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Groundwater Use Habits and Environmental Awareness in Ca Mau Province, Vietnam: Implications for Sustainable Water Resource Management

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ABSTRACT

The Vietnamese Mekong Delta including Ca Mau province (CMP) is seriously affected by land subsidence. Groundwater over-extraction is considered to be a major driver for this process. To address the reduction of groundwater (GW) extraction as a potential counter measure for further subsidence, this study focuses on understanding the importance of GW in people's life and water using habits as well as their awareness with current environmental problems in Ca Mau. Therefore, GW sampling campaigns and surveys were conducted in all 9 districts of Ca Mau province in 2019 and 2020. The analyzed water samples showed a connection with information from questionnaires and created a general picture of water using habits. GW plays an important role in people's lives, it is used for washing, cooking, drinking and other activities. People use GW for different purposes depending on their perception of water quality. For important and direct health related purposes, such as cooking or drinking, people prepare to treat water more carefully or choose another alternative water resource. The analytical approach to evaluation results based on viewpoints from general to detail helped to dig deeper into people's stories to explain research results with their behavior in each situation. When people are dependent on GW and have no option to use alternative water resources, the importance level of GW in their life increases and their awareness of GW over-extraction becomes less. If people have another water source to use such as tap water (TW), habits of using GW change. This opens up the idea that a potential alternative water will reduce the dependence of people on GW and protect GW from over-exploitation. Besides, people in Ca Mau do not have much awareness of land subsidence or the reason leading to environmental problems. Therefore, raising the awareness of people by well-design education campaigns should be strongly considered.

1. Introduction

Vietnam is one of the most threatened area with the effect of sea level rise (Hens et al., 2018) as well as climate change related to the intensity of natural disasters (MONRE, 2016; Oxfarm, 2008). The Vietnamese Mekong Delta, including Ca Mau province (CMP), is located at the Lower Mekong River and forms the very southern edge of Vietnam. The Mekong Delta has an extremely low mean elevation above sea level (around 0.8 m) (Minderhoud et al., 2019, 2017). In addition, the Mekong Delta is facing a great number of environmental challenges and sustainability problems during the twenty first century due to the decrease of sediment supply from its catchment due to upstream dams, saltwater intrusion from the sea, sea level rise and flooding as well as significant land subsidence (Allison et al., 2017; Tran et al., 2021). Human activities and climate change have impacts on saltwater intrusion into GW systems in Mekong Delta (Han et al., 2021). The Mekong delta has to deal with salinity intrusion in the dry season and flooding during the rainy season. For example, in the dry season of 2015/2016, eight provinces in the Mekong delta have announced an emergency situation due to drought and salinization (Bäumle, 2017). In recent years, due to rapid social-economic development and an increase in population, the increasing demand of freshwater led to an increased exploitation of

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GW without any planning, what causes serious problems in the Mekong Delta in general and Ca Mau Peninsula in particular (Friedrich et al., 2008; Van, 2019). Therefore, water security in the region is seriously endangered due to a decrease in freshwater quantity and quality, mainly caused by salinization, pollution and over-extraction (Ha et al., 2018). GW over-exploitation leading to an average decline of hydraulic heads of around 30 cm per year, potentially plays an important role in ongoing land subsidence (Erban et al., 2014). Land subsidence in Mekong Delta is leading to the unsustainability of area (Gustafson et al., 2018; Di Giusto et al., 2021).

The Vietnamese Mekong Delta has a transition in agriculture from mono-culture (rice farm) to multi production like shrimp-rice to be more sustainable (Nguyen et al., 2021). CMP, is the shrimp basket of Vietnam with a high demand of GW for farming. The export of these goods is of uttermost importance for Vietnam's economy. However, Ca Mau's groundwater resources are intensively affected by saltwater intrusion and a decrease of hydraulic heads resulting in a lack of freshwater for estimated 95,600 households (UN, 2020). Thus, this region urgently needs the identification, development and implementation of adapted relief measures to save it from complete inundation by the sea (Minderhoud et al., 2020). Bauer et al., 2022 described the challenges of the Mekong Delta as "a progressive loss of land and freshwater". One major counter measure to mitigate land subsidence might be to stop or significantly reduce GW extraction from deep, confined aquifers and switching to alternative water resources, such as surface water from the rivers and channels, rainwater, pumped water from the Mekong River, or desalinization of sea water. However, before even starting with one of these measures, it has to be investigated how people would react on such intensive intervention into their daily life. Many previous studies have shown that sustainable adaptation is only successful if the local people fully accept it. People intend to increase their adaptation when they are aware of the risk of climate change to many aspects of their life (Luu et al., 2019).

People in CMP are diverse in terms of living standards as well as access to water resources. To start reducing the use of GW, it is necessary to understand the importance of GW in people's life. Research needs to reflect people's opinions and their assessment of the water they are using. People's perception of GW quality and surrounding factors might influence their usage habits. Some factors affecting the acceptance of water source are public awareness about water supply, distribution, treatment as well as income and other personal factors (Baumann, 1983). Another case study in Bengaluru, India evaluated the factors impacting the acceptance of recycled water. One of the noticeable results was that 89% of the people using surface water were not aware of waste water treatment concepts or water reuse at all (Ravishankar et al., 2018). Another research in Vietnam also indicated that people's choice of water source depend on availability, quality of the water sources and financial situation of the household (Danh and Khai, 2015). In CMP, a recent study showed that people are not fully aware of the danger of submersion by the sea (Di Giusto et al., 2021). In addition, to our best knowledge, facing many problems of water use, there are still no studies on people's perception on water usage habits, with both quantitative and qualitative aspects in Ca Mau. On the one side, quantitative research is a research approach, which evaluates the relationship between variables by numeric data collection and analysis (data can be expressed in numbers or scores). On the other side, qualitative research is a research approach, which concentrates on discovering individual's experiences with phenomena by narrative or text data collection and analysis (data can be expressed in words and images) (Clark et al 2016). The combination of these two approaches creates enhanced methods that can show a more comprehensive view of people's opinion in Ca Mau from a personal perspective as well as statistical analysis (Creswell, 2017). Therefore, in this study a comprehensive GW quality assessment combined with a survey in CMP was conducted. This study emphasizes on the relationship between water quality and people's water use habits with the quantitative approach. At the same time, the open-end questions and group discussion from the qualitative approach open up explanations to the problem, explaining why people in CMP are overusing GW and evaluates their possible alternative options.

2. Methodology

2.1. Study area

The study area in this research focus in Ca Mau province (CMP). Ca Mau is the southernmost province in Vietnam, surrounded by sea in three directions. CMP includes 9 districts (Ca Mau, U Minh, Tran Van Thoi, Dam Doi, Thoi Binh, Cai Nuoc, Phu Tan, Nam Can, Ngoc Hien). This area contains high density of river and canals, it is flat and low area, average elevation is around 0.5 to 1.5 m above sea level. (Pechstein et al., 2018). Ca Mau is located in the monsoonal zone, it has a tropical monsoon climate with two main seasons (rainy and dry seasons). The rainy season is usually from May to November and the dry season is from November to May.

