# Final Report

## IGPVN activities and achievements in Soc Trang,
## Proposal of recommendations and measures for water resources management in Soc Trang

Author: Hoang Thi Hanh

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# 1. Introduction

## 1.1. Natural geographic and socio-econimic features

*Location*

Soc Trang is one of the coastal provinces in the Ca Mau peninsula belonging to the Hau estuary. Soc Trang shares the border with Tra Vinh province in the east (by the Hau River), the East Sea in the south (with the coastal line of about 72 km), Bac Lieu in the west, Hau Giang and part of Vinh Long in the north. The total area of the province is 3.331,76 $km^2$, including Soc Trang city and 10 districts (Cu Lao Dung, Ke Sach, Long Phu, My Tu, My Xuyen, Nga Nam, Thanh Tri, Chau Thanh, Vinh Chau and Tran De (with 10 wards, 12 townships and 87 communes).

Geographical coordinates:

- From 09$^o$14’ to 09$^o$56’ Northern latitude

- From 105$^o$30’ to 106$^o$20’ Eastern longitude

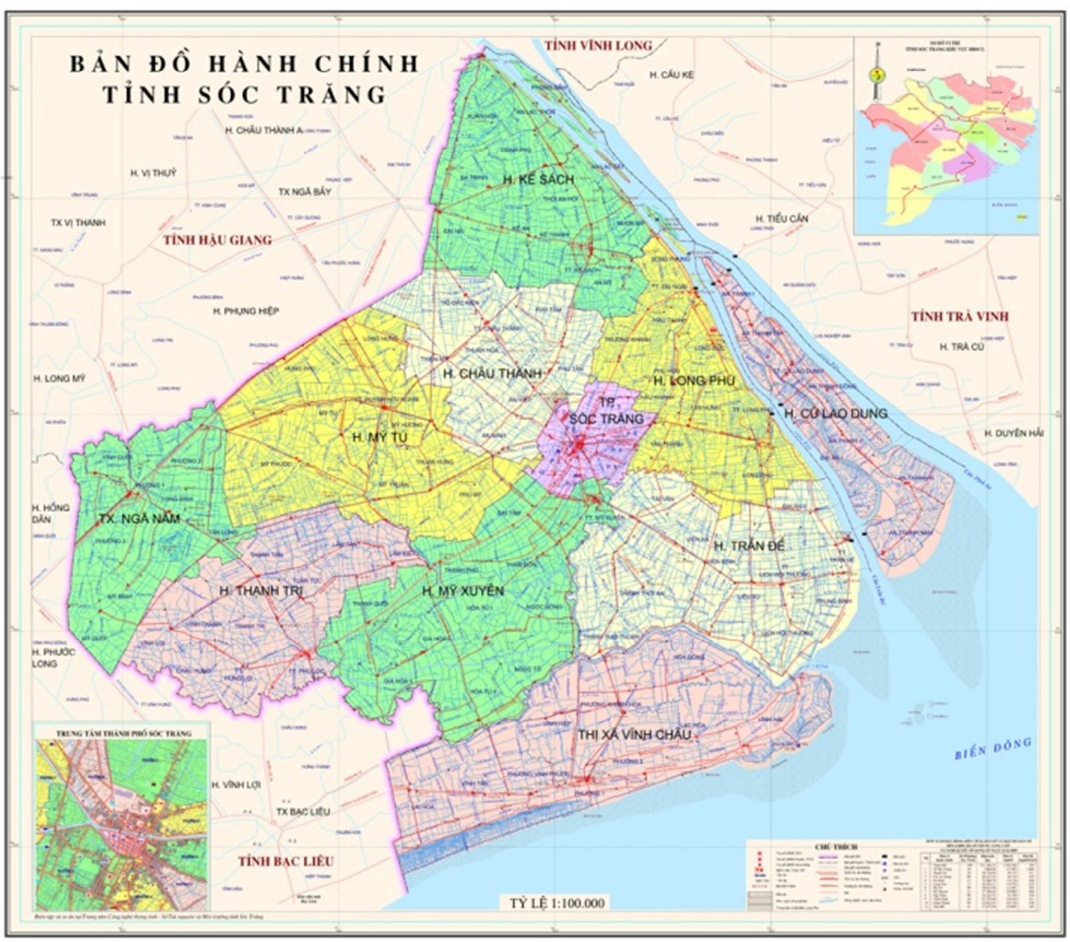


Figure 1. Administrative map of Soc Trang province

*Topography, edaphology*

Soc Trang is relatively low and flat, consisting the flat land interspersed with low areas and sand dunes. The entire province of Soc Trang is located in the south of the Hau River estuary, with the elevation fluctuating from about 0.2 - 2 m comparing to the sea level. The interior has the average height of 0.5 to 1.0 m. The province is in basin-shaped with the major slope from the Hau River to the inward, from the East Sea and Quan Lo Channel lowering down to the inland with the strips along the river and the sea.

In general, Soc Trang is situated in the lowland, including 3 types:

- Accumulative plain along the river: accounts for the major area of the province with the popular elevation of about 0.5 – 1.5 m.

- Accumulative plain along the sea: makes up a small territory of the province from Lich Hoi Thuong to Vinh Chau with the average elevation from 0.5 – 2.0 m.

- The ancient sand dunes: distribute in bow-shaped strips in parallel to the seashore with the average elevation from 1.5 – 2.0 m.

Due to the low topography, many areas separated by the system of rivers and irrigation canals and adjacent to the sea, the province is therefore very vulnerable to saline intrusion (salinity), especially in the dry season.

The terrain along the coastal line is clearly divided into 3 levels of depth:

- At the depth from 0 – 10 m water: in general, the topography is relatively sloping and flat. The estuarine areas have fairly complex topographical conditions, changing over season and due to the dynamic interactions between the river and the sea with many sand dunes and sand bars interweaving with narrow passages.

