

Article

Estimation of Groundwater Use Pattern and Distribution in the Coastal Mekong Delta, Vietnam via Socio-Economical Survey and Groundwater Modelling

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Abstract. In many provinces of Mekong delta, excessive groundwater extraction has resulted in many serious groundwater-related problems. To solve problems relevant to increasing water demand as well as other negative influence of groundwater depletion, an exigent question was raised whether at what time in future is the limits to local groundwater use reached? Hence, there is a need to know groundwater use (GWU) pattern and distribution in the study area for future groundwater management.

In this study, firstly, the study used socio-economic data of Tra Vinh Province to classify groups of gross domestic product (GDP) per capita, potential of water resources and population distributed in each district in order to design and conduct the socio-economic survey and to explore information relevant to GWU for each purpose. Secondly, the data set of 419 survey questionnaires per 9 surveyed communes were analysed by SPSS tool to estimate ratio of household using groundwater (RHHUG) for each purpose as well as average pumping rate (APR) per household for domestic use and per ha for agriculture use, respectively. Thirdly, the APRs were extended to propose the total GWU pattern and distribution during 2007-2016 by using socio-economic data of the province and expand to spatial distribution by using correlation with land surface temperature (LST) which was estimated from Landsat 8 images. Besides, the groundwater flow model of the study area was developed to verify the estimated amount of groundwater pumping (pattern and distribution) in the period.

The study found that the GWU of Tra Vinh Province in dry season of 2016 was 346,279 m³/d in which two coastal districts occupied more than 50 percentages, i.e., about 188,551 m³/d. RHHUG increased from 1.5 to 2 times during the period of 2007 to 2016 in this area. LST distribution performed a good correlation (adj-R² = 0.646) with GWU distribution in Tra Cu district. Results of groundwater modelling also showed that the discharge from aquifer (mainly pumping) was always higher than the recharge to aquifer.

Keywords: Groundwater use, pattern, distribution, groundwater modelling, field survey, land surface temperature,

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1. Introduction

Due to the growing up of population in the Mekong Delta Vietnam, surface water resources strained significantly due to saltwater intrusion, water shortage and other impacts of climate change in some recent years. Additionally, groundwater exploitation has increased dramatically and its result led to decrease groundwater levels and expand saline groundwater area which can be a serious menace to supply water for domestic in the Mekong delta. In addition, groundwater resources have played an important role in reducing the pressure of irrigation water supply for agriculture and aquaculture, especially during the dry season and in rural and coastal areas [1].

As other coastal provinces in Mekong Delta, Today, groundwater has been extracted for different purposes like in Tra Vinh Province. According to the report prepared by Provincial Department of Natural Resources and Environment (DONRE), there were only 121 abstraction wells which have been informed for the abstraction license until May 2018 with total of abstraction rate about 61,620 m³/d. However, it seems to have no clear aggregate picture or status of groundwater use by pattern or distribution, which makes a lot of difficulties to improve systematic management response to Tra Vinh Province. For these reasons, the understandings about pattern and distribution of groundwater use (GWU) plays a key part in ground resources assessment and management at the Mekong Delta in general and Tra Vinh Province in particular.

2. Materials

2.1. Study Area

Location and topography

Tra Vinh is a coastal province in southern Vietnam situated southwest of Ho Chi Minh City and lies on the coastal plain of the Mekong Delta between the coordinates of 9°31'46" to 10°04'05" latitude and of 105°57'16" to 106°36'04" longitude (Fig. 1). The natural area is 2.358,2 km²; the population is 1,040,500 people, occupying 5.8% of the area and 5.8% of the population of the Mekong Delta. Tra Vinh has 7 districts and 1 city, including Cang Long, Tieu Can, Cau Ke, Chau Thanh, Tra Cu, Cau Ngang, Duyen Hai and Tra Vinh. The topography of Tra Vinh Province is mainly flat, with an elevation range between 0.1 and 10.4 m MSL. The higher elevations are mainly located close to the coastline, while the lower lands are in the central part of the province.

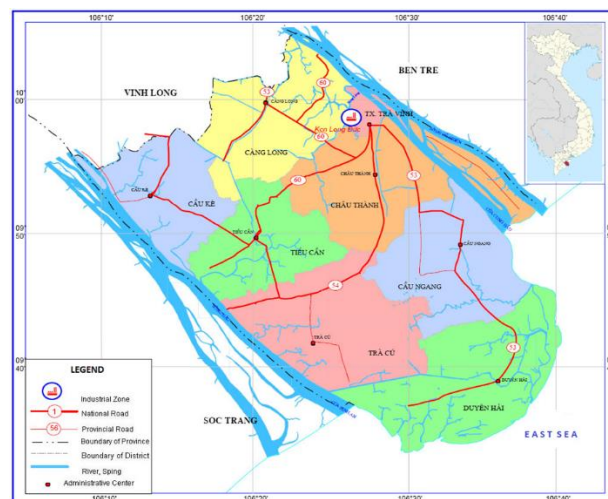


Fig. 1. Topography of the Saigon River Basin.