The population of CMP is around 1.2 million people with 603,250 males and 589,150 females in 306999 households. Sex ratio in Ca Mau is around 102.39 male/100 female. According to Ca Mau Statistic Office in 2021, main labor force is in rural area with 535,892 people with 80.01%, labor force in urban area accounts for 19.99% with 133,881 people. The occupation of people in CMP includes high level professionals, mid-level professionals, clerks, personals services, protective workers, sales workers, skilled agricultural, forestry and fishery workers, craft and related trade workers, machine operators, unskilled occupations and others. The most popular occupations are workers related to agricultural, forestry and fishery sector with 214,153 workers accounting 32. 63% and unskilled workers with 254,550 workers accounting 38.78%. The key activities in the development of economy sector is agriculture, especially aquaculture (with a total area of 297,200 ha). GW extraction in Ca Mau is mainly used for agriculture, aquaculture and domestic use in rural area, from mostly small to medium sized wells with pumping rates >200 m^3/day. However, the number of GW extraction wells is approximately 175,710 wells including only 248 centralized wells and 452 licensed extraction wells (Pechstein et al., 2018). It means most wells are illegally extracting GW without any exact estimation of extraction rates.

2.2. Questionnaires

2.2.1. Data collection

The data set was collected on the basis of questionnaires and group discussions with households in CMP. Questionnaires were collected by face-to-face interviews between the authors, an instructor from the local government and a household member. Field trips were implemented by visiting nine districts in CMP to collect data. The first survey was carried out in March 2019 with 87 questionnaires and water samples collected in all nine districts. The second survey took place in December 2019 and January 2020 with 57 questionnaires and water samples focusing on the northern part of CMP. Based on the experiences from the first field trip on March 2019, questionnaires were collected together with groundwater samples at the same location. Groundwater samples were taken systematically to cover all regions in CMP (Fig. 1a, 1b). Following the approach by Ravishankar et al (2018), the authors of this study are aware that some aspects of this study might not be representative for a commune, district or CMP as a whole. However, as this is the first study in the area, it is important to qualitatively focus on basic factors and reasons impacting groundwater extraction as well as the connection between people's story and the respective water quality. In total, 144 questionnaires and 144 GW samples were collected (Fig. 1a). At first, a survey was conducted to get the results and lead to the following up questions in discussion for better understanding of initial finding from quantitative research (Clark et al, 2016). The questionnaire was designed with 28 questions in the first version and was extended by 35

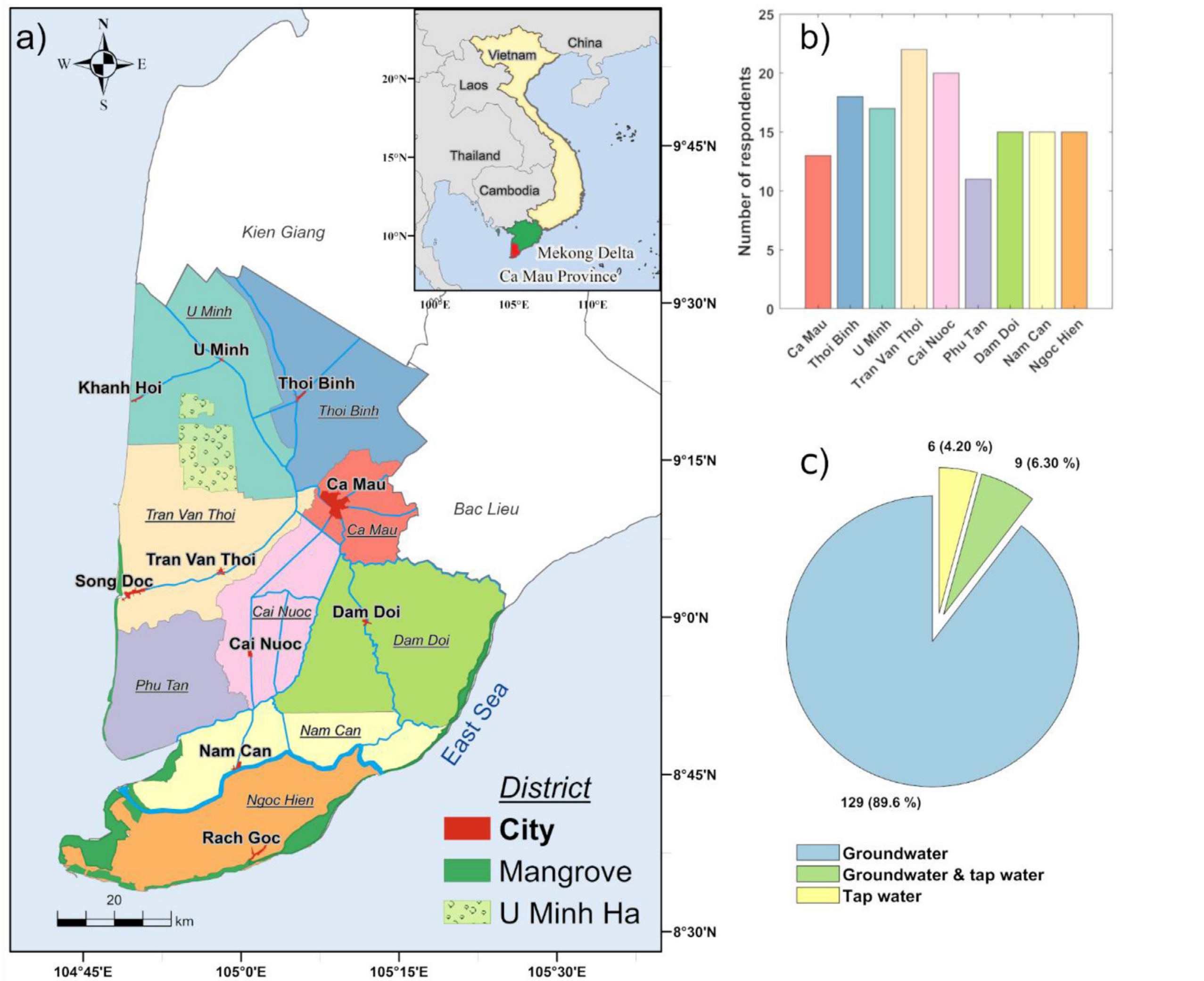

Fig. 1. a. Questionnaire locations in Ca Mau, b. Distribution of respondents in the nine districts of Ca Mau, c. Percentage of households in different groups (GW users and TW users).

questions in the second version after the evaluation of the results of the first survey. The second version focuses more on people's assessment of GW quality and their awareness of negative environmental impacts, such as salinization and land subsidence. All questions were explained and discussed with households directly. The questionnaire system is designed and divided into four main parts with easy to understand contents to match the perceptions of the respondents in CMP. The first part covers basic information surrounding the respondents, such as living conditions. The second part explores information about groundwater extraction and water use habits. The third part describes the potential of alternative water sources and the last part is about people's perceptions and awareness of overexploitation and land subsidence in CMP. The level of awareness of the people is divided by level from 1 to 4, with 1 being the lowest level, meaning that people totally have no knowledge of this issue. Level 2 means that people heard about this issue somewhere but they do not understand it clearly. Level 3 means that people know about the problem and have a basic understanding of the causes. Level 4 is the highest level when the people capture the whole picture, understand the issue and relevant information.