- At the depth of 10 – 20 m water: the topography is formed with slopes. The terrain of the estuarine areas (in the northeast) is steeper than that of the southwest. It is the outer boundary of the modern sedimentary deposits and therefore, the terrain is usually changing over time.

- At the depth of 20 – 30 m water: the topography is relatively sloping and large with sandy waves. There exist underground sloping sand dunes in some areas.

*Edaphology*

Soc Trang province has a total area of 331,176.29 hectares. The land has high fertility, suitable for the development of wet rice; industrial crops such as sugar canes, soybeans, corn; vegetables like onions, garlic; and fruit-trees such as grapefruit, mango and durian...

The land of Soc Trang can be divided into 6 groups:

- Group of sandy land has an area of 8.491 ha, including the relatively high sand dunes from 1.2 to 2 m with light mechanical composition, mainly consisting of fine sand to sandy loams

- The group of alluvial soil covers an area of 6,372 ha suitable for intensive rice cultivation and special fruit-trees

- The group of lowland with 1,076 ha suitable for 1-crop rice cultivation

- The group of of saline land accounts for an area of 158,547 ha, divided into several categories: high-level saline soil, medium-level saline soil, low-level saline soil and saline land for aegiceras and mangroves (tidal flood), of which the high-level saline soil covers a large area of 75,016 ha suitable for rice, vegetables, fruits, industrial crops, short-term and long-term plants

- The group of alkaline land covers an area of 75,823 ha, divided into 2 types including active and potential alkaline ones, which can be used for multi-cultivation modes, rice cultivation combined with aquaculture

- The group of improved land covers an area of 46,146 ha.

Despite the limitation in the natural conditions such as the lack of fresh water and salty water intrusion in the dry season and some areas affected by acidity, the land of Soc Trang brings many fundamental advantages for the diverse development of agriculture, fisheries, forming the rich eco-tourism. In particular, there are the strips of islets located in Ke Sach, Long Phu and Cu Lao Dung District stretching out to the seaport, where grow a plenty of tropical fruit-trees and the fresh air like in My Phuoc islet, Song Phung Resort and Cu Lao Dung ...It is the ideal location for the development of eco-tourism.