Climate

Tra Vinh is on tropical monsoon region, hence, two main seasons can be defined: a wet season from May to October, dominated by the Southwest monsoon; and dry season between November and April, dominated

by the Northeast monsoon. The weather is hot around the year with temperatures are relatively constant through the year with an average of 26°C. The annual rainfall data indicates a spatial variation within Tra Vinh Province. The annual rainfall varies from 1,400 – 2,400 mm/year, unevenly distributed in the year with more than 90% of the annual rainfall is in rainy season.

Hydrology and hydrogeology

Tra Vinh has a dense network of rivers and canals with two large rivers, Co Chien and Hau Rivers, along with a system of canals that provide water to the fields. The main canals are evenly distributed in the province, with the density varies from 4 to 10 m/ha. The tide is the cause of salinity intrusion into the interior, changing the quality of water in the direction of increased salinity.

There are eight distinguished aquifers in Mekong Delta, namely Holocene (qh), Upper Pleistocene (qp₃), Upper- middle Pleistocene (qp₂₋₃), Lower Pleistocene (qp₁), Middle Pliocene (n₂₋₂), Lower Pliocene (n₂₋₁), Upper Miocene (n₁₋₃) and Upper-Middle Miocene (n₁₂₋₃) aquifers. Generally, lithology of each aquifer consists of fine to coarse sand, gravel, and pebble [2]. Because of interconnection with land surface or surface water, groundwater of shallow aquifer has low-quality basically [3].

General socio-economical information

Surrounded by Tien and Hau Rivers and long coastlines, agriculture and aquaculture are main activities of Tra Vinh Province which occupied 185,868 ha and 51,600 ha, respectively. According to the Tra Vinh authorities, the economic growth of the province was around 11.64% in the period of 2006 to 2010. In the last 5 years, the agricultural economy of the province developed moderately, the industrial production value reached 35,528 bil.dong, an increase of around 4.62%/year at current prices, accounting for 36% of the total production value. The structure of agricultural production value shifted towards reducing the proportion of cultivation and husbandry, increasing the proportion of fisheries corresponding with the development orientation of the province. Therefore, Tra Vinh Province is a region with increasing high pressure derived from human activities, where most of the land cover has been modified and is used for agriculture and fisheries.

2.2. Groundwater Use Reviews

Not only use for domestic, but groundwater also shared supply with surface water for aquaculture and industrial purposes in this study area. Total amount of groundwater abstraction in Tra Vinh Province is 187,685 m³/d in 2007 [4] and the quantity of groundwater was exploited for domestic activities to increase every year by growing up of number of HH using groundwater and average rate as well (Fig. 2).

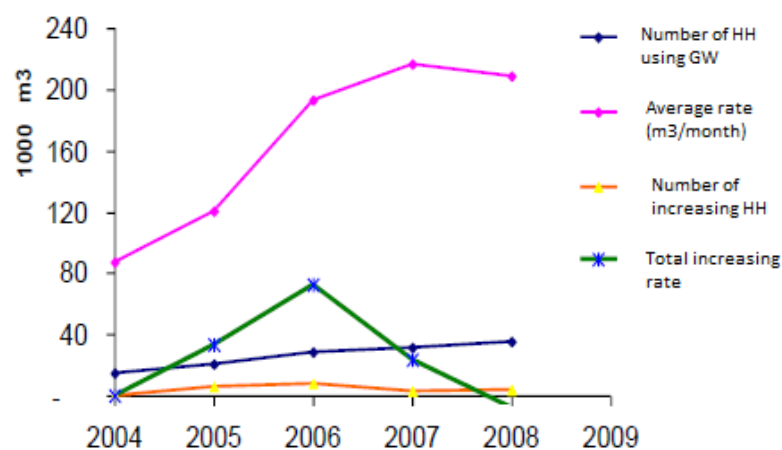


Fig. 2. Number of HH using groundwater [4].

In 2010, it is reported that 245,920 m³/day was abstracted in whole province of which, abstraction amount from wells with capacity ≥ 200 m³/day is 53,200 m³/day and that of wells with capacity < 200 m³/day is 200,720 m³/day (Table 1). Groundwater was mainly abstracted in qp₃ and qp₂₋₃ aquifers, a small amount was exploited in qp₁ aquifer, and other aquifers (n₂₋₂, n₂₋₁ and n₁₋₃) were not exploited. Total number of abstraction

wells is 88,927 wells, of which number of well with capacity ≥ 200 m³/day is 114 wells (official wells*) and that of well with capacity < 200 m³/day is 88,813 wells (non-official well**) [5].

Table 1. Statistics of abstracted wells in Tra Vinh Province in 2010.

No.	Aquifer	Groundwater abstraction (m ³ /day)		
		Official well ≥ 200 m ³ /day	Non-official well < 200 m ³ /day	Total
1	Holocene (qh)	0	7,800	7,800
2	Upper Pleistocene (qp ₃)	0	73,920	73,920
3	Middle Pleistocene (qp _{2,3})	42,000	119,000	161,000
4	Lower Pleistocene (qp ₁)	3,200	0	3,200
Whole province		53,200	200,720	245,920

*official well: wells were licensed to exploit groundwater by DONRE

**non-official well: wells were not licensed to exploit groundwater (mainly made by local households)

3. Methodology

In order to estimate pattern and distribution of GWU in Tra Vinh Province, firstly the socio-economic survey was conducted to assess population increase, revenue, land use and water resources issues, especially information relevant to groundwater use for different purposes. Secondly, the survey data was classified and calculated baseline of GWU per each household (HH) and farming area as well as ratio of household using groundwater (RHHUG) to interpolate to other zone. Thirdly, the spatial distribution of groundwater use was estimated by using correlation with land surface temperature (LST) which was estimated from Landsat 8. In addition, a local groundwater modelling was developed to verify the estimated groundwater abstraction distribution of each district and aquifer by comparing computed piezometric heads with the observed data. Figure 3 describes the framework of groundwater use estimation process with sub-objectives and tasks in this study.