After completing a questionnaire, in the following group discussion part, respondents had a deeper discussion with the interviewer to explain their answers and stories.

2.2.2. Data analysis

To evaluate the outcomes of the questionnaires, well established quantitative and qualitative approaches are applied. The quantitative approach covers statistical evaluation of the questions related to numbers such as amount of water use or number of people using the well etc. Similarly, the qualitative approach consists of a hermeneutical evaluation of questions related to words and text, such as the favorite water source or GW using purpose etc.

The selection of locations was based on the general idea to get a complete overview about the different living conditions and water resources around the whole province rather than a statistical overview based on the distribution of population. Distribution of questionnaires in Ca Mau province is shown in Fig. 1b. Information gained from data collection was expressed with the points of view from general view into detailed explanation.

According to observations and interviews, beside groundwater, there are three other types of water sources used in CMP, including rain water, tap water, and bottled water (from private water supplier). Tap water (TW) is not available for the whole province. TW is obtained from GW, which is treated at a drinking water plant and distributed usually to nearby households in the same ward or commune. Until now, fresh water management and distribution are not effective. GW is the major water source which is used mainly for domestic purposes (Ha et al., 2015) The number of households that possess the ability to use TW is not as high as compared to households using GW. In this study, although the main research subject are households using groundwater (GW users) and GW samples, tap water households (TW users) are also approached and interviewed to collect further information. For this reason, the respondents (144 questionnaires in total) were divided into two groups. Group 1 includes all households that only have GW as the main source of water called GW users, and group 2 includes households that own a GW well but also have direct access to tap water, or use TW only, called TW users. Results from 2 groups of respondents were selected, analyzed and compared to understand the difference of their thought and behaviors between 2 groups. The distribution of questionnaires in two groups is not the same (Fig. 1c). GW users accounts for 89.6% questionnaires, the percentage of people who use only TW and TW together with GW are 4.20% and 6.20%, respectively. Important reason for this extra subject is that people who get experience in using TW have more diversity in perception and they can evaluate water sources and their consumption habits in a wider view. This study focused on the group of GW users and the number of TW users is used for comparison. The number of TW users is small and do not have the meaning to be a representative for the whole group.

2.3. Water quality

GW samples were collected in parallel to the questionnaires and were analyzed in the frame of the previous study by Bauer et al. (2022), emphasizing on GW evolution and geochemistry. However, only major ions and parameters were considered in this study. The sampling methods are described in Bauer et al. (2022) in detail. Briefly, GW samples were collected from households, small businesses and water supply stations with the aim to cover the whole province. Sampling points were selected based on their spatial relevance, general access as well as permission situation. The number of samples is more than the number of questionnaires. GW was collected after 15 minutes of pumping to ensure that the sample originate from the aquifer and not the stagnant water which was standing in the well casing prior to pumping. GW was taken and measured some parameters on site, or brought back into laboratory for further analysis, as described in Section 2.3.2. To prepare for analysis, 25 mL of GW sample was filtered through a 0.45 μm cellulose-acetate filter (Satorius Stedim Biotech GmbH). 50 μL of high purity nitric acid was added to the filtered sample to prevent the precipitation of cation (APHA AWWA, 2005) and 50 μL of sodium azide was added to inhibit microbiological processes to ensure a correct anion analysis (Vanderford et al., 2011). Physiochemical parameters including temperature, pH, electrical conductivity (EC), Oxygen and redox were determined on site by using a multi parameter portable meter (WTW Multi 3630 IDS). Total alkalinity was also measured on site with a titration kit (Merck KGaA, Germany). Besides, samples after filtration and acid/sodium azide addition were transported to Germany and analyzed with IC (X-Series 2, Thermo Fisher) for anions and ICP-MS (Dionex, ICS-1000; Trennsäule IonPac As14 Supressor ERS 500) for cations at the Karlsruhe Institute of Technology in the laboratories of Institute of Applied Geosciences.

After analysis, the samples of GW were compared with the people's subjective assessment of the water quality from the questionnaires. In addition, the concentration of ions, are compared with the National Technical Regulation on Domestic Water Quality QCVN 01-1/2018 BYT to know whether the water quality meets the usage standards or not. The dashed red line represents the QCVN standards and shows clearly that some parameters of samples are over the permissible standards for domestic water (Fig. 5). If the dashed red line does not appear in the figure, it means all values of each parameter meet QCVN standards. All necessary parameters were analyzed and a comparison was carried out between the group of people using GW for non-drinking and drinking purpose. One more aspect to be discussed is samples where GW is chosen as the best water resource. Not all parameters from the list of Vietnamese standard QCVN 01-1: 2018/BYT are considered. This study focuses on some selected parameters, which are most important to evaluate domestic water quality and are easy for people to realize if they occur in harmful concentration. The parameters include pH, EC, NH_4^+, Cr, As, Cd, Sb, Pb, Al^{3+}, Mn^{2+}, Zn, B, Fe, Ba, Na^+, Ca^{2+}, Cl^-, SO_4^{2-}. pH is the basic parameter, which can affect to value of other parameters. Heavy metals such as cadmium, lead and chromium dissolve more easily in highly acid water (DeZuane, 1997). Besides, iron and manganese are not serious substances, which cause health problems, but can cause bitter taste in drinking water even at very low concentration. When water containing higher amounts of Fe^{2+} and Mn^{2+} are exposed to air, these ion can oxidize and precipitate and the water can turn to be turbid (APHA AWWA, 2005). Zinc is not harmful at small concentration, but it can cause strange taste in drinking water with concentration of above 4 mg/L. Zinc at concentrations between 3 – 5 mg/L in water can cause the greasy film when boiling (WHO, 2018). Besides, using lead pipes increases lead concentration in drinking water and after long term, it could affect children mental health. Arsenic also causes a risk to health after long term exposure (WHO, 2018). Ammonia (NH_4^+) concentration can be over the taste threshold at 35 mg/l (WHO, 2018).

3. Results and discussion

3.1. General information of respondents

In this study, households' information of GW use issues along with perceptions of GW over-exploitation are used for the analysis. Percentage of males and females among the respondents was a ratio of 2 males: 1 female. The average household size is 5.5 people per household. According to the Ca Mau Statistic Office, the population in rural area is much higher than in urban area (920948 with 77.2% in comparison with 271452 people, around 22.8%). In this study, respondents are also focused on rural area with around 91.0% and 9.00% respondents in urban area. Most respondents who used groundwater lived in rural area. In urban area, tap water is supplied to the households from water supplier station.