*Climate*

The climate of the province is characterized by equatorial tropical monsoon and divided into two distinct seasons. The rainy season starts from May to November. The dry season starts from December to April.

Temperature: The annual average temperature is 26.6ºC (in 2008), the highest temperature is in April (28.2ºC) and the lowest temperature is in January (25.4ºC).

Sunshine: The total annual average radiation is relatively high, reaching 140 – 150 kcal/cm$^2$. The total annual sunshine hours is 2,292.7 (about 6.28 hours/day), the peak is in March with 282.3 hours and the lowest point is often in September with 141.5 hours.

Precipitation: the annual average precipitation is 1,600 – 2,230 mm; it is much different over season. The rainy season accounts for 90 % of the total while very little amount is found in dry season; sometimes, rain does not occur in some month.

Humidity: The average annual humidity is 84 % (highest 89 % in rainy season and lowest 75 % in dry season).

Wind: located in the tropical monsoon area, Soc Trang obtains the major wind directions such as: West, Southwest, Northeast, and Southeast. The wind is divided into two distinct seasons including the Northeast Monsoon and the Southwest Monsoon. The rainy season is primarily influenced by the southwest monsoon, while the dry season is mainly influenced by the Northeast monsoon, with the average wind speed of 1.77 m/s.

Other factors: Soc Trang is located in the region where is less hit by storms. According to the meteorological data recorded in the past 100 years, only 2 hurricanes have hit Soc Trang (in 1952 and 1997) causing significant damages. In recent years, whirlwind has usually occured in Soc Trang. Though as weak as it was, the people's livings and production have been affected.

*Population, social-economic conditions*

The average population of the province in 2009 is 1,293,165 people, of which the urban population is 252,054 people (accounting for 19.49 %). From 2006 to 2009, the province’s population has increased to 16,692 people, with the annual average growth rate of 0.43 %.

The average density is 3.9 people/ha, relatively under populated compared to the average rate of the country. The population in the urban areas has been also increased but not with the high rate.

According to the social economic development plan of Soc Trang province, the population by 2015 is 1,433,224 people and by 2020 is 1,517,552 people.

The population growth will lead to the increasing demand for natural resources, for instance, the demand for clean water.

## 1.2. Overview on water resources

### 1.2.1. Water resources features of Soc Trang province

*Surface water system*

The surface water of Soc Trang is relatively abundant with intricate canal system, including a number of rivers, channels:

The Hau River: flows along the eastern boundary of the province, with a length of about 60 km. The Hau River flows to the sea through the two esturies of Tran De and Dinh An. It remains the major sources of fresh water for the province, but also being intruded by saline water from the East Sea.

My Thanh River: has fairly wide cross-section with the average width of about 200 m and the average depth of 11.5 – 14 m.

Quan Lo – Phung Hiep Canal: connects the Hau River, which runs along the northern boundary of the province. The canal is vital freshwater conveyor. The section crossing through the territory of Soc Trang province has an average width of 60 – 90 m with the depth of 4 – 8 m.

The Soc Trang's rivers and canals are located in the affected areas of uneven semi-diurnal tides. The water levels of the two tidal crests and feet are not equal, the average tidal amplitude is from 194 – 220 cm.

Water sources in the rivers and canals of Soc Trang province are the mixture of the in situ rainfall, sea water and the upstream flow from the Hau River.

The flow of  the Hau River is relatively powerful in the rainy season, which is also the flood period of the Hau River. The combined flow in the coastal line is about 1m/s.

Being influenced by tidal flows, the river water is intruded by saline water in the dry season and become fresher during the rainy season. The water in the rivers and canals close to the sea is saline throughout the year, therefore, it can not be used for agricultural irrigation but in return, it facilitates aquaculture.