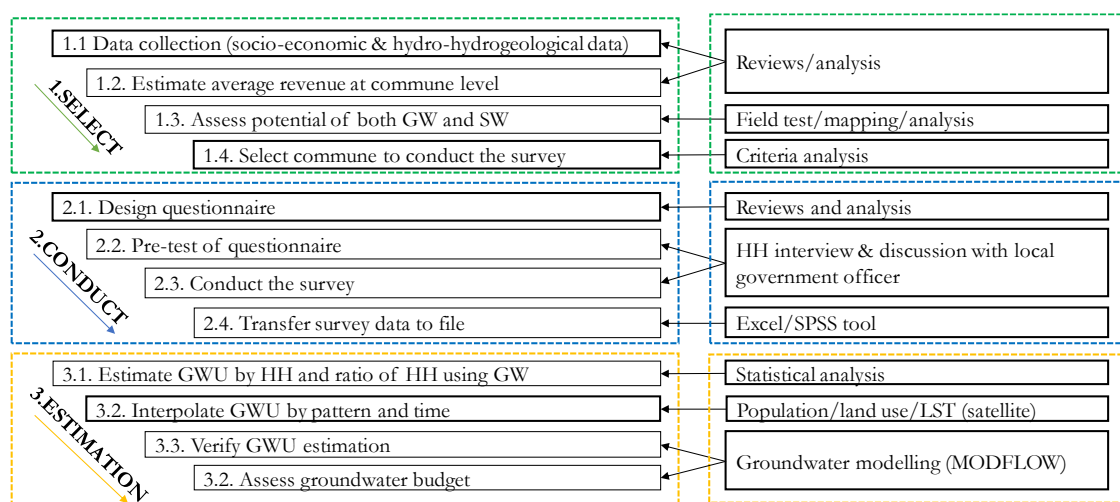


Fig. 3. Framework of this study.

3.1. Socio-Economic Survey

Commune survey selection

As the Mekong delta is characterised with high heterogeneity in both natural conditions including groundwater salinity, 3 different districts were selected for the socio-economic survey to ensure sufficient coverage of local communities with diverse dependency on groundwater to allow understanding local pattern

and distribution of groundwater use. The commune selection criteria included assessment of average revenue of local people and status of groundwater and surface water use.

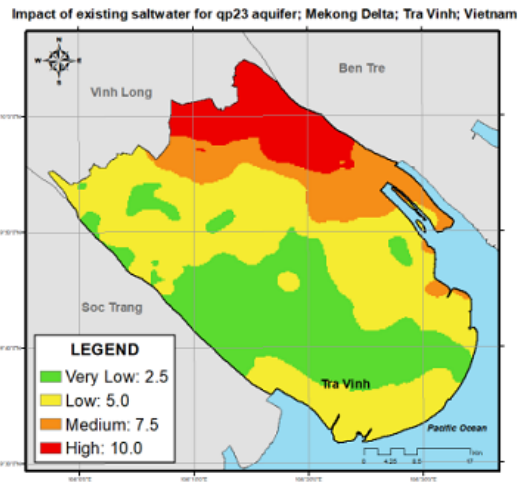


Fig.4. State of existing saline groundwater parameter rating using the electrical conductivity.

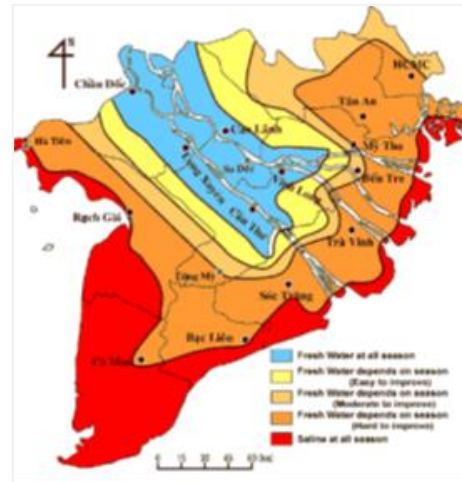


Fig. 5. Saline intrusion in the Vietnam Mekong Delta (VMD) [6].

