled by the GeNIe software, using the socioeconomic, psychosocial, hypothesis and statistical relations. 10-fold cross-validation is a technique for evaluating the prediction accuracy of a model (i.e. how accurately the predictive model performs) [43].

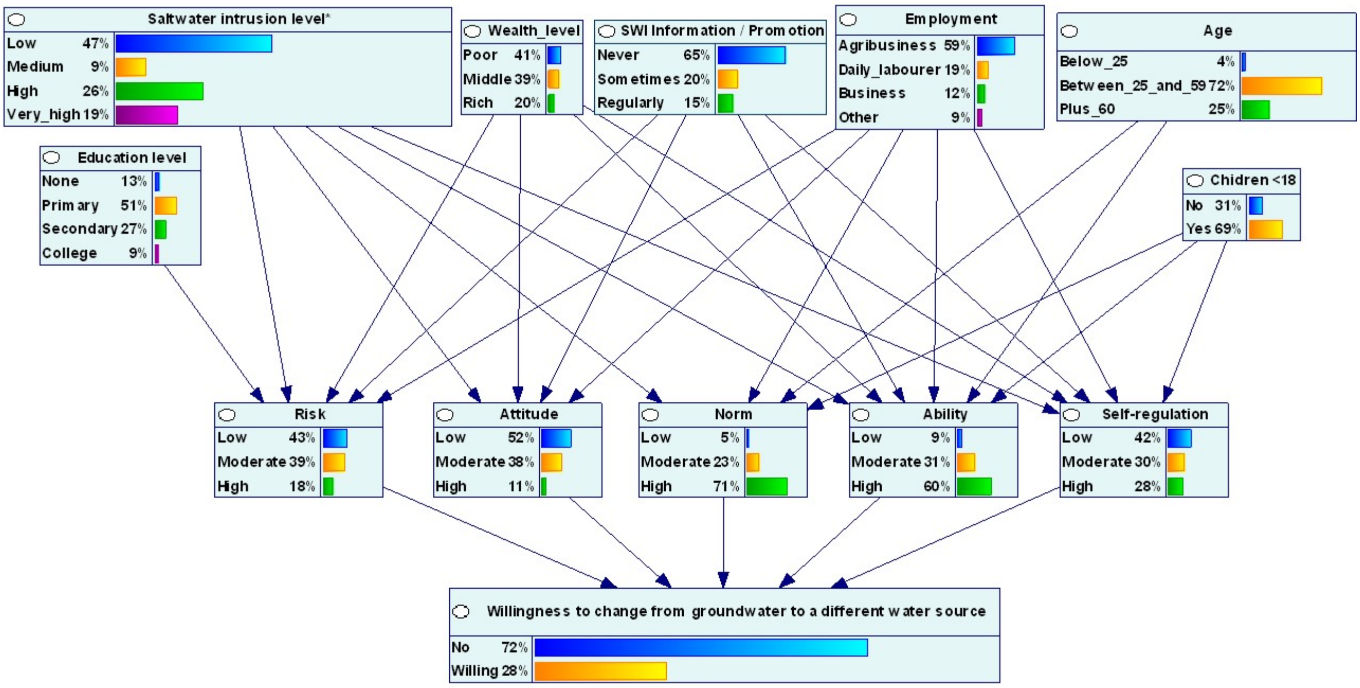
E. Three BBN model analysis

The validated BBN model will then be used to run three different model analysis, the third analysis was not specified in advance and is considered as post hoc analysis.

1. *Power of a single node mutation on the output;* Changing the input value of nodes, to find the effect on the output. These mutations of socioeconomic and psychosocial nodes do not intend that we advise to change the characteristics of the local inhabitants, it merely helps in finding what kind of household would have a

[1]The GeNIe 2.4 software helps to draw a probabilistic network to automatically calculate thee probabilities of "the hypotheses" using given evidence | (www.bayesfusion.com).

[2]The K-fold method, which is seen as a powerful cross-validation method, divides the data set into K parts of equal size, trains the network on K-1 parts, and tests it on the last, K^{th} part. The number of folds (i.e. K) determines how many times the model is trained (K-1). The model evaluation technique implemented in the GeNIe software keeps the model structure fixed and relearns the model parameters during each of the folds.



* Using data from the current situation (calibration of measurements) model simulation 01/01/2017.

Figure. 4. Final structure of the compiled BBN model. Using raw data (socioeconomic factors) and the created PCA factors. The percentages in each node indicate the probability of a node being in a certain state.

higher likelihood of changing their source of water. Knowing the power of socioeconomic factors is expected to help to define target groups. Whereas, information on the power of psychosocial factors is expected to help in defining suitable behavioural change techniques (BTCs).

2. *Change in groundwater simulation scenario;* Illustrating the influence of increasing saline levels, by changing socioeconomic node; *saltwater intrusion level*. Baseline scenario (01/01/2017), will be compared with climate change scenario (01/01/2032), figure 3.
3. *Post hoc analysis: Increase in output resolution;* The BBN model created focuses on a regional scale (province). This analysis will look at the effect of increasing the resolution to local scale (commune). To increase the resolution the BBN model will be running 313 times (i.e. each household, from which data was collected, individually).

3. RESULTS

A. Descriptive analysis of the survey study

99 % of the respondents have access to a source of groundwater. 59 % makes direct use of groundwater and use it as main water source. Whereas, from the remaining 41 % of the respondents, 40 % has access to or uses water distributed via piped infrastructure (which consists of groundwater [3]). Moreover, the water quality measurements indicate that the water quality from private groundwater wells is in 70 % of the measurements better than that of tap water (only households using both groundwater and tap water were considered). 13.1 % of the respondents reported having no education and 51.1 % reported to have education till primary school level. Detailed information on the interviewed households can be found in appendix S7.

[3] 99 % of the households has access to groundwater or to piped infrastructure (predominantly supplies groundwater abstracted from regulated wells). It is not possible to predict whether one will change in opposite direction, i.e. from not using groundwater to using groundwater. We therefore chose to not exclude households that are not using groundwater now.

Table 2. Mutation of individual nodes in the BBN model (figure 4). Illustrating what happens when assigning 100 % to one option of a node, to find the power of influence on the output of a single node (S10).

Socioeconomic nodes	$\Delta \mathbf{P}_{Willingness} = yes(\%)$[1]	**Updated** $\mathbf{P}_{Willingness\ to\ change} = yes(\%)$[2]			
Education level	**3**	None ∣ 28	Primary ∣ 29	Secondary ∣ 28	College ∣ 31
SWI level*	**12**	Low ∣ 25	Medium ∣ 36	High ∣ 36	Very high ∣ 24
Wealth level	**10**	Poor ∣ 23	Middle ∣ 33	Rich ∣ 30	
SWI information	**14**	Never ∣ 25	Sometimes ∣ 39	Regularly ∣ 30	
Employment	**20**	Agribusiness ∣ 34	Daily Labour ∣ 23	Business ∣ 14	Other ∣ 22
Age	**7**	<25 ∣ 22	25 <-> 59 ∣ 29	≥60 ∣ 29	
Children < 18	**4**	No ∣ 26	Yes ∣ 30		
Psychosocial nodes	$\Delta \mathbf{P}_{Willingness} = yes(\%)$	**Updated** $\mathbf{P}_{Willingness\ to\ change} = yes(\%)$			
Risk	**32**	Low ∣ 14	Moderate ∣ 36	High ∣ 46	
Attitude	**11**	Low ∣ 24	Moderate ∣ 35	High ∣ 27	
Norm	**21**	Low ∣ 10	Moderate ∣ 31	High ∣ 30	
Ability	**30**	Low ∣ 4	Moderate ∣ 25	High ∣ 34	
Self-regulation	**47**	Low ∣ 3	Moderate ∣ 44	High ∣ 50	

[1] Difference in lowest and highest model output (willingness) between the possible answers within an individual node. For example, in factor *Employment*, 100 % agribusiness gives a model output of 34 % and 100 % business 14 %, generating a ΔP of 20 %.
[2] The effect of assigning a 100% score to one answer of an individual node, to determine the impact of this change towards the overall output (baseline showed 28 % = *Willing*, figure 4). For example, model mutation stating that 100 % of population works in agribusiness, generates the highest model output (i.e. willingness to change of 34 %).

B. Statistical results

The test results of the three parameters, important for ensuring the quality of the newly created components using PCA, are shown in table 3. Based on statistical analysis all values for *KMO*, *Var %* and α are reasonably acceptable. Confirming the quality to use the newly created components.

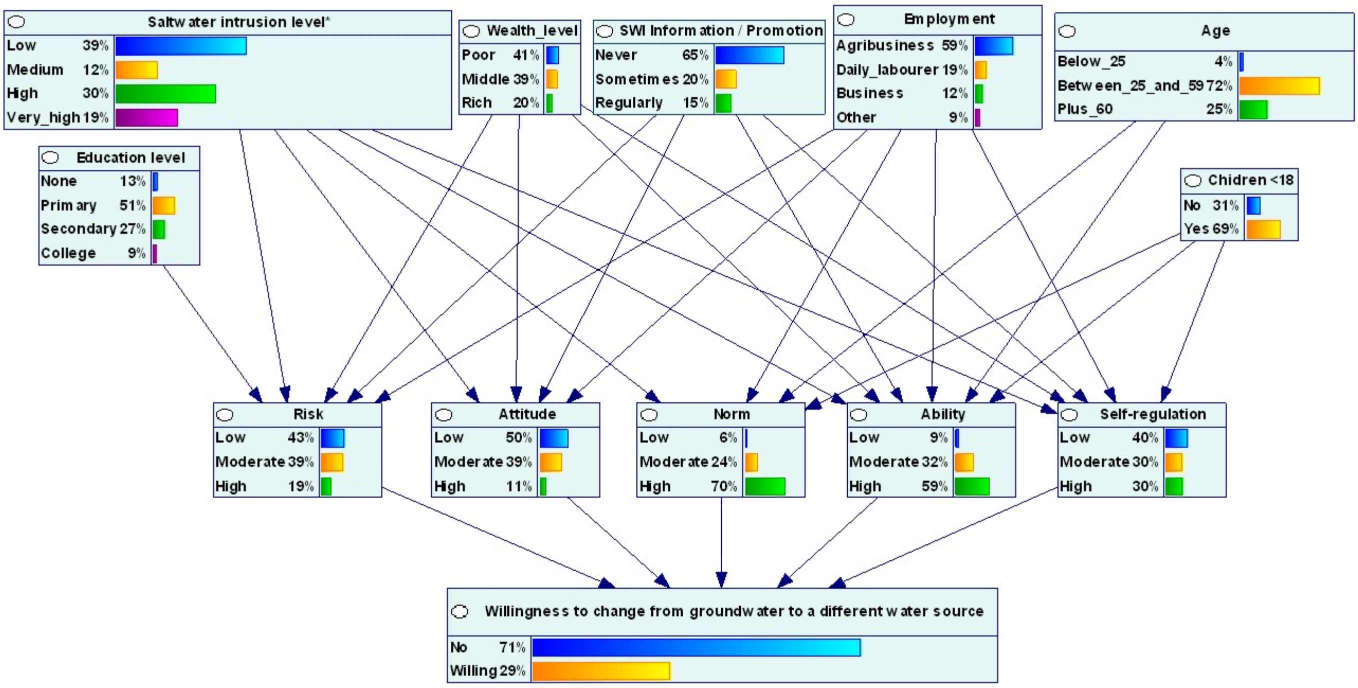
Table 3. PCA modelling value output in which the following should be considered: KMO >0.60, Var % >50 % and α >0.6 [44].

	KMO	**Var %**	α
Risk	0.64	62.59	0.69
Attitude	0.66	48.61	0.60
Norm	0.63	55.26	0.59
Ability	0.79	68.74	0.85
Self-regulation	0.69	53.00	0.73
Wealth level	0.71	33.62	0.61

The results of the chi-square test are illustrated in appendix S8. All values showing significant relationships, at a 5 % significance level, are included in the BBN model. These significant relationships are represented by an arrow in the BBN model, through which the socioeconomic node can influence the linked psychosocial node. Surprisingly there is only one statistical relationship found between socioeconomic factor *Education* and the psychosocial factors (*Risk*).

C. BBN baseline model and model validation

The BBN model in figure 4 illustrates the final structure of the BBN model. The BBN model predicted the following states for the hypotheses node (lowest in the hierarchical network), while using the data collected from the survey study: yes, willing at 28 % and no, not willing at 79 %. This output was different than the willingness measured. The willingness was also measured during the survey study using question:"Are you willing to change your daily water source?" Which resulted in a 41 % "willingness".
10-fold cross-validation showed an overall model output accuracy of 76.35 % (239/313). Moreover, output answer *no, not willing*, meaning the household is not willing to change from groundwater to a different source of water, is with 86.96 % (160/184) accuracy the most accurate answer, whereas the method found an accuracy of 61.24 % (79/129) for *yes, willing*. Another way to show the accuracy of the model is



* Using data from the model simulation scenario, climate change 01/01/2032 (figure 3).