*Groundwater*

Groundwater Soc Trang province has relative good quality and plentiful reserves. Groundwater in deep aquifers about 100 to 180 m of depth has high quality and is suitable for domestic consumption. Shallow groundwater is from 5 – 30 m of depth depending on rain water, alum and salt water in the dry season. In the study region, there are 7 exists aquifer from top to bottom as follows:

- ***The Holocene porous aquifer (qh):*** is formed with coarse grains of various originated sediments in Holocene age, including 2 types:

- the marine sediments and marine-winds sediments exposed to the surface in forms of sand dunes at the age of m, $mvQ_2^{2-3}$ or $mQ_2^3$. It is distributed at the elevation of 0.5 –  2.0 m in the coastal areas of Long Phu, Vinh Chau, Soc Trang and My Tu… The sand dunes are usually in prolong arch-form parallel to the seashore in the northeast – southwest or northwest-southeast direction with the length from 3 – 4 km, the width from 200 – 300 m and the thickness from 1 – 12 m. The components consist of fine to medium-size sand mixed with yellowish gray silt.

- The coarse grains include: fine sand and blackish gray silty sand located in the undermost of the cross section of oceanic sediments belonging to Hau Giang formation ($mQ_2^{1-2}hg$). The upper part is usually covered by silty clay and clay layers belonging to the very poor water-bearing formation of Holocene age and often lying above the very poor water-bearing formation $Q_1^3$. The thickness fluctuates from several meters to over 30.0 m.

- ***Upper Pleistocene porous aquifer* (qp$_3$)**: includes coarse-grain sediments of the soil and rocks in Long My formation (m$Q_1^3$*lm*), the major components are fine sand, fine medium-size sand mixed with little amount of gravel and the greenish grey and whitish grey shells. It is distributed in the entire area of Soc Trang with the thickness from 3 – 50.9 m (average 20.5 m). The depth of the aquifer's roof is from 24 m to 95 m (average 50.39 m) and the depth of the bottom is from 30 to 125 m (average 70.74 m).

The recharge sources for the qp$_3$ aquifer are mainly from the flows from the surrounding areas and partly from the leakage from the adjacent aquifers. In natural conditions, the water levels tend to fluctuate seasonally with an average amplitude of about 1.17 m. In addition, the water level is daily vibrating in accordance with the tidal regime of the East sea.

- ***Middle – upper Pleistocene porous aquifer* (qp$_{2\text{-}3}$):** is formed by coarse grains in the lower basement of Long Toan formation. The qp$_{2\text{-}3}$ is distributed in the entire area of Soc Trang. It is not exposed to the surface but covered with very poor water-bearing formations m$Q_1^{2\text{-}3}$*lt* and above the very poor water-bearing formation m,am$Q_1^1$*nc*. The depth of the aquifer's roof is often seen in the range 54 m to 137 m (average 82.63 m) and the bottom is at the depth of 92.0 m to 175.0 m (average 131.47 m). The aquifer's thickness fluctuates from 7 m to 81 m (average 49.75 m). The lithological components are sand of different grain sizes mixed with water-bearing gravel and thin clayed silt lenses.

- ***Lower Pleistocene porous aquifer (qp$_1$):*** is formed from the coarse grains in the undermost of Binh Minh formation (m,am$Q_1^1$*bm*). The prominent lithological components are clearly arranged with fine to coarse sand mixed with little gravel. The cross sections often describes some relatively thick aquiclude lenses. The aquifer is distributed in the entire area of Soc Trang. It is not exposed to the surface. Its roof is often found at the depth from 110.5 m to 192 m (average 145.29 m) and the bottom is at the depth from 146 m to 250 m (average 187.40 m). The aquifer's thickness is from 6 m to 79.5 m (average 40.29 m). It mainly consists fine, medium and coarse sand containing yellowish grey gravel that has good water-bearing capacity. It is also intermingled with thin lenses of clay, silt clay and silt sand.

- ***Middle Pliocene porous aquifer* (n$_2^2$):** is formed from the coarse grains in the undermost of the Nam Can formation (a,am$N_2^2$*nc*). The aquifer is covered with very poor water-bearing upper Pliocene ($N_2^2$*nc*) formation and lying above the very poor water-bearing lower Pliocene ($N_2^1$*ct*) formation. The aquifer is distributed in all over the region and not exposed on the surface. The aquifer's roof is at the depth from 156 m to 273 m (average 201.4 m) and the bottom is at the depth from 236 m to 355 (average 297.62 m). The prominent lithological components are clearly arranged with fine to coarse sand mixed with little gravel. The cross sections often describes some relatively thick aquiclude lenses. The aquifer's thickness is from 20 m to 147 m (average 96.22 m).