To assess the existing saline groundwater in the study area, the EC (electricity conductivity) test was conducted with totally 751 testing locations and then spatial distribution of the groundwater EC values by using Ordinary kriging. As electrical conductivity (EC) was used to assess the state of existing saline groundwater, the pattern of the indicator “i” is very similar to the EC interpolations previously presented in this study [7]. The interpolation of the middle Pleistocene aquifer (qp₂₋₃) is the most reliable of the three aquifers which was conducted EC campaign. It also presents the highest EC values and gradients, in this case, the north-south gradient observed in the other aquifers has a NE-SW component. Brackish and saline groundwater is presented only in the northern part of the aquifer study (Fig. 4)

For the surface water, the province can be separated into three regions, namely in the upper zone, the middle zone and the coastal zone. In the upper zone, freshwater is either available at all seasons or depending on the season (see Fig. 5). Whereas in the middle zone and coastal zone, they are coping with brackish water and saline intrusion. In addition, Fig. 5 also shows that the coastal zone is saline throughout all seasons. Saline intrusion status of both groundwater and surface water were combined to show 5 zones which have different potential water resources as:

- Easy to improve SW + Fresh GW (ESFG)
- Easy to improve SW + Saline GW (ESSG)
- Hard to improve SW + Fresh GW (HSFG)
- Hard to improve SW + Saline GW (HSSG)
- Saline SW all seasons + Fresh GW. (SSFG)

Based on the report of Party Congress at the commune level in 2015, three levels of gross domestic product (GDP) per capita were determined as high (GDP) per capita (> 30 mil.dong/year), moderate (GDP) per capita (20 - 30 mil.dong/year) and low (GDP) per capita (<20 mil.dong/year). Nine communes were selected by the classification of commune revenue and water resources potential to satisfy the survey which can cover five zones and three levels of (GDP) per capita (see in Table 2).

Questionnaire and survey design

The questionnaire was developed on the basis of GWU in each demand and past studies. The questionnaire was used by the interviewer to collect (through face-to-face interview) information from interviewees (i.e., selected respondents from local communities for the survey) for conducting a socio-economic survey. The survey was conducted during 19 to 29 March 2018 by 6 members of the survey team from Division of Water Resources Planning and Investigation for the South of Vietnam. Before implementing survey at each commune, the discussion was conducted with local authorities to get an overview about water use and land use in the local and to ask the head of each village to pick up interviewers to household for surveying. Six villages per each commune were randomly selected to conduct the survey (if the commune has not less than

6 villages). The interviews were mostly conducted with the heads of households. 419 questionnaires were interviewed: average about 47 households in each of the nine communes (see questionnaire distribution in Fig. 6).

Table 2. General information of selected communes.

Commune name	Population (person)	Area (ha)	Agriculture area (ha)			GDP/capita	Potential of WR
			Paddy	Perennial crops	Aqua-culture		
My Cam	11,832	2,298	1,006	1,053	0	High	ESSG
Huyen Hoi	14,244	3,473	2,521	577	4	Moderate	ESFG
Dai Phuoc	9,520	2,008	409	872	2	Low	HSSG
Dinh An	5,444	592	168	19	4	High	HSFG
Thanh Son	9,592	1,415	884	160	4	Moderate	HSFG
Ham Giang	2,488	1,591	252	239	15	Low	HSFG
Long Huu	10,862	3,623	627	316	1,986	High	SSFG
Truong L. Hoa	5,560	3,751	4	399	3,298	Moderate	SSFG
Dan Thanh	7,069	4,134	1,230	408	1,248	Low	SSFG

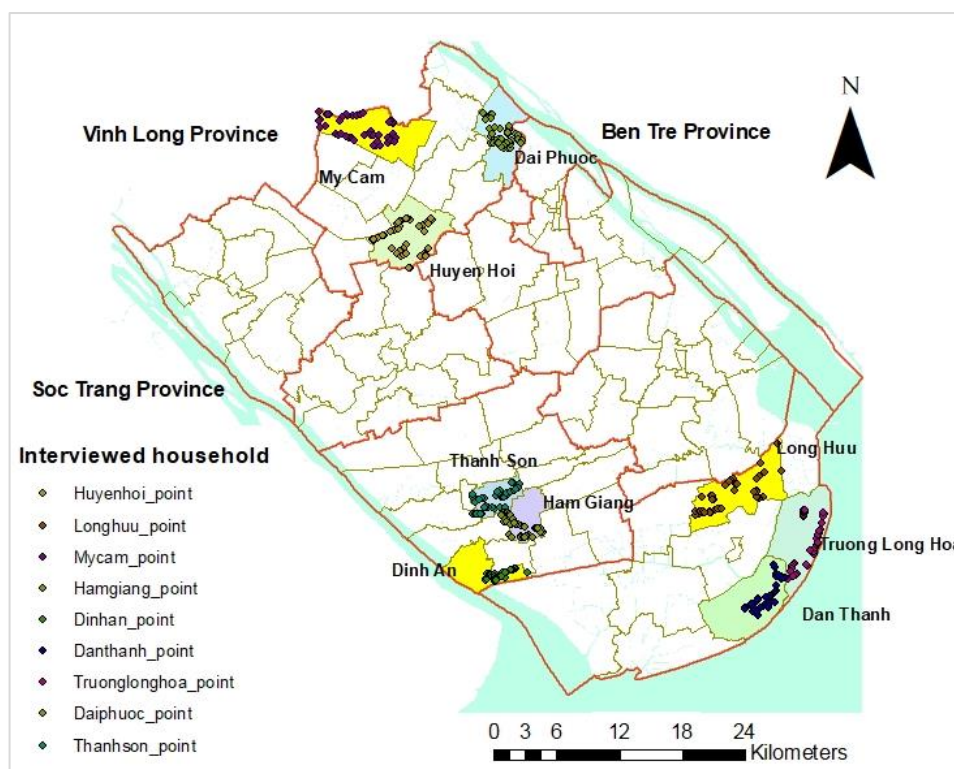


Fig. 6. Distribution of interviewed household.