Figure. 5. Changing node *saltwater intrusion level*, using the data from the climate change groundwater model scenario.

the value of the area under the (receiver operating characteristic, ROC) curve (AUC) [28] [45]. To have a good model accuracy the AUC value should at least be above 0.7, the closer the AUC is to 1, the better its performance, with a perfect test if AUC = 1 [46]).The AUC value found for this model was 0.86 (S8), which classifies the model as moderately accurate (moderately accurate = 0.7<AUC>0.9 [46]).

D. BBN model analysis results

D.1. 1. Power of a single node mutation on the output

Table 2 illustrates how the output node (i.e. the willingness to change) is influenced when we update a single socioeconomic or psychosocial node. Moreover, the most influenceable socioeconomic node, capable of changing the output solely is *Employment* (ΔP = 20 %). Whilst, *Education level* (ΔP = 3 %) is least powerful in changing the output of the hypotheses (i.e. willingness to change). A single mutation of one of the five psychosocial factors indicate that, *Risk*, *Ability* and *Self-regulation* have the highest individual influence power (ΔP = 32, 30 and 47 % respectively).

D.2. 2. Change in groundwater simulation scenario

We only considered one groundwater simulation scenario, which showed to be having significant enough change in salinity levels, compared to the current situation groundwater model. Moreover, only the main aquifer used for groundwater abstraction (the upper-middle Pleistocene, qp2-3) was considered. The current situation scenario (01/01/2017, figure 3) was used in the final BBN structure (figure 4). The climate change scenario (01/01/2032, figure 3), was used as new input for the climate change BBN model (figure 5). The climate change scenario implies a relatively higher salinity level within some communes. Commune Huyen Hoi is mainly categorized from having a low SWI level (current situation scenario) to medium SWI level (climate change scenario) and in the coastal areas (Dan Than and Truong Long Hoa) some coordinates were changed form low salinity level to high level. The changed input of socioeconomic factor *saltwater intrusion level* only resulted in a slight change of the data output (ΔP = 1 %).

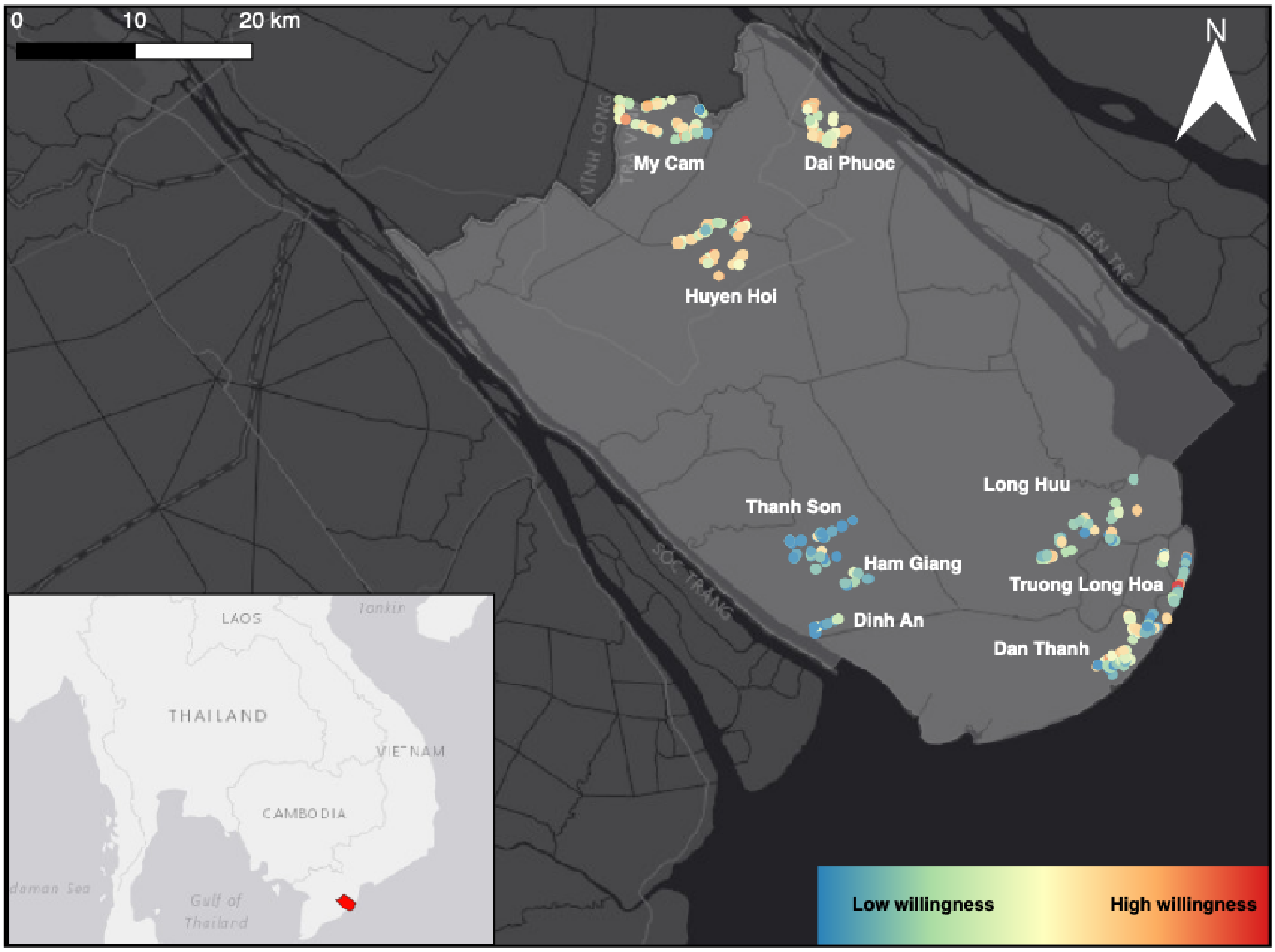


Figure. 6. 313 individual runs of the BBN model, using the current situation groundwater simulation model. Illustrated on a map to show % of willingness per household, drawn using QGIS [17].

Table 4. Local scale willingness to change

Commune	Average willingness
Huyen Hoi	57%
Đai Phúoc	47%
My Cam	39%
Dân Thành	37%
Long Huu	30%
Truong Long Hòa	30%
Hàm Giang	26%
Thanh Son	14%
Đinh An	11%

D.3. 3. Increase in output resolution

The BBN model as illustrated in figure 4 shows the probabilistic outcome on the hypothesis of the province as a whole. The map gives a more accurate indication of the willingness to change in the province. The BBN model (figure 4) classifies each household interviewed as either yes, willing; implying 100 % willingness or no, not willing; implying 100 % not willing to change. In other words, if a certain person/ household has a 51 % willingness to change the model will classify him as yes, willing and another person/ household having 49 % willingness is assigned to no, not willing.

Running the BBN model 313 times (i.e. each household individually) gives a more accurate representation of the output. Illustrating these individual runs on a map of the province and applying a spectral distribution color bar, indicating the percentage of willingness to change, gives the opportunity to easily compare the groundwater model maps and the maps created using multiple BBN model runs (figure 6). Moreover, we were able to calculate the average willingness per commune, table 4.

4. DISCUSSION

To the best of our knowledge, this is the first study that combines groundwater model simulations, socioeconomic characteristics, and people's psychosocial characteristics to find suitable SWI mitigation/ adaptation measures. This new approach can play an important role in defining the right balance between hard and soft SWI solutions, which is essential in finding long term solutions [7] [19]. The presented BBN model, constructed using household survey data and groundwater simulations, gives a visualisation of the causal linkages (or theorized to be so) between the three levels within the hierarchical model (i.e. *socioeconomic* → *psychosocial* → *willingness to change*). The simple representation of the model and the relative ease of measuring the first level (socioeconomic) factors, needed as input, make the model not only accessible for people without (any) technical abilities, but also ensures easy use of the model itself. The household data, which was collected by educated and mostly local civil servants in the Tra Vinh province (May - June 2019), in combination with the already existing groundwater model, ensured good quality data for building the BBN model. One can use the BBN model to analyse the interactions between different nodes and to measure the influence of one node on another. The BBN model showed to be a helpful tool in finding suitable target groups and specific target locations to implement SWI mitigation/ adaptation strategies more effective and efficient. On average we found good predicting performances for the designed BBN model. Both the accuracy measurements form the 10-fold cross-validation and AUC confirmed good model performances [46].

The research showed two surprising, but at the same time interesting side results. First, the water quality measurements clearly showed that water (originally groundwater) distributed by the already present piped infrastructure is somehow 'polluted'. The already present infrastructure shows us that the local authorities are working on finding alternative ways of supplying water to their inhabitants (i.e. centralised/ controlled groundwater abstraction can be seen as SWI mitigation measure). Though, at the same time the measurements imply that malfunction of the infrastructure is presumable, this should be investigated. An increase of the piped water quality could lead to an increase of people actually using the regulated water source and with it a change towards regulated groundwater abstraction. Second, it is surprising to see that *Education* has only a statistical relationship with psychosocial factor *Risk*. Literature in which a similar approach was used, show that the socioeconomic factor *Education* is of significant importance [28] [29].

A. Model analysis implications

The results of the three model analysis show that the BBN model designed in this study is capable of predicting the likelihood of the willingness to change on both regional (province) and local (commune) scale. The regional scale analysis can be used to determine suitable target groups, when designing certain SWI interventions. The model illustrates that people working in agribusiness are the best target group (table 2). Moreover, the model also suggest to design an intervention strategy that focuses on influencing behavioural factors; risk, ability and/ or self-regulation to further increase the probability of the intervention being effective (in this example we will focuses on ability). The predefined behaviour change techniques (BTCs) in the RANAS approach, indicate to focus on infrastructure and skill, when one wants to challenge a persons ability. A possible effective intervention could supply the target group with (an improved) piped water infrastructure (confidence in performance [38]). Or to educate, train or demonstrate (how-to-do-knowledge [38]) the households how to and the importance of closing the water source when not needed (i.e. saving water). Moreover, the model also suggests to focus on inhabitants who; (I) already experience a relatively "lower" groundwater quality [47], (II) are middle class, based on wealth level and (III) are between 25 and 60 years old and (IV) have children below the age of 18.

Whereas, the local scale analysis (figure 6) can be used to compare with groundwater simulations, to find suitable locations for SWI measures. For example, Huyen Hoi is the commune most willing to change from groundwater to a different source of water (57 %). This combined with the high expected risk in the area, visualized by climate change groundwater simulation scenario (figure 3), clearly shows that Huyen Hoi is suitable for implementing SWI mitigation/ adaptation strategies.

Moreover, table 2 shows that the socioeconomic node *saltwater intrusion level*, has a relatively high power of influencing the output node. Though, the model analysis in which only the groundwater simulation scenario was changed, illustrates that the willingness is not significantly affected by changing the single socioeconomic node. This suggests that it is not realistic to state that a single node mutation is effective in influencing the willingness to change and implies that a combination of factors should be influenced to generate a significant change in output.

5. LIMITATIONS & RECOMMENDATIONS

The methodology used to create the BBN model in this study has limitations and inspires for future research. First, it should be mentioned that the BBN model as illustrated in this research is merely a prediction model, that can help to understand and predict the behavioural willingness. To reliably predict behaviour, let alone the behavioural consequences of socioeconomic measures (based on self-reported studies), remains a big challenge [48]. Moreover, this is the first study that focuses on behaviour willingness as a result of SWI effects. Therefore, we would like to stress that one should be careful to not conclude too much from the BBN model as presented in this paper (i.e. reality is complex). Furthermore, the socioeconomic factors used in this research do not fully explain the psychosocial factors, likewise the psychosocial factors do not fully explain the hypothesis. The model is a simplification of reality, i.e. there are many (infinity) other socioeconomic and psychosocial factors, that may influence the behavioural willingness. Also, a change of a specif factor may influence another factor in the same hierarchical level (i.e. node education may influence node wealth level), this was not considered in the BBN model. Second, the RANAS approach is a proven approach (mainly) in the field of WaSH (Water, Sanitation and Hygiene) related studies, future research should validate whether the approach can be used for the purposes as explained in this research. Moreover, the model should be validated using data from different (coastal) areas. Such a study should confirm whether it is actual possible to use the model in different areas and how, for example, cultural differences influence the model. These studies should also consider changing and/ or adding socioeconomic characteristics to see whether this generates a better outcome of the model. The RANAS approach does suggest that a change in situation and/ or location can influence the role of the psychosocial factors [39]. Third, another interesting possible future study, would be to subdivide groundwater abstraction into the specified purposes (e.g. irrigation, industry and household purpose). To test whether there is a difference in the willingness among the different water purposes. For example, do we find a higher willingness to change for groundwater abstraction used for irrigation purposes compared to groundwater used for household water purposes. This is important, since irrigation and industry related groundwater abstraction contribute significantly to the total groundwater abstraction volume (S10). Lastly, future research should focus on finding alternative water sources, that can substitute groundwater abstraction. The lack of other high quality water sources in the area is expected to increase the difficulty of convincing people to change from groundwater abstraction to using a different water source. Moreover, such a research should also consider whether possible alternative water sources influence the output of the model. For instance, if changing to an alternative water source involves extra costs, future work should explore how this can effect the model output as presented in this research.