The interviewed households have a variety of occupations, from growing rice, farming shrimp to doing small business to working as employees of a company or officer in government.

The majority of respondents are farmers (rice or shrimp farming) with 68.1%. There are also small self-employed households including restaurants, bars, selling bottled water with 16.7%. People working in companies and government organization known as officers, accounted for 10.4% of interviewees, and finally 4.86% of interviewees were workers. In Ca Mau population, percentage of these occupations are 32.6%, 8.50%, 2.93% and 8.87% respectively (according to Ca Mau Statistic Office, 2021)

The household's income is difficult to estimate because most interviewees do not have a stable monthly income but their income is determined by the success of the crop or shrimp harvest. Usually, people in Ca Mau have more than one source of income. One person can be an employee but also a small seller or a farmer. According to Ca Mau Statistic Office, average monthly income per capita in urban and rural region in 2018 is 2,985,900 VND/pp/month (around 129.6 USD/pp/month). This income is including wage or salary (798,300 VND) (around 34.7 USD /pp/month), income from agriculture, forestry and fishery (self-employment) (1,015,200 VND) (around 44.1 USD), income from non - agriculture activities (813,400 VND) (approximately 35.4 USD) and others (359,100 VND) (around 15.6 USD). This data fits to the authors' impressions in CMP.

Respondents are mainly normal households where GW is used only for domestic purposes. Besides, there were some other types of households. Some households own their business which require much water such as bike washing, restaurant, shrimp farming. Others are private

Table 1
Purpose of using groundwater in Ca Mau province (N=144 questionnaires).

Purpose of groundwater use	Percentage of respondents using groundwater for this purpose
Washing	97.0%
Cooking	65.7%
Drinking	25.4%
Others (gardening, doing business…)	23.9%

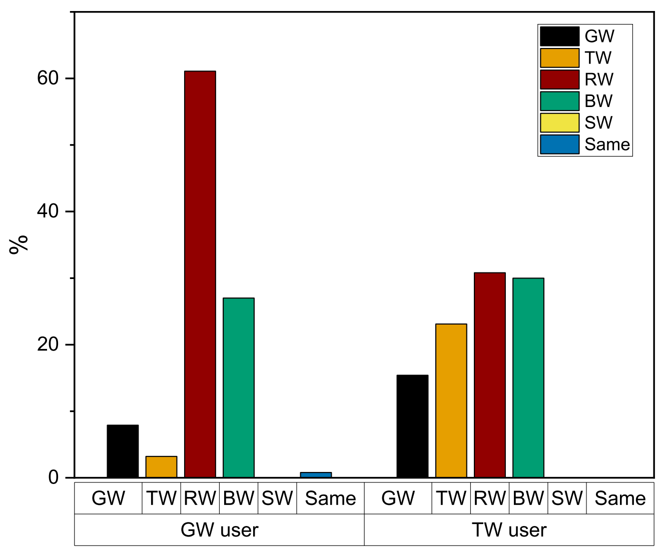

Fig. 2. Best water source in household's opinion.

water suppliers who sell water bottles or owners/managers of water station.

3.2. Current state of using water resource

Groundwater is popular and plays an important role in people's lives in CMP. To understand if people would accept stopping GW usage, it is necessary to understand the importance and specific role of GW in their daily life under social and economic aspects.

According to the results of 144 questionnaires, GW is used for many purposes in CMP, which are listed in Table 1. Households consume GW to wash clothes, dishes, cook or even drink directly. However, washing clothes and dishes consume the highest amount of GW.

Two groups of GW users and TW users have different opinions for certain aspects. For each group, their experience with TW differs, leading to their perception of several different assessments regarding water quality or convenience of use. People have sensory assessments of each water source they use, in terms of water volume, water quality, and as a consequence which water source is the best. Opinions of respondents about the best water source are shown in Fig. 2.

Among GW users, rainwater (RW) is rated as the best quality with 61.1% agreement of households and according to the respondents: "Rainwater is sweet and delicious, is usually boiled to drink tea. Rain water is only used for the main drinking and cooking purpose. Although the water quality is good, the amount of rain water is not enough for another purpose." Their opinions about rain water is based on long-time experiences of using it. According to Đoàn Thu Hà and Hồ (2014), rain water in the Mekong Delta is also considered as high quality water source and it meets Vietnamese standards for almost all parameters. However, contamination of fecal parameters are due to the condition of rain water storage and treatment (Wilbers et al., 2013). Second is bottled water (BW) with 27.0%. In fact, BW comes from groundwater but it is treated in private filtration systems and sold to people. People have confidence in the water quality after treatment with the filtration system and think that BW is of good quality.

In addition, the TW users group believes that RW, BW and TW are the top three with the best water quality, with 30.8%, 30.0% and 23.1% respectively. Even though they have access to TW, they still believe that RW has a better quality in taste. Some interviewees said that TW is sometimes still affected by pipes, strange color changes and its taste is worse than that of RW. Not so many respondents think all water sources have the same quality and no one chose surface water (SW) as the best water source. SW in Ca Mau Peninsula is widely contaminated with organic matters, nutrients, total suspended solids, and microorganisms (Giao, 2022).

On the other hand, both target groups believe that in general GW quality is not really good, with only 7.90% for GW users and 15.4% for TW users voted for GW as the best water resource. The perception of households about groundwater is nearly compatible with the water quality due to the characteristics of some parameters in terms of color, smell and taste (mentioned in Section 3.3). In addition, the role of GW in the life of the household with access to TW has decreased. The importance level of GW in people's life from the results of the survey is shown in Fig. 3.

The question posed to residents is how important GW is in their lives. The answer is divided from level 1 (not important) to level 4 (extremely important, irreplaceable). For the GW users group, none of the people choose level 1, up to 30.3% and 66.4% of the respondents choose the importance level of GW to be level 3 and 4. For the TW users, the importance of GW in people's life is less important, with 22.2% at level 3 and 55.6% at level 4 (Fig. 3). It can be seen that when the group of people is able to use TW, the importance of GW decreases.

Moreover, the use of GW for drinking purposes is a matter of great concern. GW users can be further divided into two subgroups: (i) a group of people who use GW for the purpose of drinking and (ii) a group of people how use GW for non-drinking purposes. If people use GW for the purpose of drinking, people tend to pay more attention to water quality and they usually use some pre-treatment to make water safer for drinking (Fig. 4).

The results show that only 4.2% did not use any pre-treatment before drinking GW, which might be concerning for their health. However, 25% of the subgroup did use a settling process to remove suspended particles before drinking, while 20.8% used both settling and boiling methods to ensure safe water. The majority of the respondents, 50%, relied on filtration systems to remove impurities before drinking GW. Normally, people use mini filtration systems at home. The price of a mini system is in range of 6.000.000 VND (around 260 USD) and they have to change the filter every 3-6 months with a price of around 90.000 VND/filter (around 3.90 USD). These findings highlight the importance of promoting safe water practices to ensure the health and wellbeing of the population, particularly for those who do not currently use any pre-treatment methods (Fig. 4).