Survey data analysis

SPSS tool was applied to analyze statistics of the survey data by group classification. Domestic group are formally represented water supply consumption and groundwater pumping by own well. Ratio of HHH using groundwater and average pumping rate was calculated to interpolate to whole of district and others using population data. Besides, agriculture group explained irrigation or groundwater abstraction rate which depend

on crop and seasonal. Average pumping rate per ha and ratio of HH using GW for agriculture purposes were calculated to interpolate to be used in other parts based on land use data.

3.2. GWU Interpolation to Other Non-Survey Area

GWU (individual) extrapolation to total by classifications

Ratio of household using groundwater (RHHUG) and average pumping rate of nine survey communes were applied to interpolate for other districts which have same of potential of water resources. Besides, ratio of household using groundwater by each year from 2007 to 2016 was estimated by linear regression between ratio of the survey and the previous ratio of Sanh (2010) [4].

GWU expand (individual) to spatial distribution by using LST distribution (Landsat 8)

The land surface temperature (LST) is the temperature of the Earth's surface as derived from remotely sensed thermal infrared data [8]. The Landsat 8 LST was computed by fusing images of MODIS LST and Landsat 8 brightness temperature (Tb), provided by Hazaymeh and Hassan (2015) [9]. In Tra Vinh Province, most of abstraction well located in household area of near household area which was used for the agriculture demand of some annual crops or in some sand dunes along the coastal line. Barren land with high accumulation of sandy soil or the conversion of land from vegetated area to build up area indicate the highest LST value [10]. Therefore, land surface temperature (LST) distribution can be applied to estimate the distribution of GWU in rural areas (to improve the pumping package of groundwater model) where there are limits data of household distribution as well as land use.

Verify GWU estimation by using groundwater modelling

In the last section, the ratio of number household using groundwater (RHHUG) was identified by linear regression between ratio in 2007 [4] and the ratio in 2016 of the survey. During the groundwater model calibration process (groundwater model development will be explained later), RHHUG of each district used the estimated pumping from LST distribution by annual and seasonal and simulated piezometric heads were checked with the observed data.

3.3. Groundwater Modelling Process

Groundwater modelling has become a very important process in managing groundwater resources. Over the past forty years, it was considered to be one of the primary tools, which was used to understand groundwater flow and seawater movement in coastal aquifer [11, 12]. A transient groundwater flow model (GMS-10.2) was constructed to verify amount of groundwater pumping (pattern and distribution proposed) from 2007 to 2016 using boundary conditions from the regional groundwater model, which covered whole of Mekong Delta area [5]. The domain of the model has an area of 2,215 km². The hydrogeological conceptual model was simulated by 15 layers in which consists of eight aquifers separated by seven aquitards. In this model, the aquifers and aquitards are anisotropic a heterogeneous [2]. The model grid was divided by 135 rows and 151 columns with a uniform grid size of 500 x 500 m. The layers of 2, 4, 6, 8, 10 and 12 represented for aquitards or impervious layers. Layers of 1, 3, 5, 7, 9, 11 and 13 represented for aquifers qh, qp₃, qp₂₋₃, qp₁, n₂₋₂, n₂₋₁, and n₁₋₃ respectively. Seashore lines in the west and east were specified head boundaries. General head boundaries were assigned at the distribution boundaries of aquifers qh, qp₃, qp₂₋₃, qp₁, n₂₋₂, n₂₋₁, and n₁₋₃. The absolute average elevations of groundwater level (in monthly) at the points on the specific head and general boundaries were interpolated from absolute average groundwater level at the nearest observation wells and piezometric heads from the regional model [5].

Geostatistical tools (GMS) was applied to simulate hydraulic conductivity distribution of 15 layers. The potential recharge zones in a spatial scale was produced based on the analysis, field and laboratory results, and available data used in Tra Vinh Province [13]. The potential amount of recharge can vary from 8% to 12% of total annual precipitation. The water levels were simulated by using the surface water model [14] to input by river and canal nodes in the groundwater flow modelling. Additionally, the limited river conductance from previous model [15] was interpolated to other river and canal sections by the function of interaction parameter and ratio of wetted parameter [16] to simulate the river leakage of the first aquifer. From upper

estimation, initial groundwater abstraction of each district and aquifer was by year and seasonal from 2007 to 2016.

4. Results

4.1. Groundwater Use (GWU) Estimation (Individual)

Domestic group

Most households still have used own groundwater well for domestic, it occupied around 80 percentage of total number of households in coastal zone. In northern district, RHHUG is lowest; around 23 % as Huyen Hoi commune, some of communes even did not use groundwater due to high salinity concentration of groundwater in this part. Average pumping rate (APR) per household (HH) varied from 1.05 m³/HH/d to 2.05 m³/HH/d and its trend increased from northern part to coastal part (Table 3).