6. CONCLUSION

Mitigation of saltwater intrusion in coastal areas is challenging and will require more than only hard solutions. A parallel implementation of hard and soft solutions, in which involvement of local communities is essential, is expected to have a long term impact. In this study we used a Bayesian Belief Network to create a model, that uses both data from groundwater simulations and socioeconomic data collected from a survey study. The model was designed to help to explore and understand the possible impact on the willingness of a population on mitigating saltwater intrusion. The model simply illustrates how socioeconomic characteristics influence psychosocial factors and how these psychosocial factors determine the likelihood of the willingness to change from using groundwater to a different water source. The BBN model reveals that there are critical combinations between socioeconomic characteristics, which indirectly facilitate the willingness to change. Employment and SWI information/ promotion are found to be important individual (indirect) drivers. Moreover, the model showed a high influence from psychosocial (behavioural) factors; risk, ability and self-regulation. Furthermore, the model analysis showed how one can use the BBN model for different purposes. Comparing the local (commune) scale model analysis (figure 6) with groundwater simulations (figure 3), enables to compare location specific SWI risk with location specific willingness to change. In other words, we visualise the SWI risk (groundwater model) and illustrate whether the willingness to change matches the level of SWI risk. This can help to determine suitable locations for SWI measures.

Whereas, the regional (provincial) scale model analysis can be used to define target groups and suitable intervention strategies (using RANAS behavioural change techniques (BCTs)) to effectively influence the willingness of the target group.

Concluding, the method described in this paper can be used as a tool to find suitable target groups and locations, to implement SWI mitigation/ adaptation strategies. Defining suitable locations (local scale analysis + groundwater simulations) in combination with the right target groups (regional scale analysis) is expected to increase the effectiveness of a mitigating measure.

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REFERENCES

1. Intergovernmental Panel on Climate Change(IPCC), “IPCC’s Fifth Assessment Report (AR5) | Chapter Climate Change 2014 Synthesis Report Summary for Policymakers,” Tech. rep. (2014).
2. J. Klassen and D. M. Allen, “Assessing the risk of saltwater intrusion in coastal aquifers,” J. Hydrol. **551**, 730–745 (2017).
3. Y. Kiro, Y. Yechieli, V. Lyakhovsky, E. Shalev, and A. Starinsky, “Time response of the water table and saltwater transition zone to a base level drop,” Water Resour. Res. **44** (2008).
4. G. Ferguson and T. Gleeson, “Vulnerability of coastal aquifers to groundwater use and climate change,” Nat. Clim. Chang. **2**, 342–345 (2012).
5. M. D. Webb and K. W. Howard, “Modeling the Transient Response of Saline Intrusion to Rising Sea-Levels,” Ground Water **49**, 560–569 (2011).
6. L. A. . Tuan, H. C. Thai;, M. F. ;, and S. B. T., “Flood and salinity management in the {Mekong} {Delta},” Challenges to sustainable development Mekong Delta: Reg. national policy issues research needs: Lit. analysis. Bangkok, Thailand: The Sustain. Mekong Res. Netw. (Sumernet) pp.15-68 **333.**, 408–426 (2012).
7. A. Smajgl, T. Q. Toan, D. K. Nhan, J. Ward, N. H. Trung, L. Q. Tri, V. P. Tri, and P. T. Vu, “Responding to rising sea levels in the Mekong Delta,” Nat. Clim. Chang. **5**, 167–174 (2015).
8. A. K. Nguyen, Y.-A. Liou, H. P. Phung, P. H. Tran, P. P. Hoang, and H. T. Nguyen, “Estimation of Salinity Intrusion by Using Landsat 8 OLI Data in The Mekong Delta, Vietnam A Study on Long-term Validation of Land Surface Process Parameterization in Multiple Areas View project Environmental Impact Assessment and Adaptation Strategy Formu,” NOT PEER-REVIEWED (2018).
9. H. Le Dang, E. Li, I. Nuberg, and J. Bruwer, “Farmers’ Perceived Risks of Climate Change and Influencing Factors: A Study in the Mekong Delta, Vietnam,” Environ. Manag. **54**, 331–345 (2014).
10. UNDP, “Vietnam Drought and Saltwater Intrusion: Transitioning from Emergency to Recovery. Analysis Report and Policy Implications,” Tech. Rep. July (2016).
11. G. P. Karatzas and Z. Dokou, “Optimal management of saltwater intrusion in the coastal aquifer of Malia, Crete (Greece), using particle swarm optimization,” Hydrogeol. J. **23**, 1181–1194 (2015).
12. N. Alfarrah, K. Walraevens, N. Alfarrah, and K. Walraevens, “Groundwater Overexploitation and Seawater Intrusion in Coastal Areas of Arid and Semi-Arid Regions,” Water. **10**, 143 (2018).
13. S. Shrestha, T. V. Bach, and V. P. Pandey, “Climate change impacts on groundwater resources

in Mekong Delta under representative concentration pathways (RCPs) scenarios," Environ. Sci. & Policy **61**, 1–13 (2016).
14. S. Pech and K. Sunada, "Population Growth and Natural-Resources Pressures in the Mekong River Basin," (2008).
15. A. Maxmen, "As Cape Town water crisis deepens, scientists prepare for 'Day Zero'," Nature **554** (2018).
16. J. Temple, "India's water crisis is already here. Climate change will compound it," (2019).
17. Q. D. Team, "QGIS Geographic Information System," (2019).
18. A. Wutich, A. C. White, D. D. White, K. L. Larson, A. Brewis, and C. Roberts, "Hard paths, soft paths or no paths? Cross-cultural perceptions of water solutions," Hydrol. Earth Syst. Sci. Copernicus GmbH **18**, 109–120 (2014).
19. Economist, "Thirsty planet - Hard and soft solutions (Special report water)," (2019).
20. C. Pahl-Wostl, J. Sendzimir, P. Jeffrey, J. Aerts, G. Berkamp, and K. Cross, "Managing change toward adaptive water management through social learning," (2008).
21. D. B. Brooks, O. M. Brandes, and S. Gurman, *Making the most of the water we have : the soft path approach to water management* (Earthscan, 2009).
22. "Mekong Delta Plan Long-term vision and strategy for a safe, prosperous and sustainable delta," Tech. rep. (2013).
23. M. o. I. o. R. o. Slovenia, "Statistical data on transportation," (2016).
24. D. Hai, C. T. Districts, T. Vinh, and World Bank, "Participatory Poverty Assessment Tra Vinh Province, Vietnam," Tech. rep., Oxfam Great Britain (1999).
25. S. K. Tuan Pham Van, "Estimation of groundwater use pattern and distribution in the coastal Mekong Delta, Vietnam via socio-economical survey and groundwater modeling," ASEAN Acad. Netw. (2019).
26. A. M. Thomson, K. V. Calvin, S. J. Smith, G. P. Kyle, A. Volke, P. Patel, S. Delgado-Arias, B. Bond-Lamberty, M. A. Wise, L. E. Clarke, and J. A. Edmonds, "RCP4.5: a pathway for stabilization of radiative forcing by 2100," Clim. Chang. **109**, 77–94 (2011).
27. P. P. B. Silva, "Impact of Climate Change on Groundwater Availability | A Case Study on Tra Vinh, Vietnam," Ph.D. thesis (2018).
28. D. Daniel, A. Diener, S. Pande, S. Jansen, S. Marks, R. Meierhofer, M. Bhatta, and L. Rietveld, "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. Heal. **222**, 847–855 (2019).
29. A. E. Gamma, J. Slekiene, G. von Medeazza, F. Asplund, P. Cardoso, and H.-J. Mosler, "Contextual and psychosocial factors predicting Ebola prevention behaviours using the RANAS approach to behaviour change in Guinea-Bissau," BMC Public Heal. **17**, 446 (2017).
30. C. Nauges and C. Van Den Berg, "Perception of Health Risk and Averting Behavior: An Analysis of Household Water Consumption in Southwest Sri Lanka," (2009).
31. A. Irwin, O. Solar, and J. Vega, "Social Determinants of Health, the United Nations Commission of," Int. Encycl. Public Heal. pp. 557–561 (2017).
32. H.-J. Mosler, O. R. Blöchliger, and J. Inauen, "Personal, social, and situational factors influencing the consumption of drinking water from arsenic-safe deep tubewells in Bangladesh," J. Environ. Manag. **91**, 1316–1323 (2010).
33. H.-J. Mosler, S. Kraemer, and R. Johnston, "Achieving long-term use of solar water disinfection in Zimbabwe," Public Heal. **127**, 92–98 (2013).
34. M. Ringnér, "What is principal component analysis?" Nat. Biotechnol. **26**, 303–304 (2008).
35. D. Filmer and L. Pritchett, "Estimating Wealth Effects Without Expenditure Data–Or Tears: An Application to Educational Enrollments in States of India," Demography. **38**, 115–132 (2001).
36. S. Vyas and L. Kumaranayake, "Constructing socio-economic status indices: How to use principal components analysis," Heal. Policy Plan. **21**, 459–468 (2006).
37. D. J. Mckenzie, "Measuring Inequality with Asset Indicators forthcoming, Journal of Population Economics," Tech. rep. (2004).
38. N. Contzen and H.-J. Mosler, "The Risks, Attitudes, Norms, Abilities, and Self-regulation (RANAS) approach to systematic behavior change," eawag. (2012).
39. H. J. Mosler, "A systematic approach to behavior change interventions for the water and san-

itation sector in developing countries: A conceptual model, a review, and a guideline," Int. J. Environ. Heal. Res. **22**, 431–449 (2012).
40. L. Andrade, K. O'Malley, P. Hynds, E. O'Neill, and J. O'Dwyer, "Assessment of two behavioural models (HBM and RANAS) for predicting health behaviours in response to environmental threats: Surface water flooding as a source of groundwater contamination and subsequent waterborne infection in the Republic of Ireland," Sci. The Total. Environ. **685**, 1019–1029 (2019).
41. J. Pearl, *Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference - Judea Pearl - Google Books* (Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1988).
42. L. Uusitalo, "Advantages and challenges of Bayesian networks in environmental modelling," Ecol. Model. **203**, 312–318 (2007).
43. J. Rodriguez, A. Perez, and J. Lozano, "Sensitivity Analysis of k-Fold Cross Validation in Prediction Error Estimation," IEEE Transactions on Pattern Analysis Mach. Intell. **32**, 569–575 (2010).
44. A. Field, *Discovering Statistics Using SPSS - Introducing Statistical Methods Series*, vol. 21 (SAGE Publications, London, England, 1995).
45. A. Rakotomamonjy, *Optimizing Area Under Roc Curve with SVMs* (204).
46. M. Greiner, D. Pfeiffer, and R. Smith, "Principles and practical application of the receiver-operating characteristic analysis for diagnostic tests," Prev. Vet. Medicine **45**, 23–41 (2000).
47. W. Botzen, J. Aerts, and J. van den Bergh, "Willingness of homeowners to mitigate climate risk through insurance," Ecol. Econ. **68**, 2265–2277 (2009).
48. B. F. Skinner, "SCIENCE AND HUMAN BEHAVIOR," Tech. rep. (2005).

Supplementary materials for

The role of behavioural willingness on mitigating saltwater intrusion in the Vietnamese Mekong Delta

Combining socioeconomic data with groundwater simulations using Bayesian Belief Networks

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Contents of this file

Introduction

The supplementary materials are subdivided into two parts. The first part will give some extra information on: S1) the research questions, S2) the SALINPROVE project and S3) concluding words/ thoughts from the student. This material will be disregarded when the article is submitted to a journal. The second part consist of more detail information on: S4) the methods used in the research (RANAS approach, Bayesian Belief Networks and Principal Component Analysis), S5) supplementary theoretical background, S6) the questions used in the survey study, S7) supplementary descriptive analysis on the interviewed households, S8) extra information and values of the various tests performed, S9) extra information on the groundwater model and finally S10) Groundwater abstraction statistics and some node mutations of the BBN model.