***- Lower Pliocene porous aquifer ($n_2^1$):*** is formed from coarse grains in the undermost of Can Tho formation (a,am$N_2^1$*ct*). The lower Pliocene aquifer is widely distributed in the entire area of Soc Trang. It is usually covered with very poor water-bearing $N_2^1$*ct* formation and lyinng directly above the very poor water-bearing $N_1^3$*ph* formation. The roof of the aquifer is located at the depth from 262 m to about 390 m (average 320.15 m) and its bottom is at the depth from 298 m to 450.90 m (average 388.44 m).

The lithological components of the $n_2^1$ aquifer are mainly fine to medium sand mixed with silt in greenish gray and reddish brown in some areas, sometimes intermingled with thin lenses of clay, silty sand containing carbonate. The thickness of the aquifer is from 35 m to 98 m (average 65.38 m).

***- Upper Miocene porous aquifer ($n_1^3$):*** formed from coarse grains in the undermost of Phung Hiep formation (a,am$N_2^1$*ct*). The aquifer's roof is found at the depth from about 307 m to 485 m (average 403.72 m), its bottom is at the depth of over 500 m. The lithological components of the $n_1^3$ aquifer mainly consists of fine to coarse sand mixed with thin lenses of clay- silt. The average thickness is about 96.28 m.

### 1.2.2. Current status of groundwater exploitation and utilisation

Currently, the local people in Soc Trang mainly use groundwater for domestic consumption due to the fact that the surface water was contamited and/or saline. Moreover, people exploit groundwater for industrial production, agriculture (onion irrigation in Vinh Chau district) and aquaculture.

According to the report on Groundwater exploitation, utilisation and protection planning for Soc Trang upto 2020 (Soc Trăng DONRE, 2010), the total water demand of the province is about 225,000 $m^3$/day in 2015 and 320,000 $m^3$/day in 2020. Pressure on groundwater increases by time especially while the surface water is facing to contamination and salt water intrusion.

*Groundwater abstraction for water supply in urban areas*

Currently there are 32 well groups of 56 production wells exploiting groundwater for domestic and service water supply. The total pumping rate is about 36,570 $m^3$/day, which mainly occur in the Soc Trang city.

The centralized water supply stations are available in most of the towns in all the districts of Soc Trang province, where 1 – 4 pumping wells are operated at each stations.

The centralized production wells exploit groundwater of the $qp_1$ and $n_2^2$ aquifer with the common depth of 100 – 480 m. Other production wells of lower pumping rate exploit groundwater of the $qp_{2-3}$ and $qp_1$ with the depth vary between tens of meter to over 100 m.

Table 1. Groundwater production wells for domestic and service water supply in the urban areas of Soc Trang province