Table 3. Calculation of GWU for domestic use in 9 survey communes.

Commune name	Number of HH survey	Bottle water		In-house tap water		Own well	
		RHHUG (%)	APR m ³ /HH/d	RHHUG (%)	APR m ³ /HH/d	RHHUG (%)	APR m ³ /HH/d
My Cam	47	0	0	0	0	0	0
Dai Phuoc	46	0	0	0	0	0	0
Huyen Hoi	47	23	0.007	49	0.191	87	1.054
Thanh Son	47	38	0.005	45	0.189	74	2.204
Ham Giang	45	45	0.003	47	0.374	84	1.872
Dinh An	47	17	0.005	74	0.503	43	1.800
Long Huu	47	72	0.006	45	0.297	91	3.424
Truong L. Hoa	48	79	0.004	43	0.256	85	3.736
Dan Thanh	45	89	0.007	38	0.617	84	4.380
Average	46.6	40	0.004	38	0.270	61	2.052

Agriculture group

During dry season, groundwater was exploited much more to balance salinity of aquaculture farm in coastal and near coastal zone. Abstraction time always was gained continuously 15 to 20 days during salt intrusion period with average rate over 4.36 m³/d/ha (total 41.8 m³/ha of whole farming season). On the other hands, groundwater is main irrigation source of some annual crops such as water melon, pepper, onion, etc., in duration from January to April of the dry season. The calculation showed that the APR for irrigation of some annual crops was about 30 m³/d/ha (as in Table 4).

Table 4. Calculation of GWU for agricultural use in nine survey communes.

Commune	Aquaculture		Irrigation	
	RHHUG (%)	APR (m ³ /ha/d)	RHHUG (%)	APR (m ³ /ha/d)
My Cam	0	0	0	0
Dai Phuoc	0	0	0	0
Huyen Hoi	0	0	0	0
Thanh Son	0	0	93	24.84
Ham Giang	1.50	3.69	95	33.38
Dinh An	1.60	4.58	91	32.06
Long Huu	1.80	3.60	97	30.83
Truong Long Hoa	1.90	4.22	98	26.98
Dan Thanh	2.60	5.73	97	32.19
Average	1.88	4.36	95	30.05

Groundwater use interpolation to other non-survey area

The study investigated the correlation between the estimated groundwater use (GWU) by statistic data including number of HH and land use at the commune level of Tra Cu district and estimated GWU by land surface temperature (LST) from Landsat 8 Image (acquisition date 2-22-2014). The correlation reveals that GWU estimation using LST distribution shows a statistically significant positive correlation to the GWU estimation using statistical data ($\text{adj-R}^2 = 0.646$) (Fig. 7).

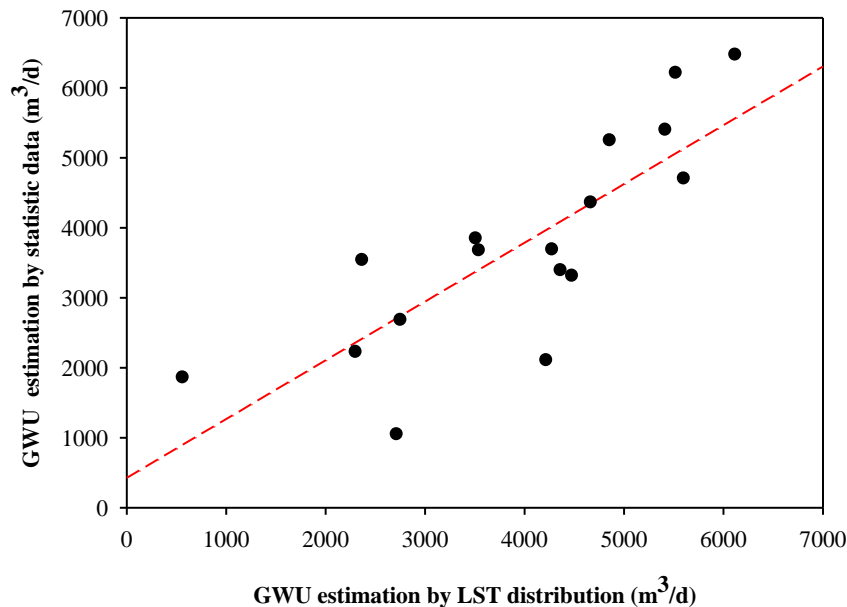


Fig. 7. Scattered plot of GWU estimation in 17 communes of Tra Cu district by using statistical data and LST distribution.

Time series of groundwater use in the period from 2007 to 2016 was inputted to pumping package of the groundwater model. The result shows that piezometric heads presented closed fluctuation with the observed data in the period of 2014 to 2016. However, piezometric heads are still lower than the observed values (>1 meter) from 2007 to 2014 for both two aquifers (qp₃ and qp₂₋₃) (see red and black lines in Fig. 8). Thus, groundwater use at each certain seasonal of the period was adjusted more by changing the ratio of HH using GWU of the corresponding district to improve piezometric heads at some observed wells. As a result, the piezometric heads were improved significantly (see green and black lines in Fig. 8) with mean RMSE of RMSE of qp₃ and qp₂₋₃ aquifer varied from 1.103m to 0.090m and 0.620m to 0.253m, respectively (see detail in Table 5).