The importance of GW in people's lives is affected by their intention in using GW as well as whether they have other water sources such as TW to use. Besides using GW, people also have access to other water sources such as RW, SW, BW or TW for different purposes. The self-assessment question of best quality water opens up potential alternatives to replace GW as main water source. Fig. 2 shows that RW is preferred by people and rated as the best quality water source for both GW users and TW user groups. RW is also a popular drinking water source in the Mekong Delta with positive characteristics of color, taste and smell (G. J. Wilbers et al., 2013b). However, the quantity of RW is not enough for people's demand during the dry season when they only can collect and store rain water in few and rather small containers (Li et al., 2016).

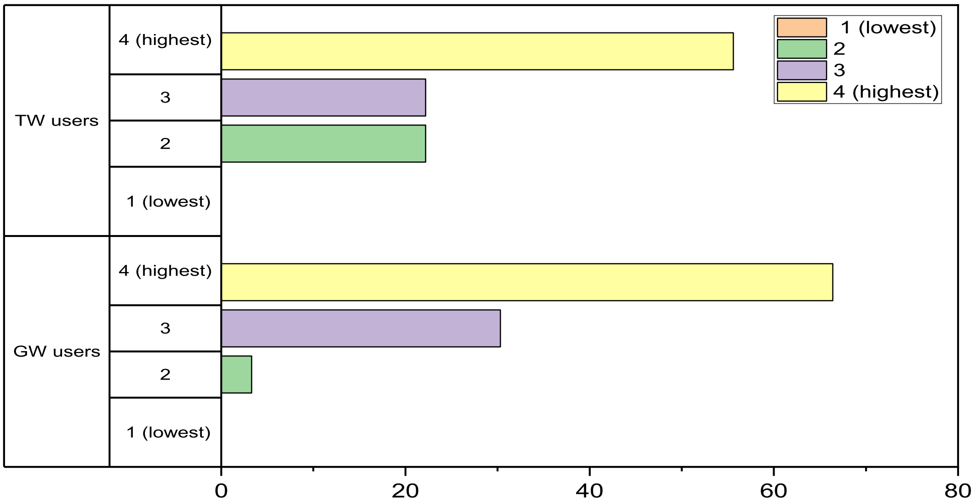

Fig. 3. Importance level of groundwater in 2 groups of households.

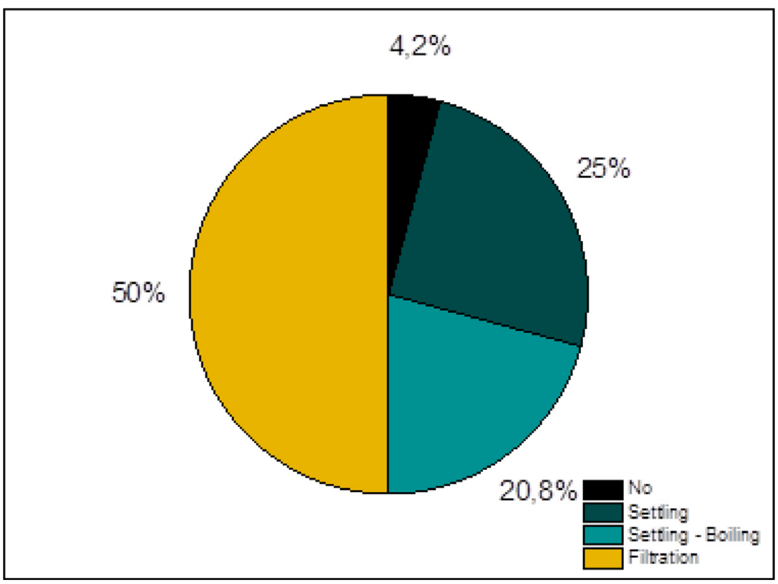

Fig. 4. Treatment practices for groundwater before using for the purpose of drinking.

3.3. Groundwater quality at the locations where GW is used for the purpose of non-drinking and drinking

Since the scientific assessment of water quality through proper measuring equipment is not an option for most of the people in CMP, their decisions and actions in using water depend on their individual gustatory and olfactory senses. According to feedback from residents through interviews, when people perceive strange water quality in regard to taste, color or odor, they will not use GW for drinking. According to the findings of Bauer et al. (2022), the analysis of water samples regarding EC, reveals that certain GW does not meet the necessary standards for direct consumption as drinking water. The graphical representation in Fig. 5 presents a comparative analysis of water quality parameters (as discussed in Chapter 2.3) in areas where GW is used for drinking purposes (blue boxplot) and areas where GW is not utilized for drinking (red boxplot). In general, values where GW is used for non-drinking purpose have a wider range and there are more outliers in the plot. The depth of the GW extraction wells also has to be considered to know which aquifer households use for each purpose. The median depth of 120m for both groups correspond to the upper-middle Pleistocene aquifer qp2-3, which is the common aquifer on a household wells in Ca Mau, accounting for 63.37% amount of exploitation based on the estimation of GW model (Hoan et al., 2022). However, non-drinking purpose wells have few exceptions with deeper wells. This indicates that the depth is not extremely important, this also agrees with Bauer et al., 2022 who identified that water chemistry is more a regional feature rather than a vertical one.

On the one hand, the results state that most samples for non - drinking purpose (red boxplot) show that EC and pH parameters met the regulatory limits. However, many water samples in the study area show concentrations of NH_4^+, B, Fe^{2+}, Ba^{2+}, Na^+, Cl^-, SO_4^{2-} exceeding the threshold value for drinking water in Vietnam (Fig. 5). Due to the noticeable strange taste, color or general appearance of these samples, households evaluated their quality poorly, and thus, did not choose them as a source of drinking water. Non-drinking water have higher pH, also correlated with EC. There are some dependent variables of high EC, mostly Cl^-, pH, SO_4^{2-}, Na^+, $Ca^{2+}$and B. It is interesting that NH_4^+ is higher in the group of samples with higher EC. This could probably support the assumption that presumably contaminated saline GW from the shallow aquifer is leaking into deeper aquifers (Bauer et al., 2022).

Regarding the "easy-to-detect" water quality parameters above, GW samples utilized for drinking purposes (blue boxplot) are comparatively superior to the water quality of samples not used for drinking purposes, as depicted in Fig. 5. However, further investigation into the questionnaires is necessary to explain this result, as there are some exceptions that require deeper analysis.