Annex 1: Thesis supplementary material

S1. Research questions

Main question:

'Does the local population of the Tra Vinh province expect and experience the same risk of saltwater intrusion as can be seen from groundwater model simulations? If so, how willing (or not) are the inhabitants to adapt to these effects and how could their behaviour be influenced?'

Steps taken to answer main question:

I. Use the RANAS approach to collect data on behaviour in the Tra Vinh province
II. Design a Bayesian Belief Network (BBN) model to find the relation between socioeconomic factors, psychosocial factors and the willingness to change / adapt
III. Link the BBN model to groundwater (SWI) simulations to see whether behaviour and actual risk match
IV. Can we use the BBN model to find location suitable SWI adoption/ mitigation strategies?

S2. The SALINPROVE project

This research is part of a project named SALINPROVE, in which IHE Delft Institute for Water Edu-cation (UNESCO-Deft) plays a front role. The SALINPROVE project started in 2016 and aims to address the most widespread problem linked to groundwater exploitation in heavily populated coastal aquifers, namely that of saltwater intrusion. The project focuses on three different locations (Maputo; Mozambique, Laizhou Bay; China and Tra Vinh province; Vietnam) towards defining the dimension and impacts of the existing groundwater salinization problems, more importantly, feasible solutions, both at present and under future climate and socioeconomic change. This research will focus on the Tra Vinh province located in the Vietnamese Mekong Delta. Partners for this location are amongst others; the Dutch Ministry of Foreign Affairs, Ho Chi Minh City University of Technology (HCMUT) and multiple institutes located in Vietnam. The past two years of research can be summarized into three main activities;

Figure 1. The Mekong River Basin drains into six countries and has the world's third largest delta, which is crucial to the food security of Southeast Asia. The delta provides 50 % of Vietnam's food; it accounts for 90 % of Vietnam's rice production making this country world's second most important rice exporter, with an export value of several billion USD.

1. Problem diagnosis of salinity and impacts
2. Monitoring of groundwater salinity
3. Modelling of salt water intrusion

This research will contribute to the fourth and final phase of the overall project:

4. Co-construction of cost-effective mitigation/ adaptation measures

S3. Concluding words/ comments from the author

The future of (amongst others) Vietnam's water resources in combination with its history of violence make me somewhat anxious. The ecosystem created by the Mekong Delta, rich diversity and fertility, will "perish" with groundwater depletion, decrease in surface water discharge and an increase in saltwater intrusion. Most of the economic strength of the Mekong Delta area depends on this complex system of river streams, where seasonality and occasional flooding play an important role. It is only a matter of time before Vietnam's economic epicentre will runout of water. Let alone "high" quality water used for household purposes. The Mekong Delta's neighbouring countries, i.e. India and China, who are already buying their way into the Mekong Delta water resources, are working on providing sufficient water (and energy) for their own inhabitants. This further aggravates the problem; downstream this will result in a decrease of surface water discharge and consequently a decrease in fertility rate of the soil and the overall water volume available in these downstream countries. In conclusion and worst-case scenario, friction between the Mekong Delta's countries and the neighbouring countries over the precious water rights will be inevitable, let us hope that a "water war" can be prevented using innovative mechanisms to ensure sufficient and clean fresh water. This said, it is actually not a matter of willingness to change, it is a must for these local inhabitants to change. The real question is to what substitute source can they change?

Annex 2: Article supplementary material

S4. Methods used in the research

1) The RANAS approach

"Behaviour is a difficult subject matter, not because it is inaccessible, but because it is extremely complex. Since it is a process, rather than a thing, it cannot easily be held still for observation. It is changing, fluid, and evanescent, and for this reason it makes great technical demands upon the ingenuity and energy of the scientist" (Skinner, 2005).

A method which enables one to measure observable behaviour, with which one can use the data to design and evaluate behaviour change strategies that target a specific behaviour in a specific population, is the *Risks, Attitudes, Norms, Abilities,* and *Self-regulation* (RANAS) approach (Contzen & Mosler, 2012). The approach considers three behavioural outcomes; behaviour, habit and intention (Contzen & Mosler, 2012). The five psychosocial factors are:

Risk factors; individual's understanding and awareness of the risks as a result of SWI. Example: a person's thoughts of not being at risk of increasing water scarcity in the future. This would indicate a low level of perceived severity. The low perceived severity can also be a result of a lack of knowledge around groundwater abstraction, SWI and/ or climate change. Therefore, knowledge is considered as a risk sub-factor.

Attitude factors; a person's stance towards the behaviour. Example: a person who thinks groundwater depletion will not affect his or her lifestyle, i.e., has a low level of attitude towards beliefs about groundwater depletion and SWI (i.e. beliefs).

Norm factors; represent what behaviours are perceived to be normal and abnormal. Example: a person may think it is not important to get water from a non-saline source, i.e. low level of personal norm.

Ability factors; individual's confidence in his or her ability to practice a behaviour. Example: one may think that he/ she is not able to reduce groundwater abstraction and/ or change source type, i.e. low level of self-efficacy.

Self-regulation factors; a person's attempts to plan and maintain a certain behavior. Example, one has a low action control level if he/ she does not pay attention to the salinity level of the water sources used. Commitment and or remembering to pay attention may increase the person's action control.

Initially RANAS was developed to change behaviour in the Water, Sanitation and Hygiene (WaSH) sector in developing countries, though research in different fields show that the approach is applicable to all kinds of human behaviour (Inauen & Mosler, 2014). Several research projects prove that the RANAS approach is worth applying (Gamma et al., 2017; Inauen & Mosler, 2014; Lilje & Mosler, 2018). Most of these studies, using RANAS, focus on Wash related topics. To use the RANAS approach to change behaviours outside WaSH contexts, the health-risk factors have to be altered to others that correspond to the behaviour in question (Mosler, 2017), in this research the health-risk factors are changed with the risk of running out of groundwater for daily purposes. Moreover, the WaSH promotion, which is an essential part of the RANAS methodology, was altered to a different socioeconomic factor SWI promotion, since this factor corresponds to the behaviour in question (Mosler, 2017).

To compare the RANAS approach with other approaches that measures observable behaviour is somewhat difficult, since the research focus of RANAS is still primarily on WaSH related studies. However, literature compares RANAS with the Knowledge, Attitudes and Practice (KAP) approach. KAP is also a widely used approach in the WaSH related research area. We

chose RANAS above KAP, mainly since RANAS; 1. considers more behavioural factors and 2. provides a systematic method of selecting interventions (i.e. behavioural change techniques (BCTs)). A limitation of the RANAS approach, is the remaining fact that self-report studies (i.e. self-reported behaviour) often overestimates the behaviour when compared to observed frequencies (Seimetz, Slekiene, Friedrich, & Mosler, 2017).
In this research, RANAS is used to help to understand the mindsets of the population and transform this understanding into ideas for possible interventions. The statistical analysis performed in this research isn't a perfect sketch of reality, but in many ways a start of an acceptable prediction. This study clearly shows how difficult it is to measure behaviour. "Even though we have observed behaviour for many years, we are not necessarily able, without help, to express useful uniformity' or lawful relations."(Skinner, 2005).

2) Bayesian Belief Network

"A Bayesian belief network is a graphical model that permits a probabilistic relationship among a set of variables" (Pearl, 1988). Bayesian Belief Networks can model the interaction between variables that are causally linked (or theorized to be so) in probabilistic manner (Daniel et al., 2019). In this study, a hierarchical model is used, which means that the model is written in multiple levels, that estimates the parameters of the posterior distribution (Allenby, Rossi, & Mcculloch, 2005). A BBN model consists of nodes representing variables of interest and links between nodes indicating informational or 'causal' dependencies among the variables. Moreover, a complete BBN model consists of (Kabir, Tesfamariam, Francisque, & Sadiq, 2015): 1. several variables (nodes) and a set of links between the variables; 2. a state division/ scale for each variable; and 3. an assigned conditional probability for each of the variables states. The efficacy of a BBN is realized by its capability to both being able to perform top-down inference, inferring the top hierarchical nodes and observing their influence on the cause (hypothesis, lowest in hierarchies) (predictive analysis) and bottom-up inference, inferring the cause (hypothesis, lowest in hierarchy) and observing the effect of this inferring on the top hierarchical nodes (i.e. diagnostic analysis) (Cockburn & Tesfamariam, 2012; Ismail et al., 2011).

3) Principal component analysis of the psychosocial factors

PCA is a mathematical algorithm that identifies patterns in data. The algorithm uses orthogonal transformation to convert multiple variables (in this research multiple questions), while retaining most of the variation in the data set, into a set of linearly uncorrelated variables called principal components (Ringnér, 2008). The data reduction technique enables one to interpret larger sets of data in a smaller number of components, which can be meaningfully interpreted. The psychosocial (behavioural) components were created out of at least three 1 – 5 *likert scaled* questions. The dimension reduction technique was performed using SPSS software, indicating a single component extraction, i.e. only one component was constructed. Following, the range of the newly created component was subdivided into three equal subranges; Low (e.g. lowest value – lowest value + 1/3 of range), Moderate, High. These subranges are used in the BBN model as indices of the psychosocial (behavioural) characteristics (nodes).

S5. Theoretical background information

1) Saltwater intrusion

Saltwater intrusion (SWI) is a common phenomenon in coastal aquifers that can affect the quality of water intended for drinking, irrigation and/ or industry purposes (Karatzas & Dokou, 2015). SWI is the movement (flow) of saltwater into fresh water bodies like rivers or aquifers, due to natural processes or human activities. Saline water has a higher mineral content than freshwater, it is therefore denser and has a higher water pressure. As a result, saltwater can push inland beneath the freshwater. However, under natural conditions, the seaward movement of freshwater prevents saltwater from encroaching coastal aquifers, and the interface between freshwater and saltwater (zone of dispersion or transition zone) is maintained near the coast or far below land surface (Sherif & Hamza, 2001; Werner & Simmons, 2009).
SWI is a major concern for most coastal areas as it can induce contamination of valuable fresh water resources. Moreover, SWI may also effect coastal ecosystems and cause damage to agricultural activities, resulting in a change of the socioeconomic balance in these coastal areas (Klassen & Allen, 2017a; Shrestha, Bach, & Pandey, 2016). The natural process of SWI in coastal regions, can be influenced by natural or indirect human activities; sea level rise and human activities; groundwater abstraction respectively (Klassen & Allen, 2017). These factors, which influence SWI, may increase the possibility of (long-term) negative effects. The human activity of extensive groundwater abstraction can reduce freshwater flow toward coastal discharge areas and cause saltwater to be drawn toward the freshwater zones of the aquifer (Klassen & Allen, 2017a). The pumping activities may result in both lateral encroachment in the coastal area and vertical upconing of saltwater near discharging wells, both leading to contamination of the water in coastal freshwater aquifers. Moreover, sea level rise may influence the interface pushing the transition zone landward (Ferguson & Gleeson, 2012; Klassen & Allen, 2017). SWI could lead to:

- Reduction in the productive capacity of affected land, causing social and psychological hardship as well as economic hardship
- Loss of water quality for stock and domestic water supplies
- Degradation of the environment and wildlife habitats
- Damage to roads and other structures
- Damage to water-using household equipment

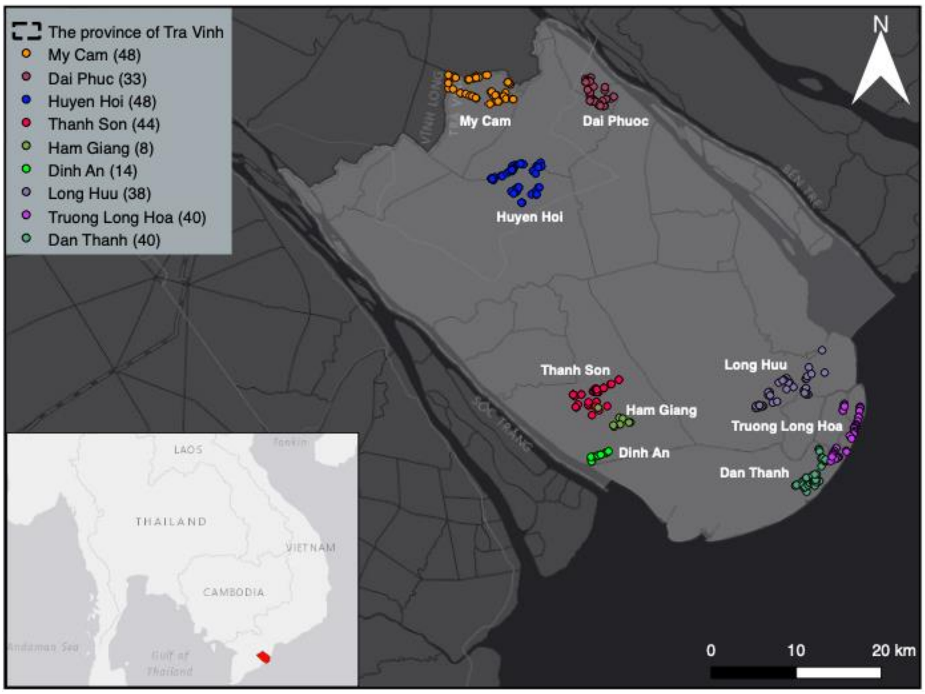
An example of negative effects of saltwater intrusion is already visible in Bangladesh: “Where in the past we see migration due to annual flooding, or river bank erosion, now we see saltwater intrusion more commonly which affects the environment long term. It makes it harder to grow crops because the land is permanently altered by the saline water” (Park, 2019). Moreover, the East coast of the United States also encountered these negative effects, farmers in Maryland are aware of the SWI phenomena and want to design an action plan to overcome both degradation of the environment and reduction/ loss in crop yields (Biron, 2019).