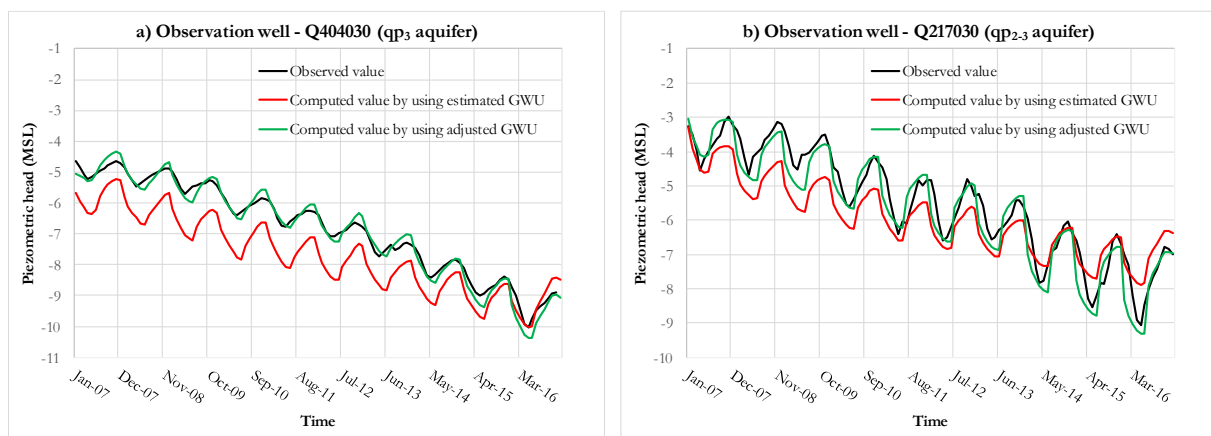


Fig. 8. Piezometric heads comparison by applying different GWU pattern and distribution.

Table 5. Errors comparison of piezometric heads by applying different GWU pattern and distribution.

ERROR, m		Aquifer qh		Aquifer qp ₃		Aquifer qp ₂₋₃	
		Estimated GWU	Adjusted GWU	Estimated GWU	Adjusted GWU	Estimated GWU	Adjusted GWU
MAE	Min	-1.718	-0.702	-0.030	0.000	0.028	0.019
	Max.	0.490	0.353	1.801	-0.808	1.657	1.482
	Mean	-0.860	-0.049	0.980	-0.245	0.678	0.384
RMSE	Min	0.000	0.000	0.001	0.000	0.001	0.000
	Max.	2.953	0.493	3.245	0.653	2.745	2.196
	Mean	0.967	0.221	1.106	0.090	0.620	0.253

Table 6 shows the corrected ratio of HH using groundwater via groundwater model calibration process. Due to salt intrusion in dry season, groundwater tends to be exploited more in coastal zone to satisfy domestic and agriculture demand. This is a reason why ratio of HH using groundwater in the coastal zone increased around double during past 10 years.

Table 6. Ratio of HH using groundwater by districts from 2007 to 2016.

Year	Number of HH	Ratio of HH using groundwater (%)							
		TP. TV	Cang Long	Cau Ke	Tieu Can	Chau Thanh	Cau Ngang	Tra Cu	Duyen Hai
2007	220,869	6%	34%	64%	43%	48%	33%	26%	40%
2008	221,665	9%	42%	73%	56%	58%	49%	33%	43%
2009	222,193	8%	43%	63%	55%	57%	43%	35%	39%
2010	222,789	8%	43%	58%	55%	57%	45%	37%	45%
2011	224,293	7%	43%	63%	55%	57%	45%	39%	56%
2012	225,590	11%	45%	62%	59%	60%	48%	37%	61%
2013	226,786	8%	47%	65%	62%	62%	53%	40%	60%
2014	228,004	9%	49%	68%	66%	65%	56%	48%	76%
2015	229,045	10%	51%	71%	70%	67%	59%	61%	69%
2016	231,238	10%	53%	73%	74%	70%	61%	83%	71%

4.2. Groundwater Use Pattern and Distribution

GWU concentrated mainly in coastal districts (Duyen Hai, Tra Cu and Cau Ngang) with over 58 percentages (199,179 m³/d) of total GWU in Tra Vinh Province. From 2007 to 2016, GWU of Tra Cu and Duyen Hai increased rapidly from 31,631 m³/d and 51,974 m³/d to 67,231 m³/d and 82,537 m³/d, respectively (Fig. 9).