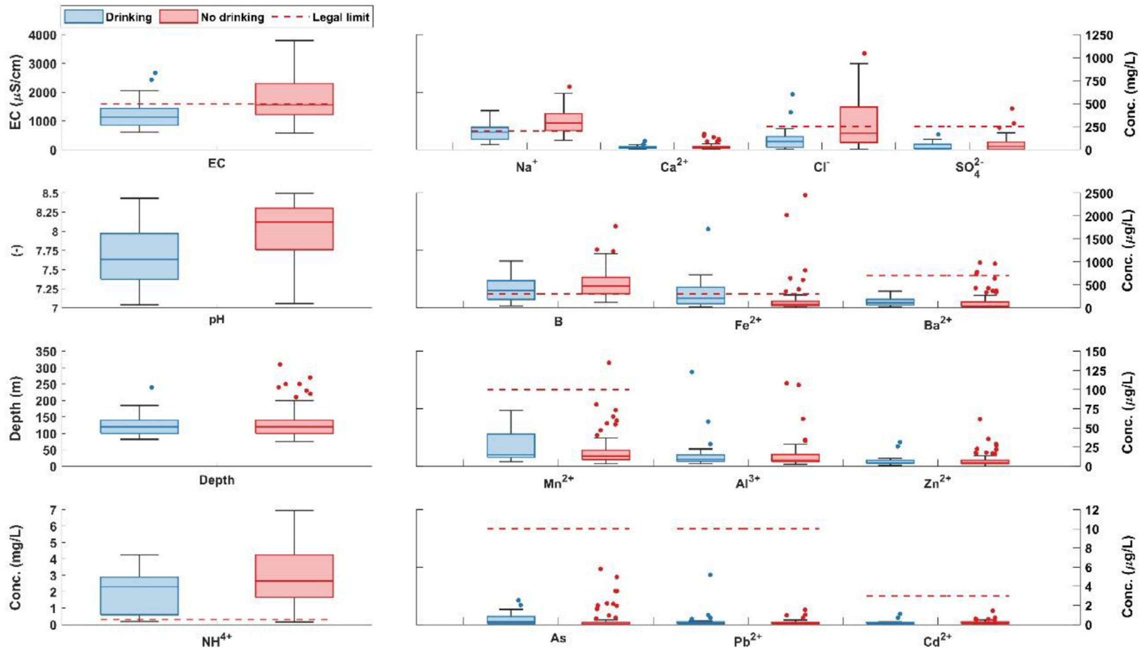

Fig. 5. Groundwater quality at the locations where GW used for the purpose of non – drinking (red boxplot) and drinking (blue boxplot).

For samples with iron (Fe) concentration exceeding the standards (>0.30 mg/L) that people use for the purposes of drinking, people also have different ways of treating GW before consumption as drinking water source. Seven of them use treatment methods before consumption. Of those two households use sedimentation, three use sedimentation with filtration and boiling, and two use a mini filtration system. Two households do not use pre-treatment and rely on other sources like RW and BW for drinking, using GW only as a backup in emergencies.

In the case of samples with Boron (B) levels exceeding the permissible limit (>0.30 mg/L), 15 samples were found to exceed the limit. Among these, two samples were consumed without any pre-treatment, five samples were settled, two were boiled, five were filtered, and one sample was obtained from a water treatment plant. Unlike iron, Boron is a substance that has minimal impact on taste and is challenging to detect for the households by themselves.

For Sodium concentration, there are twelve households exceeding the standard (>200 mg/L). At the same time all twelve households have Boron concentration exceeding the standard, too. Of these twelve samples, one is from a water plant. Two households do not use any measure before using the GW because these households use mainly RW and BW as their primary drinking source, GW is an additional option for them in case of emergency. The other four households are using sedimentation and they also use additional sources for drinking, like RW and BW. Two households boil water, three households treat water with filtration systems and they do not use any other water sources. When households use treatment for GW, it could be assumed that they intend to increase the water quality before they use it for drinking water source.

Similarly, in a household with Chloride concentrations exceeding the standard (>250 mg/L) (concentration of Sodium, Boron also exceeds the standard), there are two locations. One household has a professional water treatment system, filtration and UV disinfection to treat water after extraction and distribute water as a supplier of potable water. Another household uses only a small amount of GW for drinking; they also use BW (filtered water) and RW instead.

Households using GW for both, cooking and drinking purposes, often have high water quality, with chemical parameters in the range of permissible limits. Biological parameters can be discussed further in future studies. For those households that use GW for drinking purposes but do not have good enough water in terms of quality, when digging into the discussion, it could be realized that they only use very little amount of GW for this purpose. In addition, they also have a different amount of water from rain or bottled water as main sources, or they will treat GW with different treatment before use, depending on their ability (Table 2). It is suggested by previous studies that people in CMP should treat GW before drinking (Ha et al., 2022). However, treatment for GW has to be appropriate with current water quality.

People have a certain perception of GW quality leading to their different usage behavior. Therefore, people's perceptions as well as their stories need to be discussed more to find out about what factors can affect their water use habit, perhaps convenience and applicability of water sources, available alternative water sources and economic conditions.

3.4. GW quality of households where GW is perceived as best water resource

Through their perceptions, people identify some uncertainties in the quality of the water they use. It can be said that the perceptions of the people and their responses are important factors in determining water quality as well as the role of GW in people's life and the status of GW extraction.

Figs. 6 and 7 shows that most samples, which are perceived to have the best water quality, adapt with QCVN standards. There are not so many samples to parameters over the thresholds. For each situation there will be a reasonable explanation in Table 2.

For households whose water samples exceed the QCVN standard for Boron, the first sample is from a restaurant. Assuming that the quality of all types of water is same, they use a large amount of GW daily for restaurant business (400 – 500L/day). GW use brings financial benefits to the household at a very low cost, therefore GW is still the best water source in their situation. The remaining three out of five samples from households are using GW as the main source of water for drinking. They believe in the quality of their current water source because two households use a mini-filtration system for private households and one household is a supplier of potable (bottled) water with a professional treatment system. The fifth household uses a sedimentation method. This household still uses GW and RW in combination because of the low cost although TW is available. When RW runs out in the dry season,

Table 2
Reasons why households still appreciate GW although some parameters of GW samples do not meet the standard.

Group	Reasons	Extend explanation for the reasons
GW as drinking water source	Use of basic water treatment before utilization (settling, boiling, filtering via cloth) before drinking	The traditional practices of water treatment brings a sense of assurance regarding the quality of the treated water, thus rise a level of confidence of household when they use GW for drinking.
	Use of mini filtration system at home before drinking	People trust in the water treatment quality of modern filtration devices as advertised.
	Use of professional water treatment system (for private water supplier) before drinking	GW sample is an input of professional water treatment of private water supplier. They treat GW then distribute water bottles to households nearby.
	Use of professional water treatment system (for water station) before drinking	GW sample is an input of professional water treatment plan which is designed for specific GW to guarantee the output can be delivered to people and used for all purposes.
	Use of rain water or tap water mainly, GW is only used in case of emergency	GW is only used with a small amount if people is lack of other water sources (TW, RW). GW is not the first priority water source in these cases.
GW as the best water source	Do business with high amount of water utilization (restaurant, shrimp farm)	People use a considerable amount of water for their business operations. GW has the lowest cost and meets their business water usage demands.
	Use of professional water treatment system (for private water supplier)	GW is an essential input for professional water treatment by private water suppliers. It directly relates to their economic benefit and becomes a significant source of their income.