2) Hard and soft solutions

The many possible freshwater mitigation/ adaptation strategies already defined can be categorized into hard and soft solutions. “Historically, water management has focused on building and managing water supply infrastructure to meet human water demands. This approach brought into use large-scale, centralized water infrastructure including major systems for flood control, irrigation, water treatment, municipal water distribution, sewage systems, and water storage. Known as the ‘hard path’, this approach to water management has improved human water security around the world” (Wutich, 2014). The hard path to solving water problem is one that relies almost exclusively on centralised infrastructure to capture (e.g. large water dams, basins), treat (e.g. desalinization plants) and deliver water supplies (e.g. piped water infrastructure). When water has been scarce, the solution has been to find a new source, or to bring it from somewhere else (Economist, 2019). With the acute need for water, which one now can find in for example Cape Town and several cities in India, it is expected that these *hard solutions* will not be abandoned. Bringing water in, for example in India where trains were used to supply the city of Chennai with freshwater (Emily Schmall, 2019), or to exploit a new source (e.g. desalinisation), will remain a short term, but better option than to move millions of people. However, only using hard solutions is no longer enough to supply the demand of water and needs to be complemented (Wutich, 2014). This complement approach has come to be known as the "soft path" solutions. Soft path solutions, which focus on reforming institutions (such as water policies and regulations), improving water-efficient technologies, and managing agricultural and residential water usage (Gleick, 2002), always require the involvement of local communities and seeks to improve the way water is used (e.g. via efficient technologies, saving measures and education and/ or training), rather than to find new sources of supply (Economist, 2019; Smajgl et al., 2015). Especially when one looks further than supplying a city with a freshwater source it becomes clear that soft solutions are of great importance. Take for instance the side effects which arise from SWI in the Mekong Delta; pollution of a freshwater source is the acute problem, land and environment degradation are side effects, which will result in socioeconomic distress (Qi & Qiu, 2011).

S6. Survey questionnaire

1) The 313 interviewed households | Figure constructed using QGIS



2) Survey questionnaire

Socio-demographic information of the household
Select date and time
Record location
Name of village
Select interview number, which is indicated on your map
Name of person who conducts the interview?
Name of person interviewed?
What is the gender of the respondent?
What is the age of the respondent?
How many people live in your household?
How many children are below the age of 18?
What is your highest level of education?
What is the main source of income in your household?
What belief do you follow?
How often do you watch TV or listen to the radio?
What kind of social media source do you use? If they use multiple only select most used)
How often do you open your social media in a day?
How much money does your household earn roughly in a month? (x1000 VND)
Are you the owner of your house?
How many rooms does your house have?
What type of walls does the main house have?
What type of roof does the main house have?

What type of floor does the main house have?
Do you or someone living in your household have the following (not broken)?
How much do you pay per month for buying commercial potable water? (on average)
How much do you spend on household water each month? (on average)
Water related habits
Do you use groundwater in your daily life?
What type of water source do your mainly/ primarily use for household purposes?
What portion of the overall water used comes from groundwater?
How deep is your well from which you collect the water?
What is your average monthly water bill? (x1000 VND)
What is the price (VND) per m^3 that you pay?
Do you know, on average, what volume of groundwater your household uses every month? (m3/month)
What is the pump capacity of the pump you have? (m^3/h)
How long do you pump every day (on average, hour/day)?
Do you use / pump groundwater for irrigation purposes?
What water source do you mainly use for irrigation?
Can you estimate how much water you use every day for irrigation? (m^3)
Do you use different water sources in the dry and the wet season?
Which water source do you mainly/primarily use during dry season?
Which water source do you mainly/ primarily use during wet season?
How difficult is it to collect water in dry season?
How difficult is it to collect water in wet season?
Do you always treat your household drinking water?
What percent of your drinking water do you treat? Give an estimate
Knowledge and perceptions on groundwater abstraction and saltwater intrusion
How much do you expect you can reduce your groundwater usage and change this with another water source?
Is the quality of your household water during dry season different than the quality in wet season?
How safe do you think it is to drink the water directly from your primary drinking water source?
What is the quality of the raw water which you do treat for drinking water purposes?
What is the quality of the raw water which you do not treat for drinking water purposes?
Have you experienced a decrease in quality over the past years?
What do you think is the primary cause of salt water pollution?
How big is the impact of salt water intrusion in groundwater on your daily life?
Answer the following eight questions with true or false:
1. Increase in salt level in your water is no real problem.
2. Surface waters (river, streams, ponds) have better quality than ground water (wells deeper than 50 m)
3. Bacteria/viruses are the only reason why you should purify water before drinking
4. Sea level rise is a problem for the Tra Vinh province

5. Abstracting groundwater is okay, since rain will recharge the groundwater
6. Salt intrusion can only come from the sea
7. Salt water intrusion is mainly the result of groundwater abstraction
8. Irrigation using groundwater is okay since the unused water will reach the underground water level
Who in your opinion is responsible for supplying a fresh (high quality) water source?
What do you think is the most convenient water source?
Why do you think this is the most convenient water source?
What water source has the highest quality in your opinion?
Are you willing to pay somewhat more for your water?
Are you willing to pay more for your water if you know that it will be better for your family?
What would your main reason be of NOT improving your water supply system?
Have you ever received any information on groundwater depletion?
Have you ever received any information on salt water intrusion?
Do you think the information about groundwater depletion and saltwater intrusion is useful for you?
Did the information on salt water intrusion and / or groundwater depletion affect your behaviour?
From who? (can choose more than one)
Did you already implement any changes in your daily household water use?
What are these changes?
What was the main reason for changing your household water?
Did the change of household water source result in extra expenses? If yes, how much per month
How often do you hear the information/promotion from people who you mentioned before?
How often do you talk with your neighbours / friends / relatives about the environment, SWI, groundwater depletion and similar topics?
If you HAVE to change your primary water source, how do you think this will look like? (one only)
Suppose that the government could help your village with just ONE of these issues. Which would YOUR FAMILY choose?
What would be your main driver to buy purified water?
Who much are you willing to pay in VND for 1L purified water delivered at your home?
Future expectations on water availability
With your knowledge about the impact that saltwater intrusion can have on the Tra Vinh province, how strong do you feel an obligation to change your household water consumption?
Answer the following five questions with true or false.
There is no regulation or law on using groundwater for irrigation purposes
Irrigation using surface water (water from ponds and rivers etc,) is prohibited
Irrigation using groundwater is better than irrigation using surface water
Groundwater abstraction for irrigation is prohibited by law
Abstraction of groundwater should not be monitored
How many of your neighbours / friends already changed their water source, due to saltwater intrusion? Can you estimate the percentage?
Do you think it is important to look for alternative household water sources?

People who are important to you, how much do they approve/think you to adapt/change?
Do you think the risk of you not having enough fresh water will increase in the future?
How confident are you that you can ALWAYS get unsalted water / fresh water every day?
How difficult would it be to get unsalted water every day?
How confident are you to always get unsalted water, if you have many things to do?
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?
What do you see as a possible and suitable way to (further) adapt / change your water consumption?
How important is it for you to get water from unsalted water source?
Do you have a plan how you can get fresh water, if the water source that you use now becomes salty? How?
How much do you pay attention to the level of saltiness of your water when drinking water?
How much do you pay attention to the level of saltiness of the water which you use for irrigation?
Are you willing to change your daily water source?
Can we test the salinity level in your household water? If yes, we will only need some water from your main water source. (µS/cm)

* The order of the questions as illustrated above is different from the actual survey. For more information on the questionnaire please contact klessenstycho@gmail.com

S7. Descriptive analysis of the data

1) Demographic profile of the respondents

Variables	*n**	%
Gender	313	
Male	209	66.8
Female	104	33.2
Location	313	
Dai Phuoc	33	10.5
Dan Thanh	40	12.8
Dinh An	14	4.5
Ham Giang	8	2.6

Huyen Hoi	48	15.3
Long Huu	38	12.1
My Cam	48	15.3
Thanh Son	44	14.1
Trường Long Hoà	40	12.8
Employment	313	
Agriculture	186	59.4
Daily labourer	61	19.5
Service	22	7.0
Military / police	2	.6
Housewife	3	1.0
Business	37	11.8
Student	2	.6
Completed highest education level	313	
None	41	13.1
Primary	160	51.1
Secondary	83	26.5
College and higher	29	9.3
Religion	313	
Vietnamese folk religion	190	60.7
Buddhism	102	32.6
Roman Catholicism	2	.6
Caodaism	2	.6
Non-religious	4	1.3

Other	13	4.2
Children below 18 years old living in the household?	313	
Yes	216	69
No	97	31
Type of household floor	313	
Rudimentary (Mud)	104	33.2
Tiled, Concrete	209	66.8
Type of household wall	313	
Rudimentary (wood planks, mud wood, corrugated iron, or stone mud)	94	30.0
Stone cement or brick cement)	219	70.0
Type of household roof	313	
Rudimentary (Plastic, Wood)	25	8.0
Iron, Roof tiles	288	92.0

2) Wealth level versus employment status

Wealth level * Employment status | Crosstabulation

		Employment					Total
		Agribusiness	Daily labourer	Business	Service	Other	
Wealth level	Poor	57	25	6	2	2	92
	Middle	80	17	12	3	2	114
	Rich	49	19	19	17	3	107
Total		186	61	37	22	7	313

S8. Results of the various tests performed

1) Descriptive statistics of psychosocial factor

	Socioeconomic \ Psychosocial	Risk	Attitude	Norm	Ability	Self-regulation
p value of Pearson Chi-square test	Education	0.016	0.282	0.342	0.380	0.301
	SWI level	0.000	0.000	0.001	0.000	0.000
	Wealth	0.025	0.000	0.061	0.000	0.000
	SWI promotion	0.000	0.000	0.125	0.003	0.001
	Employment	0.000	0.007	0.009	0.000	0.000
	Age	0.077	0.180	0.000	0.002	0.087
	Children<18	0.337	0.090	0.004	0.035	0.045

Indicated in green the statistical relationships used in the BBN model. Statistically significant $p < 0.05$.