| Name | Year of Construction | Year of Operation | Basic information | | | | Operation | |
|---|---|---|---|---|---|---|---|---|
| | | | Depth (m) | Screening depth (m) | | Target aquifer | Pumping rate ($m^3$/day) | Pumping time (hr/day) |
| | | | | From | To | | | |
| TCN TT Châu Thành | 1992 | 2004 | 136 | 70 | 71 | $qp_1$ | 320 | |
| TCN Trà Quýt | 1998 | 2002 | 128 | 120 | 132 | $qp_1$ | 144 | 18 |
| TCN Trà Quýt A1 | 2008 | 2011 | 170 | 115 | 125 | $qp_1$ | 648 | 24 |
| XNCN Kế Sách | 1991 | 2006, 2009, 1998 | 170 | 157 | 165 | $qp_1$ | 1300 | 24 |
| XNCN Long Phú | 1996 | 2008 | 115 | 148 | 168 | $qp_1$ | 2800 | 15 |
| TCN thị trấn Long Phú | 2004 | 2004 | 150 | 100 | 112 | $qp_1$ | 70 | 24 |
| XNCN Mỹ Tú | 1997 | 1998 | 157 | 132 | 148 | $qp_1$ | 500 | 24 |
| XNCN Mỹ Tú | 2005 | 2005 | 170 | 141 | 154 | $qp_1$ | 250 | |
| XNCN TT. Mỹ Xuyên | 2006 | 2006 | 463 | 437 | 460 | $n_1^3$ | 4204 | 24 |
| TCN ấp 2 | 2002 | 2002 | 100 | 90 | 98 | $qp_{2-3}$ | 168 | 24 |
| TCN ấp 4 | 2003 | 2003 | 125 | 110 | 122 | $qp_1$ | 24 | 24 |
| TCN ấp 7 | 2004 | 2004 | 130 | | | $qp_1$ | 0 | 0 |
| XNCN Ngã Năm | 2011 | 2011 | 100 | 90 | 98 | $qp_{2-3}$ | 900 | 24 |
| TCN Hưng Lợi | 2008 | 2008 | 120 | 103 | 115 | $qp_1$ | 1440 | 24 |
| XNCN Thạnh Trị | 1991 | 1991 | 105 | 86 | 103 | $qp_{2-3}$ | 1000 | 24 |
| XNCN Phú Lợi | 2005 | 2005 | 126 | 110 | 125 | $qp_1$ | 5000 | 16 |
| TCN khóm 6 | 2001 | 2001 | 112 | 100 | 110 | $qp_1$ | 30 | 24 |
| TCN khóm 5 | 2003 | 2003 | 126 | 105 | 125 | $qp_1$ | 50 | 24 |
| Công ty TNHH MTV cấp nước Sóc Trăng | 2003 | 2003 | 205 | 180 | 200 | $n_2^2$ | 10000 | 24 |
| NMN P7 | | | 155 | 138 | 152 | $qp_1$ | 24 | 10 |
| TCN Cao Minh Chiếu | 2005 | 2005 | 480 | 422 | 440 | $n_1^3$ | 1600 | 17 |
| TCN khu 6 | 2004 | 2004 | 120 | 110 | 118 | $qp_1$ | 24 | 24 |
| TCN khu3 | 2003 | 2003 | 130 | | | $qp_1$ | 48 | 24 |
| TCN phường 8 | 2006 | 2006 | 140 | 118 | 138 | $qp_1$ | 80 | 24 |
| TCN khu 7 | 2006 | 2006 | 145 | | | $qp_1$ | 120 | 24 |
| XNCN Sung Dinh | 2007 | 2007 | 480 | 422 | 440 | $n_1^3$ | 1500 | 17 |
| Chi nhánh cấp nước Trần Đề | 2008 | 2008 | 150 | 130 | 145 | $qp_1$ | 1920 | 24 |
| XNCN Vĩnh Châu | 2005 | 2005 | 150 | 98 | 110 | $qp_1$ | 2000 | 24 |
| TCN Phường 2 | 2003 | 2003 | 128 | 106 | 126 | $qp_1$ | 250 | 24 |
| TCN ấp Chợ | 2008 | 2008 | 110 | 105 | 108 | $qp_{2-3}$ | 12 | 4.8 |

| Name | Year of Construction | Year of Operation | Basic information | | | | Operation | |
|---|---|---|---|---|---|---|---|---|
| | | | Depth (m) | Screening depth (m) | | Target aquifer | Pumping rate ($m^3$/day) | Pumping time (hr/day) |
| | | | | From | To | | | |
| TCN Phước Hòa B | 2008 | 2008 | 158 | 135 | 155 | $qp_1$ | 144 | 24 |
| Total | | | | | | | 36570 | |

*Groundwater abstraction for water supply in rural areas*

There are 121 centralized production wells for water supply in rural areas in Soc Trang province, managed by the Center for Rural Water Supply and Sanitation in Soc Trang. The total pumping rate is about 23,395 $m^3$/day. The pumping rate of each production well varies between 10 -1900 $m^3$/day. The well depth is from 100 – 560 m. There are 53 out of those 121 production wells having exploitation license.