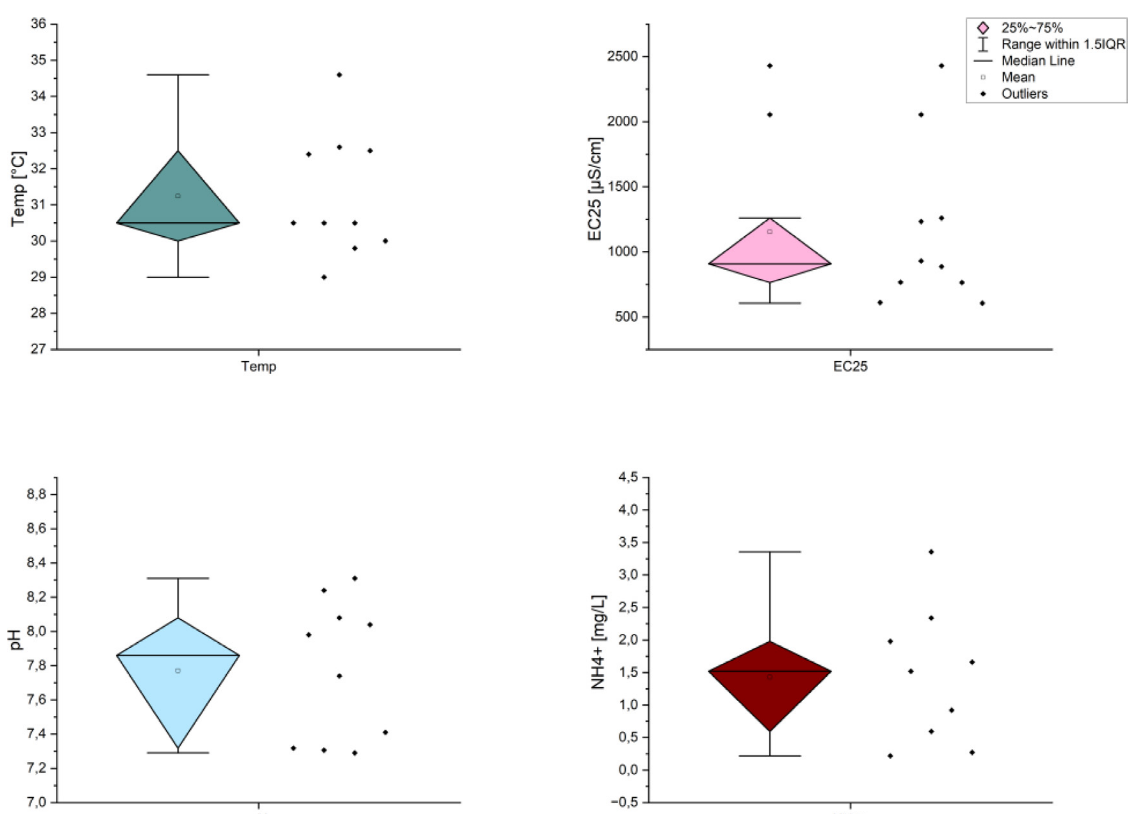

Fig. 6. Groundwater quality at the point of GW as best water source (in people opinion) (Temperature, EC25, pH, NH_4^+).

the main water source could be GW. The last household does not use GW for drinking purposes, GW is used as the main source of water, not only for washing and cooking purposes, but also in shrimp farming. Each month, the household uses much electricity to pump underground water up and the electricity bill to pump groundwater reach to 9.000.000 -10.000.000 VND/month (391 USD to 434.8 USD). GW is used for work that generates a large income for the family, so it is appreciated for its quantity and quality.

Only two samples have chlorine content exceeding the standards. Both use GW as main water source and apply modern filtration systems before use. One uses a mini-filtration system for the household and one uses a large filtration system for bottled water production and distribution. This also explains the simple reason that although the original water quality is not good to reach the standards, GW is mainly used and still is be the best water source.

Depending on the different cases, people always have their own reasons to choose which water source they consider to be the best, even though the water quality does not meet the standards of domestic water. The quality of GW and RW is highly appreciated, but RW has a great limitation in terms of inadequate water storage volume, so it is still used

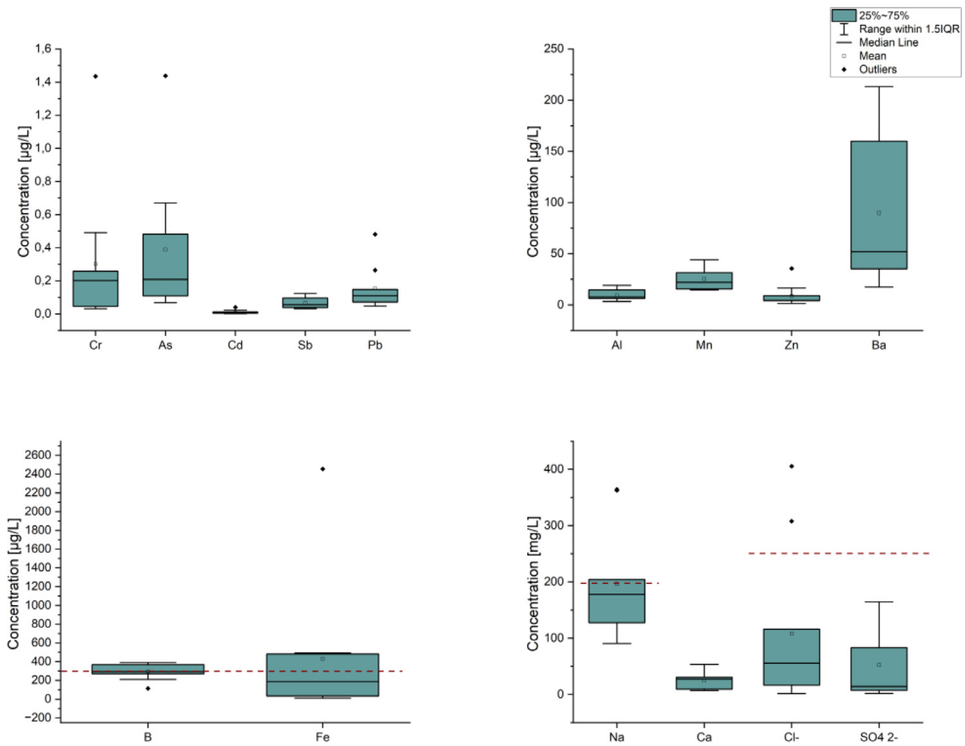

Fig. 7. Groundwater quality at the point of GW as best water source (in people opinion) (other parameters).