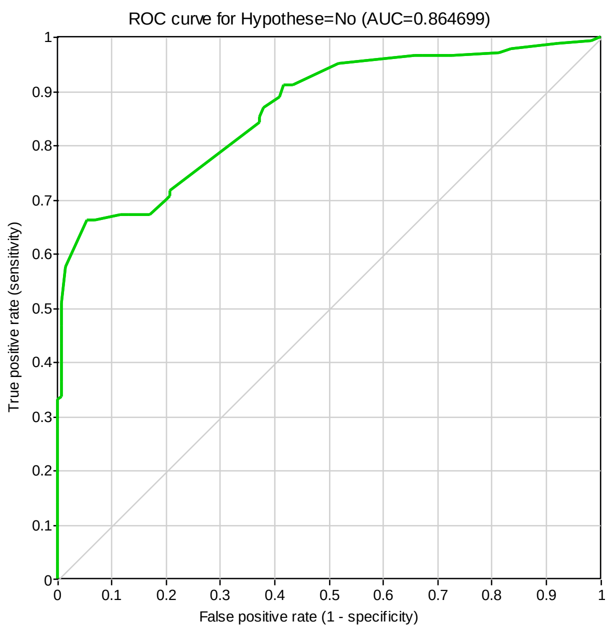
2) Variables for creating the wealth level

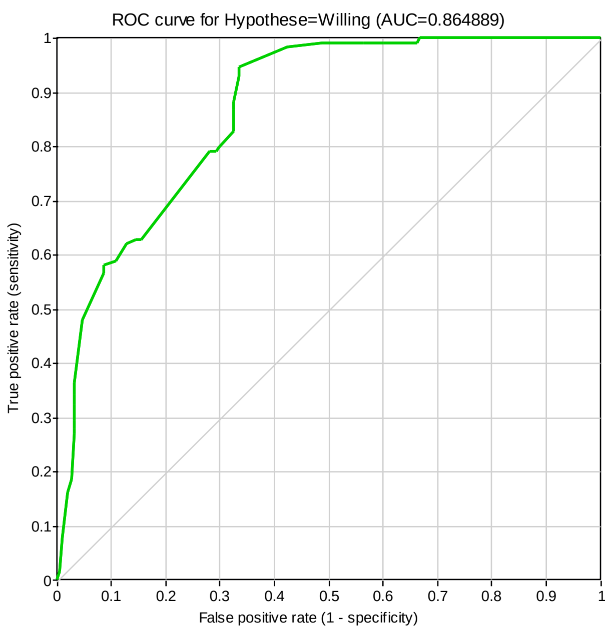
No	Variables	Categories
1	Has a refrigerator	1 = Yes; 0 = No
2	Has air-conditioning	1 = Yes; 0 = No
3	Has a motorbike	1 = Yes; 0 = No
4	Type of household's floor	1 = Tiled, Concrete; 0 = Rudimentary (Mud)
5	Type of household's roof	1 = Iron, Roof tiles; 0 = Rudimentary (Plastic, Wood)
6	Type of household's wall	1 = Bricks; 0 = Rudimentary (Wood, Plastic, Iron)

PCA was performed to create the socioeconomic factor wealth level. The PCA for these household's assets gave one factor which represents the relative wealth level.

3) Model validation test – using 10-fold cross-validation

The ROC curve and area under the cover calculations, for both output answer: no, not willing and yes, willing:





S9. The groundwater model

Below some detailed information on the groundwater model is presented (source SALINPROVE team). For further questions and/ or detailed information on the groundwater model please contact the SALINPROVE project team.

Study area information

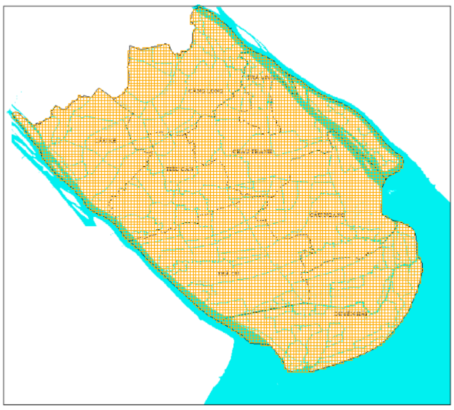
The study area covers an area of 2,247km^2 in the Vietnamese Mekong Delta, i.e. the whole province of Tra Vinh. The southeast border of the area is the 65 km long coastline, the northwester is the only man-made border in which the provincial borders were maintained, the northeast and southwest are limited by two big rivers: Co Chien and Hau rivers respectively. The groundwater system in Tra Vinh province is divided into 13 layers, representing 7 aquifers and 6 aquitards. Layers of 1, 3, 5, 7, 9, 11, and 13 represent the aquifers. In this research only aquifer layer 5 was considered: Layer 5 represents the Upper-middle Pleistocene aquifer (qp2-3), the composition of soil in this aquifer is mainly fine - medium sand, sometimes mixed with small pebbles.

Table 1. Depth of stratigraphy in Tra Vinh province. Illustration of the first three aquifers, used for groundwater abstraction

Aquifer	Area (km^2)	Top depth (m)			Bottom depth (m)			Thickness (m)		
		Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.
qh	2,341	0.0	35.0	10.6	13.0	60.0	30.3	2.0	60.0	18.8
qp_3	2,341	26.0	83.0	48.5	61.0	134.5	90.0	8.5	79.6	40.9
qp_{2-3}	**2,341**	**66.0**	**136.0**	**95.7**	**118.0**	**201.5**	**150.2**	**28.0**	**79.5**	**47.0**

Set-up numerical model:

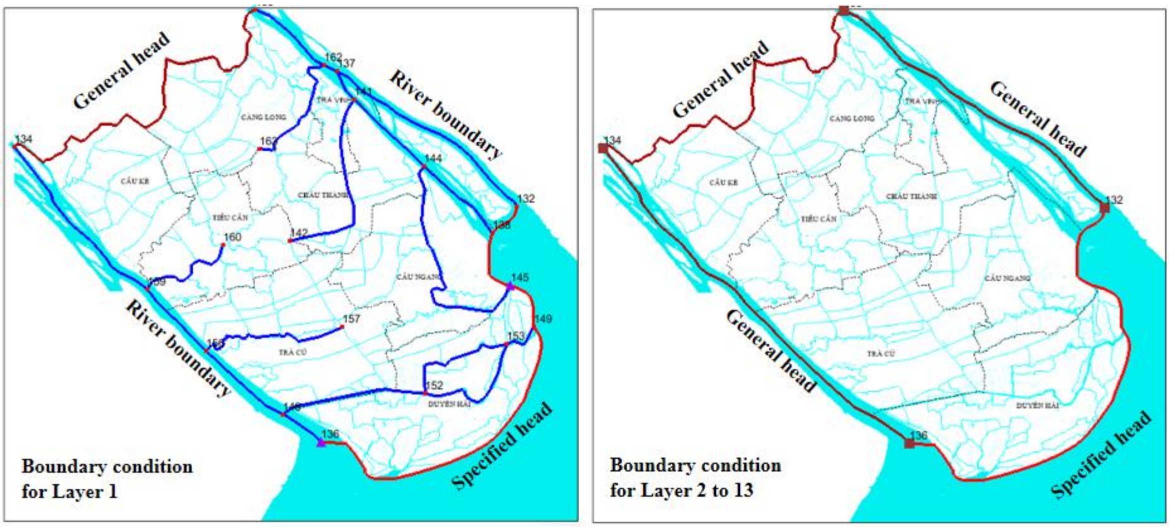
The model with the length of X axis is 75,000 m, the length along the Y axis is 67,000 m. The modelling area is divided into 135 rows and 151 columns, with a total of 20,100 grid cells. The size of each grid is 500 m x 500 m.



The absolute ground surface elevation is transferred from the topographic map of Mapinfor software into 6,926 points. The data of these 6,926 points was used via a "2D scater Data" module to include in a later stage in the final model. Moreover, the elevation of the different subsurface layers (aquifers and aquitards) were established based on the stratigraphic data from 56 boreholes and with reliable stratum information of previous studies within the province. Furthermore, the sparse density of the boreholes (56 boreholes/ 2,247 km^2), resulted in an additional 204 ‘virtual boreholes’, that are based on 6 hydrological cross-sections. The data of the layer elevation of the 260 (virtual) boreholes was also imported into the model via a "2D scater Data" module. This module allows the use of interpolation methods (in this report the natural neighbour interpolation method was used) to build the elevation contour maps for the bottom of layers.

With the elevation contour maps in place the layer properties of each layer were determined. Horizontally hydraulic conductivities of the aquifers are determined from the results of 59 pumping tests and the vertical hydraulic conductivities, specific storage of the aquifers is taken as 1/10 of the horizontal hydraulic conductivities.

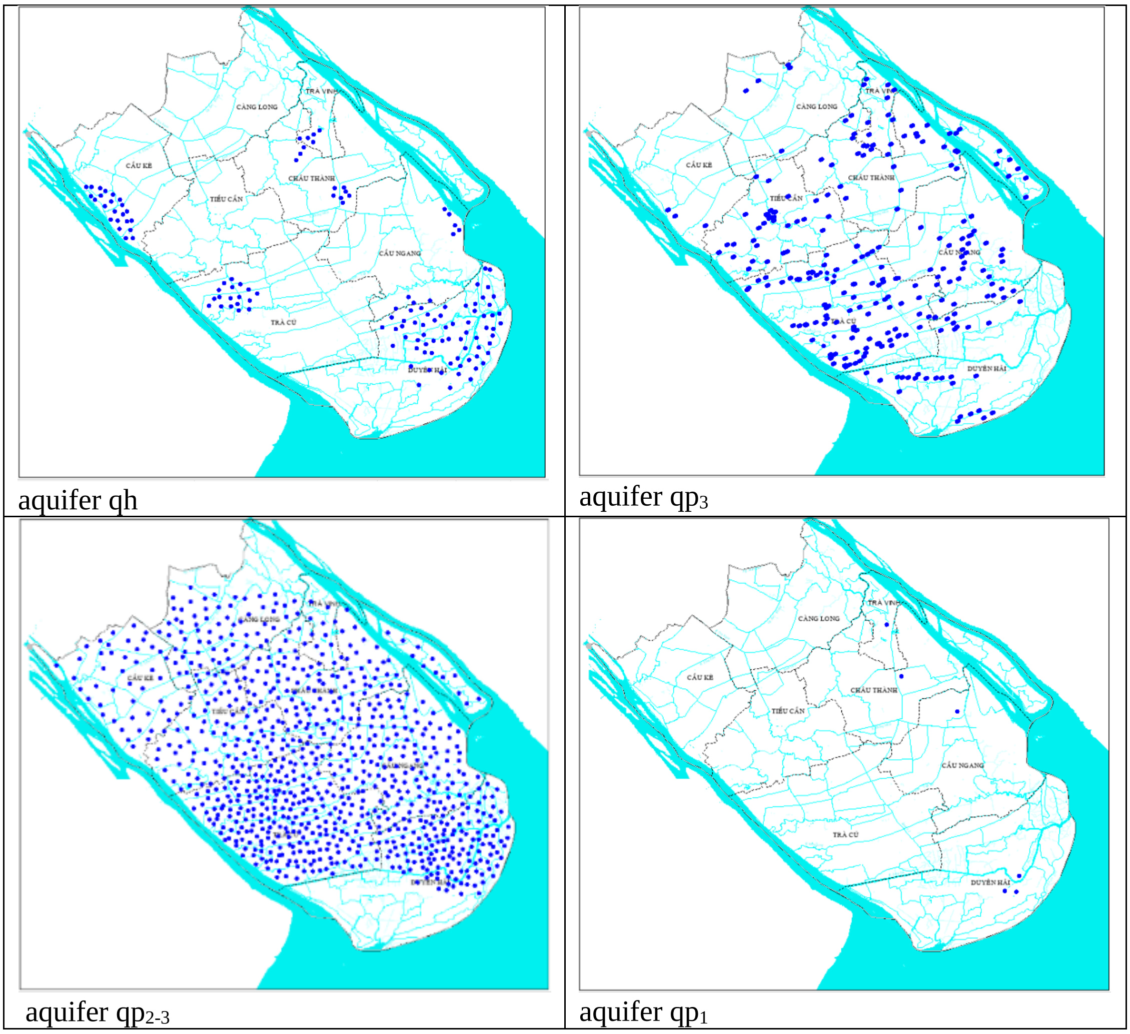
The river boundaries were assigned a conductance coefficient of $0.05 m^2/day/m^2$ and the smaller rivers within the province a conductance of $0.01 m^2/day/m^2$, infiltration was only considered in the first aquifer. Moreover, water exchange between the sea and groundwater along the coastline, as well as the exchange of groundwater between the study area and the area outside the domain of the model are assigned a specified head boundary condition. The figure below gives a clear illustration of the boundary conditions per layer.



Conditions boundary for layers of the model

Groundwater monitoring data was measured using 6 monitoring wells of the three top aquifers (qh, qp3, qp2-3). This data was used to calibrate the groundwater flow model. These monitoring wells have a continuous sequence of data for 10 years, from 2006 to 2016. From the daily series of groundwater level data, calculating the series of 120 monthly average water data.