Table 2. Groundwater production wells for domestic water supply in rural area in Soc Trang province

| No. | District | No. of wells | Pumping rate ($m^3$/day) | No. of licensed wells |
|---|---|---|---|---|
| 1 | Châu Thành | 15 | 2665 | 9 |
| 2 | Kế sách | 12 | 1402 | 10 |
| 3 | Long Phú | 11 | 1652 | 4 |
| 4 | Mỹ Tú | 16 | 1777 | 8 |
| 5 | Mỹ Xuyên | 10 | 3288 | 4 |
| 6 | Ngã Năm | 9 | 1124 | 1 |
| 7 | Thạnh Trị | 9 | 1836 | 4 |
| 8 | Trần Đề | 27 | 6647 | 8 |
| 9 | Vĩnh Châu | 10 | 2554 | 4 |
| 10 | Cù Lao Dung | 2 | 450 | 1 |
| Tổng | | 121 | 23395 | 53 |

*Groundwater abstraction at household scale*

There are totally 79,981 private wells exploiting groundwater from qh, $qp_{2-3}$ and $qp_1$ aquifers in Soc Trang province; of which, 65,288 wells extract groundwater from $qp_{2-3}$ and only 4 wells extract groundwater from $n_2^2$.

Table 3. Number of private wells of each aquifer

| No | District/City | No. of private wells | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **qh** | **$qp_3$** | **$qp_{2-3}$** | **$qp_1$** | **$n_2^2$** | **$n_2^1$** | **$n_1^3$** | **Total** |
| 1 | TP.Sóc Trăng | 470 | 12 | 784 | 38 | - | - | - | 1,304 |
| 2 | Kế Sách | - | 2,490 | 7,929 | 281 | - | - | - | 10,700 |
| 3 | Long Phú | - | 1,192 | 9,681 | 341 | 1 | - | - | 11,215 |
| 4 | Ngã Năm | - | 590 | 5,268 | 136 | - | - | - | 5,994 |
| 5 | Thạnh Trị | - | 381 | 6,507 | 47 | 1 | - | - | 6,936 |
| 6 | Mỹ Tú | - | 2,117 | 2,824 | 11 | - | - | - | 4,952 |
| 7 | Vĩnh Châu | 49 | 996 | 9,928 | 1,284 | - | - | - | 12,257 |
| 8 | Mỹ Xuyên | 68 | 205 | 10,733 | 135 | - | - | - | 11,141 |
| 9 | Cù Lao Dung | - | 450 | 4,668 | 106 | - | - | - | 5,224 |
| 10 | Châu Thành | 217 | 568 | 3,910 | - | - | - | - | 4,695 |
| 11 | Trần Đề | - | 2,050 | 3,018 | 417 | 2 | - | 76 | 5,563 |
| | Total | 804 | 11,051 | 65,250 | 2,796 | 4 | 0 | 76 | 79,981 |

*Groundwater abstraction for industry, agriculture and aquaculture*

There are about 126 production wells for industry, agriculture and aquaculture water use of 25,249 $m^3$/day, with the depth of 90 – 460 m, exploiting groundwater from the $qp_{2-3}$, $qp_1$ and $n_2^2$ aquifers.

Table 4. Number of groundwater production wells for industry, agriculture and aquaculture use in Soc Trang

| No. | District | No. of wells | Pumping rate ($m^3$/day) | No. of licensed wells |
|---|---|---|---|---|
| 1 | Châu Thành | 5 | 226 | 5 |
| 2 | Kế sách | 5 | 115 | 4 |
| 3 | Long Phú | 9 | 1720 | 9 |
| 4 | TP Sóc Trăng | 41 | 15295 | 30 |
| 5 | Mỹ Xuyên | 11 | 1008 | 8 |
| 6 | Thạnh Trị | 3 | 556 | 3 |
| 7 | Trần Đề | 29 | 5577 | 29 |
| 8 | Cù Lao Dung | 5 | 40 | 5 |
| 9 | Vĩnh Châu | 18 | 712 | 18 |