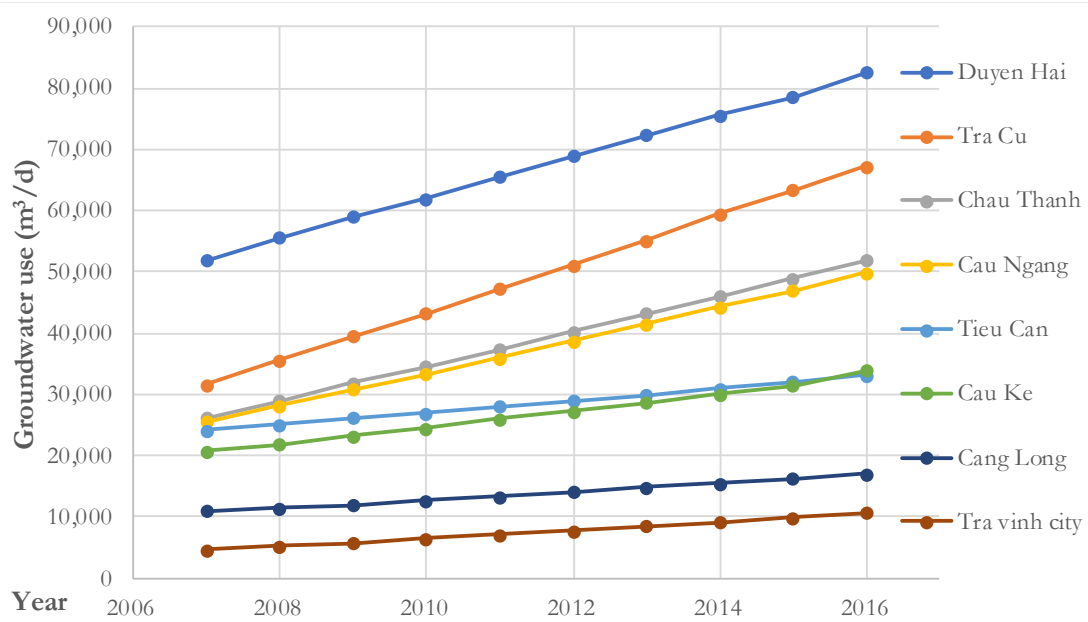


Fig.9. GWU estimation by districts from 2007 to 2016.

4.3. Groundwater Budget Analysis by Groundwater Modelling

The groundwater model also reveals flow budget of groundwater system in the study area. From the groundwater model results, the model estimated total inflows including land recharge, river recharge, leakage and boundary were always smaller than total outflow.

Although aquifer qh absorbed total of river recharge and land recharge in the whole study area, however sum of discharge by pumping and filtration to below aquifer (qp₃ aquifer) was approximated to be about 128,320 m³/d. It means that the changing storage of qh aquifer is low and it also explained by the stable fluctuation of piezometric heads in duration from 2007 to 2016 in two main aquifers (qp₃ and qp₂₋₃) (Fig. 10).

In qp₂₋₃ aquifer (main abstracted aquifer), 82 percentage of inflow was leakage flow with lower and upper aquifer. However, the over groundwater abstraction reduced the storage of aquifer and induced the decline of groundwater level significantly in the period of 10 years.

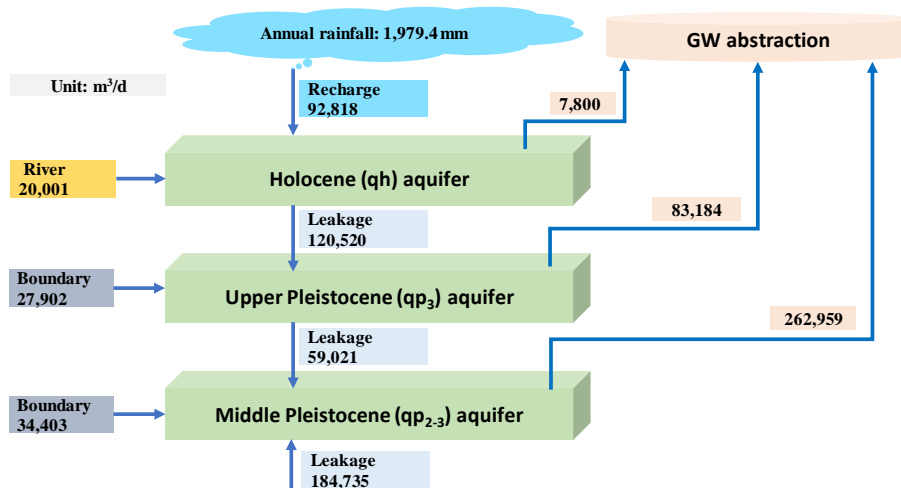


Fig. 10. Groundwater budget of three top aquifers in 2016.

5. Conclusions

In northern part, where most groundwater is brackish and saline, the ratio of HH using groundwater is only 44 percent at present. However, in middle part and coastal part, their ratios were 83 percent and 73 percent, respectively. Average rate of GWU in coastal part also was much higher than the rate in northern part, particular is 3.78 m³/HH/d and 1.05 m³/HH/d.

Ratio of household using groundwater in each part was different. It varied from 61 percent to 83 percent in coastal part and middle part and around 50 percent in northern part, respectively. In dry season of 2016, groundwater abstraction was estimated 346,279 m³/d in which sum of Duyen Hai, Tra Cu and Cau Ngang district occupied about 67 percent. Land surface temperature (LST) presented a good correlation with groundwater use (GWU) distribution with adj-R² = 0.646. In future, it can be applied to estimate GWU in other area and in regional scale.

Results of groundwater modelling also showed that the discharge from aquifer (mainly pumping) was always higher than the recharge to aquifer. It explained why the observed groundwater level declined about 0.5 m per year during the period from 2007 to 2016.

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