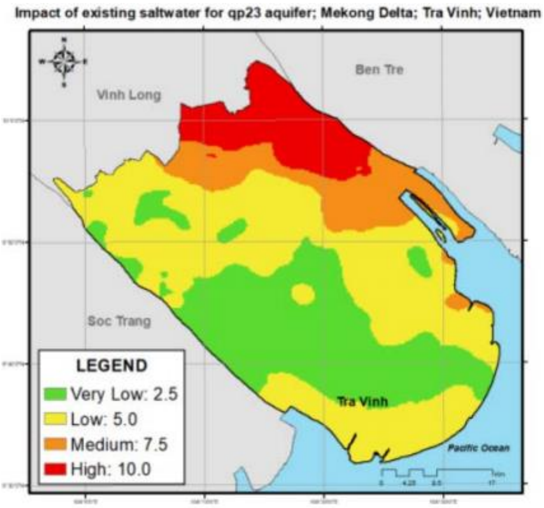
Groundwater exploitation was also considered in the model data and was used from two sources: The Department of Natural Resources and Environment in Tra Vinh province (Tra Vinh DONRE) according to results of management of groundwater exploitation licenses until 2018 and at Division for Water Resources Planning and Investigation for the South of Vietnam (DWPIS). These two reports indicate that in the study area, there are currently about 88,930 abstraction boreholes with about $370{,}410 m^3/day$. With the largest volume abstracted from the upper - middle Pleistocene aquifer. The data was processed by spreading the abstraction wells according to district and aquifer (figure below). The estimated 88.831 small boreholes without a specific location were combined to 1,378 ‘large’ boreholes each with an abstraction rate of 140 m^3/d.



Input the location of the boreholes in the model

Groundwater recharge was estimated based on literature. A distinction was made between confined and unconfined aquifers. The recharge rate was calculated based on an annual time step. Field and laboratory experiments where used to determine infiltration capacity of soil and soil parameters. Five possible locations were tested, checked and sampled, namely; 1) Long Huu, 2) Chau Thanh, 3) Cau Ke, and 4) Cang Long. The five locations were checked, using a double ring infiltrometer to determine the in-situ infiltration capacity of the soil. The soil in each location was sampled and tested with laboratorial experiments to determine specific soil parameters (hydraulic conductivity, soil texture, moisture content, porosity and field capacity), used for the recharge assessment model. The recharge assessment model results showed the following: The highest estimated recharge was in 2007 with 197 mm which is around 11 % of the total annual rainfall and the lowest recharge was measured in 2013 with 120mm, 8 % of the annual precipitation. Based on these results, the potential amount of recharge can vary from 8 % to 11 % of total annual precipitation.

Moreover, water measurements were taken during a household survey study in 2018. 419 households were interviewed, the interviewee took groundwater measurements of most surveyed households. From these measurements a contour map was created of the upper-middle Pleistocene aquifer. To interpolate the measurement points Ordinary Kriging was used, as a result the contour map illustrated below was constructed:



State of existing saline groundwater parameter rating, using the electrical conductivity

S10. Abstraction volume estimations, BBN model mutations and extra information

1) Number of households using groundwater calculations for 2007 (Sanh, 2010)

No.	District	Number of wells	Average depth (m)	Abstracted rate (m^3/d)
1	Tra Vinh city	786	87.1	692
2	Cang Long	8,591	97.1	15,749
3	Cau Ke	11,617	101.3	23,510
4	Tieu Can	13,484	98.1	31,014
5	Chau Thanh	11,711	91.6	39,102
6	Cau Ngang	11,419	100	22,619
7	Tra Cu	14,129	101	26,065
8	Duyen Hai	12,863	103	28,934
	Total	**84,600**	**97.4**	**187,685**

* In 2016, annual groundwater abstraction was estimated to be 347,793 m^3/d, in which the coastal zone (Duyen Hai district) occupied approximately 24 percent.

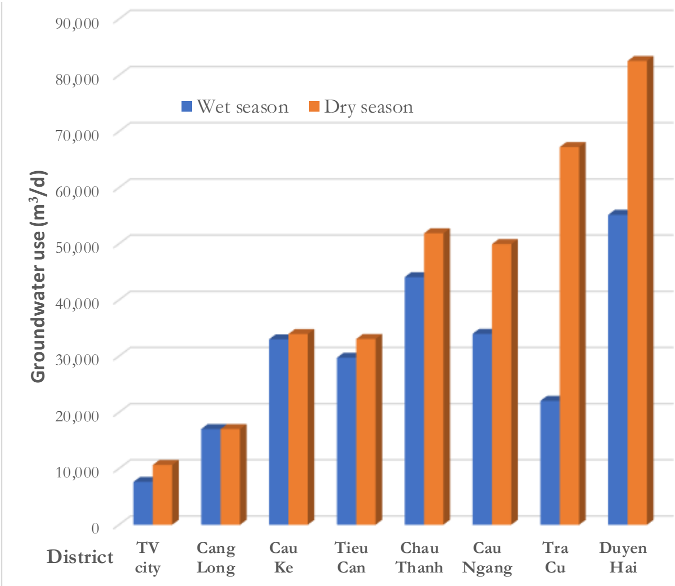
Domestic use of groundwater

Previous studies estimated a mean water use per household varying form 1.05 m^3/household/day to 2.05 m^3/household/day. Moreover, this study clearly indicates that groundwater abstraction increases from the northern part of the province towards the coastal part (i.e. the more we move to the sea the more groundwater is abstracted for household purposes) (Tuan Pham Van, 2019).

Agriculture group

Findings from the SALINPROVE project show higher groundwater abstraction rates during dry season. Both for crop irrigation to reach suitable conditions for crop growth (i.e. compensating for the low levels of rain) and aquaculture to balance salinity levels in the ponds. The research estimated an average pumping rate, during dry season, for some of annual crops such as water melon, pepper, onion, etc.. The calculation showed an average pumping rate of about 30 m^3/d/ha (Tuan Pham Van, 2019).

Seasonal estimated groundwater use - Tra Vinh Province, 2018 (Tuan Pham Van, 2019)



2) Vietnam's administrative units' system, survey district and commune description

First level	**Second level**	**Third level**
Province	District	Commune
Tra Vinh	Cang Long	My Cam Dia Phuoc Huyen Hoi
	Tra Cu	Dinh An Ham Giang Thanh Son
	Duyen Hai	Long Huu Truong Long Hoa Dan Thanh

Water salinity classification

Class	**Salinity TDS (mg/ L = ppm)**	**Use?**
Fresh	<1,000	Drinking & Irrigation
Brackish	1,000-5,000	Irrigation – with careful management
Highly Brackish	5,000-15,000	-
Saline	15,000-30,000	-
Sea water	30,000-40,000	-
Brine	40,000-300,000+	-

* The U.S. EPA sets the maximum contaminant level for TDS at 500 ppm. The World Health Organization (WHO) sets the maximum contaminant level for TDS at 1000 ppm.

3) BBN model mutations

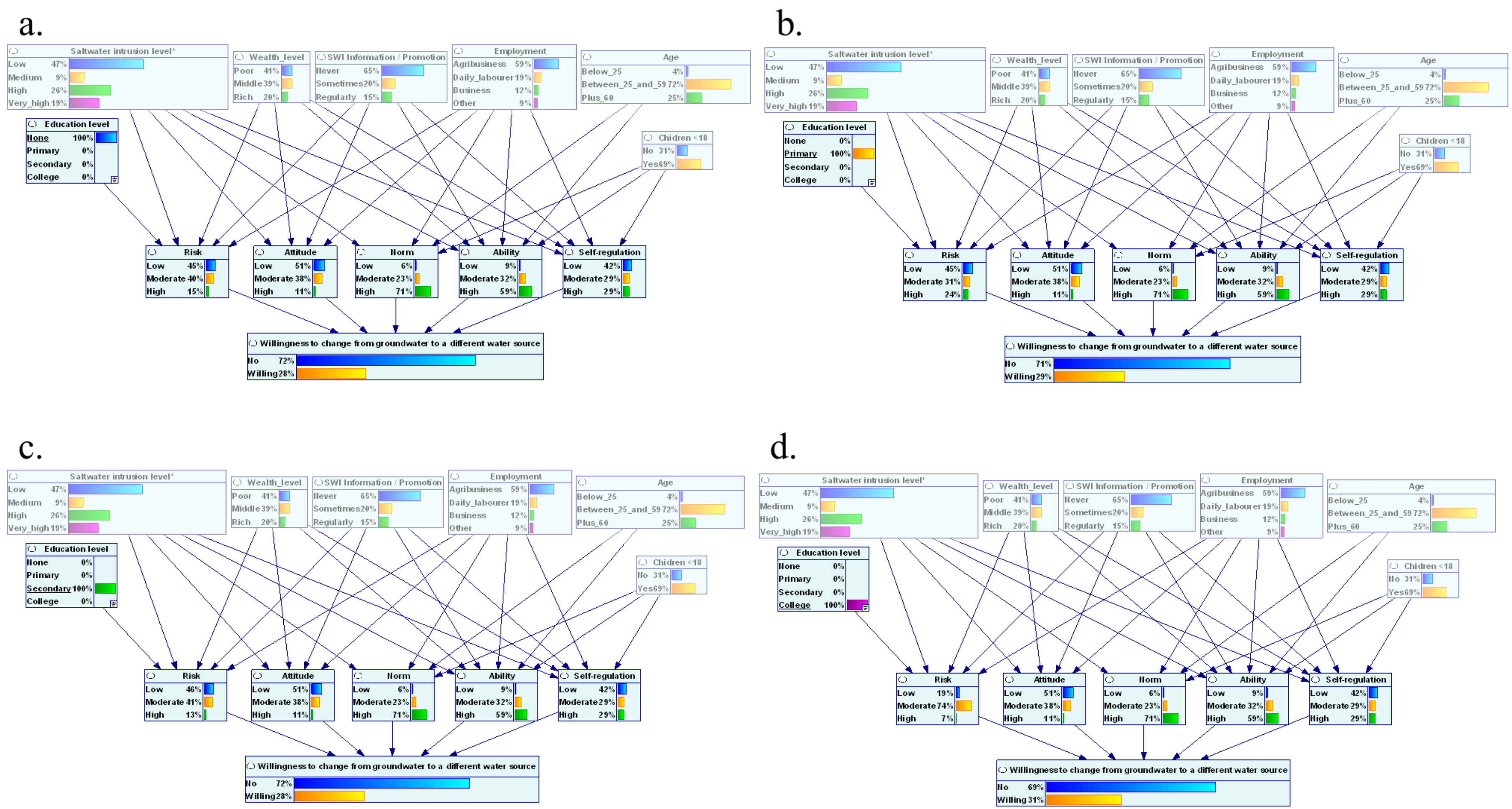


Figure S10.1. Updated probability in psychosocial nodes after changing the belief of socioeconomic node Education being a. "None", no education, b. "Primary", c. "Secondary", and d. "College"

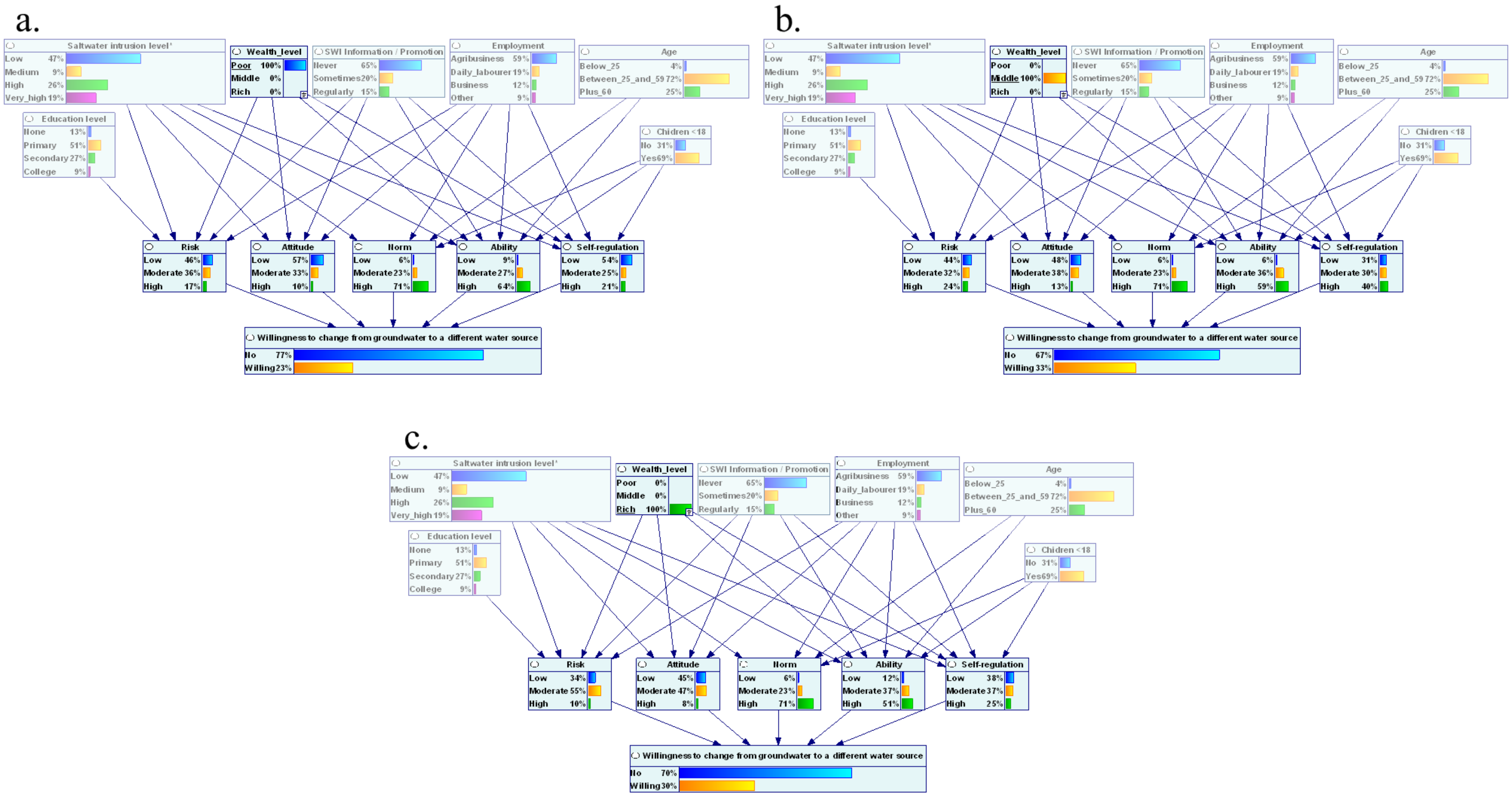


Figure S10.2. Updated probability in psychosocial nodes after changing the belief of socioeconomic node Wealth level being a. "Poor", b. " Middle" and c. "Rich"