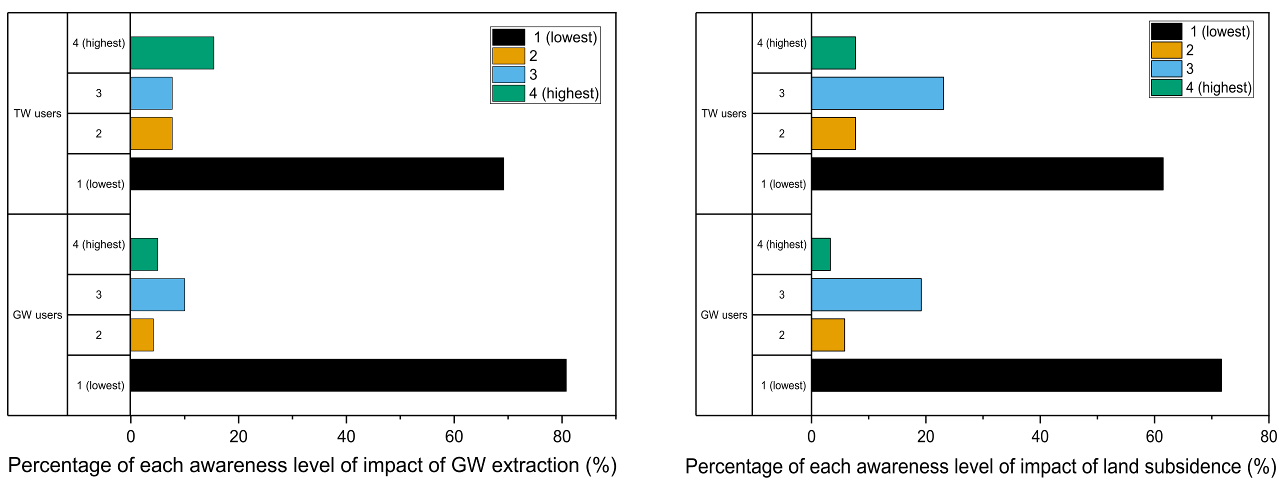

Fig. 8 & 9. Awareness level of people with impact of GW extraction and land subsidence state.

only in the rainy season, in general GW is preferred in comparison with rain water. Seemingly unlimited availability is a strong positive aspect of using GW in people's opinion.

3.5. Evaluation of people awareness about the impact of groundwater extraction on land subsidence

Changing people's living habits is not simple. The priority of this study is to understand people's thoughts and perceptions of their issues. The next question in the questionnaire sheds further light on people's awareness of land subsidence impact and the effects of excessive GW extraction. Most of the people have low or extremely low awareness of these two problems as shown in Figs. 8 and 9.

In the two questions on the awareness issue, the number of households is also divided into two groups as in the previous part: GW users and TW users. According to the results collected, 80.8% of GW users had the lowest level (level 1) of awareness of the impact of GW extraction, 69.2% for the TW users group. With the highest level of awareness about the impact of GW extraction, the GW users group only has 5.00% of the households at this level, while TW users group has 15.4%.

Similar to the question of people's perception of land subsidence in Ca Mau, the level of awareness among GW users on this issue from level 1 to level 4 was 71.7%, 5.8%, 19.2% and 3.30% respectively. As for the TW users, the level of awareness of the people is higher with the rate from low to high of 61.5%, 7.70%, 23.1% and 7.70%.

In general, respondents in this study mainly are not aware of the impact of GW extraction as well as land subsidence in Ca Mau. The level of awareness of people about these issues is extremely low and needs to be promoted. In addition, the importance of GW to people's life is extremely high (Fig. 3), which could lead to a low level of awareness.

The opinions about the importance of GW and people's awareness of excessive GW extraction as well as land subsidence show an inverse relationship. The more people depend on groundwater use, the harder it is to pay attention to the issues surrounding excessive groundwater extraction. Similar to the farmers in the Red River Delta, people do not have the intention to adapt to climate change when they do not realize any threat to their life and health (Luu et al., 2019). Currently, GW plays an important role in people's lives, while their awareness of overexploitation and land subsidence in Ca Mau is limited, it leads to the lack of attention to climate change issues. According to Eslami et al. (2021) inadequate understanding of environmental systems and processes in the Mekong Delta results in misinterpretation of socio-environmental aspects, ineffective policymaking, and an uninformed public opinion. The latter aspect is important, as only a well educated and informed society may accept change in their daily life.

It can be seen that the TW users and GW users object groups have quite different answers, although the number of TW users' questionnaires is still small compared to GW users. For the next study, it is necessary to expand the number of TW users and focus on making a case study in an area that contains both two subjects for deeper comparison.

The proposed alternative water sources should also be analyzed and applied to each condition, considering the advantages and disadvantages of this water source for each area to get the most accurate results. RW is mentioned frequently in the answers of households as potential alternative water resources. Research on how to overcome the disadvantages of RW subtraction is also very interesting when RW has gained the interest of the people using it.

4. Conclusion

This study has created a general picture of the Ca Mau household's GW using habits. The research approach of evaluating ground water quality parameters and then going into detail about each response of the people has shown more closely and explained the analysis results as well as the connection between the survey and sample analysis data.

The study shows the opinions of households concerning GW use habits based on questionnaires that are reasonably collected according to the spatial and social condition distribution. These results do not claim to be statistically representative for the whole CMP population, however, it is a crucial first step in the evaluation of GW use habits in CMP. GW plays an important role in people's life, it is used for washing, cooking and other activities (restaurant business, shrimp farming, bottled water business, etc.). Depending on the people's perception of different GW qualities, they use GW for different purposes. People estimated the water quality through their perception without knowing the water quality though professional analysis techniques. For important and direct health-related purposes such as cooking and drinking, people have to prepare and treat GW as well as provide alternative water sources to GW if they feel that the water quality is inadequate. As people become more dependent on groundwater (GW users), their awareness of the potential impacts of GW extraction becomes less, and the importance of GW in their lives increases. Besides, people do not have much awareness about land subsidence processes in Ca Mau in general and especially about the potential, that GW extraction can be a major factor for land subsidence. If people have more options to use water, such as TW users, habits of use or dependence on GW as well as their perception of the harmful effects of groundwater extraction change. This opens a research direction to find potential alternative water besides tap water to meet the needs of the people - as a solution to reduce the current excessive exploitation of GW.

Author contributions

Van Cam Pham: Conceptualization, Methodology, Investigation, Formal analysis, Writing - Original Draft, Visualization. **Jonas Bauer:** Investigation, Writing - Review & Editing, Visualization. **Nicolas Börsig:** Investigation, Writing - Review & Editing, Project administration. **Johannes Ho:** Investigation, Review & Editing. **Long Vu Huu:** Investigation & Review. **Hoan Tran Viet:** Review & Editing. **Felix Dörr:** Review & Editing. **Stefan Norra**: Writing - Review & Editing, Supervision, Project administration, Funding acquisition

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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