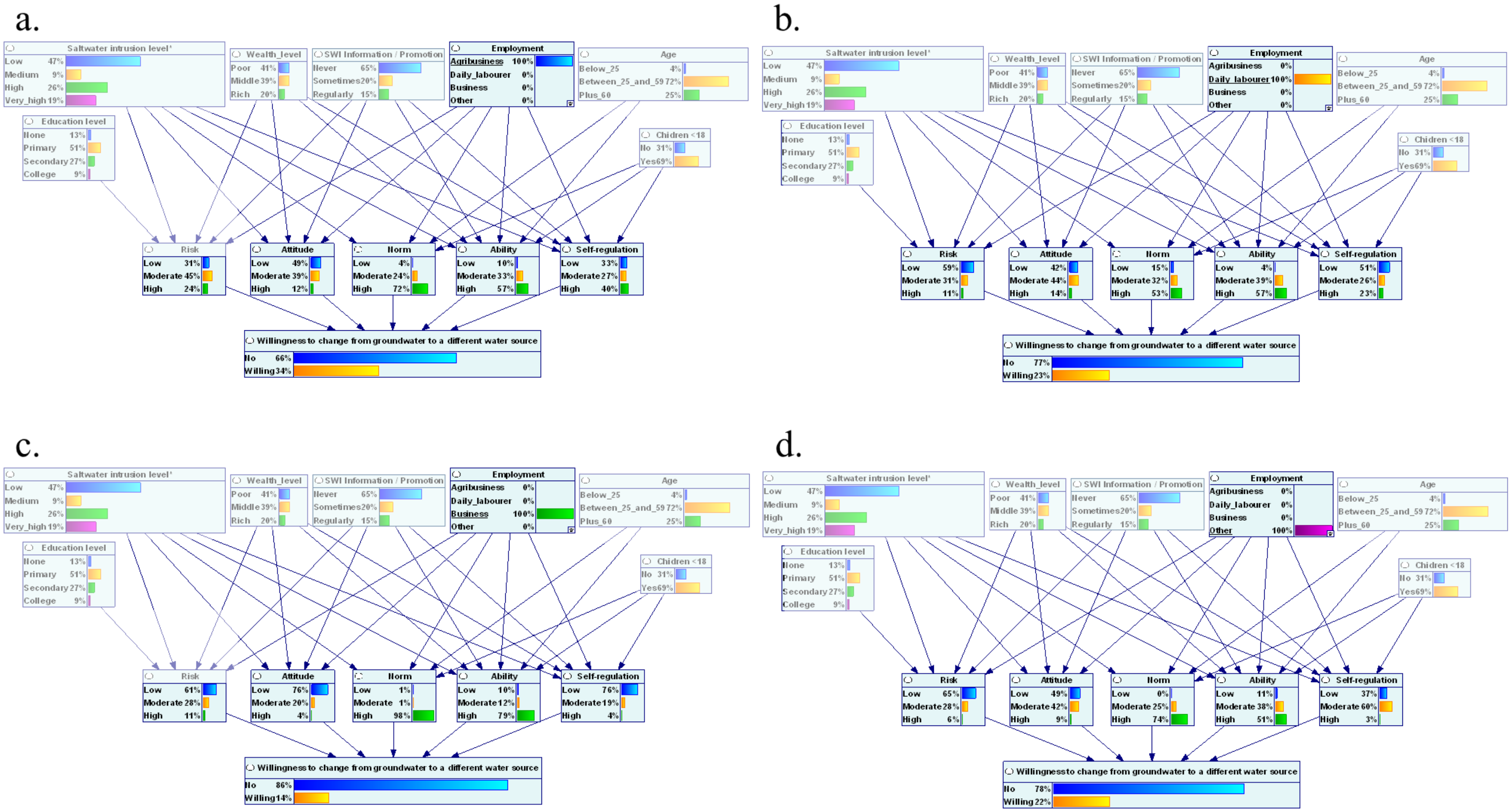


Figure S10.1. Updated probability in psychosocial nodes after changing the belief of socioeconomic node Employment being a. "Agribusiness", b. "Daily labourer", c. "Business", and d. "Other"

References

Allenby, G. M., Rossi, P. E., & Mcculloch, R. E. (2005). *Hierarchical Bayes Models: A Practitioners Guide Hierarchical Bayes Models*. Retrieved from http://faculty.washington.edu/bajari/iosp07/rossi1.pdf

Carey Biron. (2019). Salty soil sends U.S. farmers, officials scrambling. Retrieved from https://www.reuters.com/article/us-usa-water-farming-feature/salty-soil-sends-u-s-farmers-officials-scrambling-idUSKBN1WA0XQ

Contzen, N., & Mosler, H.-J. (2012). The Risks, Attitudes, Norms, Abilities, and Self-regulation (RANAS) approach to systematic behavior change. *Eawag*. Retrieved from http://www.eawag.ch/en/department/ess/main-

Daniel, D., Diener, A., Pande, S., Jansen, S., Marks, S., Meierhofer, R., … Rietveld, L. (2019). Understanding the effect of socio-economic characteristics and psychosocial factors on household water treatment practices in rural Nepal using Bayesian Belief Networks. *International Journal of Hygiene and Environmental Health*, *222*(5), 847–855. https://doi.org/10.1016/J.IJHEH.2019.04.005

Economist. (2019). Thirsty planet - Hard and soft solutions (Special report water). Retrieved from http://www.fao.org/fileadmin/templates/library/pdf/The_Economist.pdf

Emily Schmall. (2019). Indian City Ships Drinking Water in by Train | Time. Retrieved from https://time.com/5637602/chennai-india-drinking-water-train/

Ferguson, G., & Gleeson, T. (2012). Vulnerability of coastal aquifers to groundwater use and climate change. *Nature Climate Change*, *2*(5), 342–345. https://doi.org/10.1038/nclimate1413

Gamma, A. E., Slekiene, J., von Medeazza, G., Asplund, F., Cardoso, P., & Mosler, H.-J. (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

Gleick, P. H. (2002). Water management: Soft water paths. *Nature*, *418*(6896), 373–373. https://doi.org/10.1038/418373a

Hans Mosler. (2017). RANAS - Behaviors in other areas. Retrieved August 15, 2019, from https://www.ranasmosler.com/behaviors-in-other-areas

Inauen, J., & Mosler, H.-J. (2014). Developing and testing theory-based and evidence-based interventions to promote switching to arsenic-safe wells in Bangladesh. *Journal of Health Psychology*, *19*(12), 1483–1498. https://doi.org/10.1177/1359105313493811

Kabir, G., Tesfamariam, S., Francisque, A., & Sadiq, R. (2015). Evaluating risk of water mains failure using a Bayesian belief network model. *European Journal of Operational Research*, *240*(1), 220–234. https://doi.org/10.1016/j.ejor.2014.06.033

Karatzas, G. P., & Dokou, Z. (2015). Optimal management of saltwater intrusion in the coastal aquifer of Malia, Crete (Greece), using particle swarm optimization. *Hydrogeology Journal*, *23*(6), 1181–1194. https://doi.org/10.1007/s10040-015-1286-6

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

Klassen, J., & Allen, D. M. (2017b). Assessing the risk of saltwater intrusion in coastal aquifers. *Journal of Hydrology*, *551*, 730–745. https://doi.org/10.1016/J.JHYDROL.2017.02.044

Lilje, J., & Mosler, H.-J. (2018). Effects of a behavior change campaign on household drinking water disinfection in the Lake Chad basin using the RANAS approach. *Science of The Total Environment*, *619–620*, 1599–1607. https://doi.org/10.1016/J.SCITOTENV.2017.10.142

Park, W. (2019). The country disappearing under rising tides - Rising sea levels are making traditional ways of life impossible. Rural Bangladeshis are having to adapt to survive. Retrieved from https://www.bbc.com/future/article/20190829-bangladesh-the-country-disappearing-under-rising-tides?fbclid=IwAR0-TbpFvW-nG9o3o_rf4986bhXFbx4xpS-Y76lcAukTl-JbnV-PiHVUXoM

Pearl, J. (1988). *Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference - Judea Pearl - Google Books*. San Francisco, CA, USA: Morgan Kaufmann Publishers Inc. Retrieved from https://books.google.nl/books?hl=en&lr=&id=mn2jBQAAQBAJ&oi=fnd&pg=PP1&ots=4rHP3E4H72&sig=rt9iW24bjFhkVuOTbCLFs2Mkn90&redir_esc=y#v=onepage&q&f=false

Qi, S.-Z., & Qiu, Q.-L. (2011). Environmental hazard from saltwater intrusion in the Laizhou Gulf, Shandong Province of China. *Natural Hazards*, *56*(3), 563–566. https://doi.org/10.1007/s11069-010-9686-3

Ringnér, M. (2008). What is principal component analysis? *Nature Biotechnology*, *26*(3), 303–304. https://doi.org/10.1038/nbt0308-303

Sanh, N. Van. (2010). Research on water resources in Tra Vinh province: water use and exploitation, solutions for using sustainable water resources and management. *Can Tho University*, 167–177.

Seimetz, E., Slekiene, J., Friedrich, M. N. D., & Mosler, H.-J. (2017). Identifying behavioural determinants for interventions to increase handwashing practices among primary school children in rural Burundi and urban Zimbabwe. *BMC Research Notes*, *10*(1), 280. https://doi.org/10.1186/s13104-017-2599-4

Sherif, M. M., & Hamza, K. I. (2001). Mitigation of seawater intrusion by pumping brackish water. *Transport in Porous Media*, *43*(1), 29–44. https://doi.org/10.1023/A:1010601208708

Shrestha, S., Bach, T. V., & Pandey, V. P. (2016). Climate change impacts on groundwater resources in Mekong Delta under representative concentration pathways (RCPs) scenarios. *Environmental Science & Policy*, *61*, 1–13. https://doi.org/10.1016/J.ENVSCI.2016.03.010

Skinner, B. F. (2005). *SCIENCE AND HUMAN BEHAVIOR*. Retrieved from http://www.bfskinner.org/books4sale.asp

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

Tuan Pham Van, S. K. (2019). Estimation of groundwater use pattern and distribution in the coastal Mekong Delta, Vietnam via socio-economical survey and groundwater modeling. *ASEAN Academic Network*. Retrieved from http://aseanacademicnetwork.com/node/Files/TD447-1.pdf

Werner, A. D., & Simmons, C. T. (2009). Impact of sea-level rise on sea water intrusion in coastal aquifers. *Ground Water*, *47*(2), 197–204. https://doi.org/10.1111/j.1745-6584.2008.00535.x

Wutich, Amber and White, Alexandra C and White, Dave D and Larson, Kelli L and Brewis, Alexandra and Roberts, C. (2014). Hard paths, soft paths or no paths? Cross-cultural perceptions of water solutions. *Hydrology and Earth System Sciences*, *18*(1), 109–120.

“If a frog is put suddenly into boiling water, it will jump out, but if the frog is put in tepid water which is then brought to a boil slowly, it will not perceive the danger and will be cooked to death…”