### 1.2.3. Current state of water resources management and protection

*Advisory to the PPC to issue secondary regulations and implementation of the legal documents in water resources sector*

The Soc Trang DONRE advised the PPC on issuing secondary regulations in water resources sector:

- Decision No. 11/2008/QĐ-UBND dated on 14/4/2008 of the Soc Trang PPC regulating on registration for groundwater exploitation and utilisation at household scale

- Directive No. 03/2009/CT-UBND of the Soc Trang PPC on strengthening groundwater management in Soc Trang province in order to raise community awareness on groundwater exploitation, utilisation and protection

- Decision No. 29/2014/QĐ-UBND dated on 10/12/2014 of the Soc Trang PPC on cooperating mechanism in groundwater management and protection in Soc Trang province

- Plan No. 53/KH-UBND dated on 12/8/2014 of the Soc Trang PPC on improvement of integrated water resources management and protection efficiency in 2014 – 2020

The Soc Trang DONRE organized the implementation of the Decrees issued by the government:

- Decree No. 43/2015/NĐ-CP dated on 06/5/2015 on establishment and management of water sources protection corridor

- Decree No. 54/2015/NĐ-CP dated on 08/6/2015 regulating on favorable conditions for water saving and effective water use

- Circular No. 42/2015/TT-BTNMT dated on 29/9/2015 of the MONRE regulating on technique for water resource planning

Additionally, the Soc Trang DONRE compiled a Guide book for Water resource – Mineral management for local authorities (2012) to assist the DONRE officials in performing their functions and duties on state managment of water resources.

*Water resources planning and principle investigation*

- the project "Planning for groundwater resource exploitation, utilisation and protection in Soc Trang province to 2020" completed in 2010 and approved by the Soc Trang PPC in the beginning of 2011. To date, the results of this planning is still being applied as a basis for management of groundwater exploitation licensing in Soc Trang.

- the project "Planning for surface water resource exploitation, utilization and protection in Soc Trang province to 2020, orienting to 2030" (currently processing the survey data, collected data, running the water quality model, topographical mapping of some major rivers), which is expected to be completed at the end of 2016 and will be sent to MONRE for comments and then, submitted to the Provincial People Council for approval.

However, according to the Water Resources Law dated on 21/06/2012 and the Circular 42/2015/TT-BTNMT dated on 29/9/2015 of the MONRE regulating water resources planning techniques; the Soc Trang PPC should carry out a general water resources planning, not a planning for surface water only.

- the project "Review, investigation, assessment and delineation of the registration compulsory areas for groundwater exploitation in Soc Trang province”. Currently the project proposal, cost estimation and bidding plan are being considered by the PPC and will be implemented following the Water Resources Law 2012 and the Circular 27/2014/TT-BTNMT of the MONRE.

However, the implementation of principle investigation, inventory and assessment of water resources in Soc Trang province faces difficulties and obstacles due to limited budget and unavailable detailed guidelines of the central level.

*Water resources licensing*

Basis for water resources licensing:

- Water Resources Law dated on 21/06/2012
- Decree No. 201/2013/NĐ-CP dated on 27/11/2013 of the Government
- Circular No. 27/2014/TT-BTNMT dated on 30/5/2014 of the MONRE
- Circular No. 40/2014/TT-BTNMT ngày 11/7/2014 of the MONRE
- Planning for groundwater resource exploitation, utilisation and protection in Soc Trang province to 2020” (completed in 2010)

The Soc Trang DONRE submitted the applications and advised the PPC to grant permit for:

- Permit for groundwater exploration
- Permit for groundwater exploitation
- Permit for surface water exploitation and utilisation
- Permit for discharging wastewater to water source
- Permit for groundwater drilling work

In the Circular No. 27/2014/TT-BTNMT regulating on registration procedure and application form for water resources licensing, Point c, Paragraph 1, Article 4, Chapter II states that registration for groundwater exploitation is compulsory in the coastal plain areas of intercalating fresh and saline aquifers or in the areas adjacent to salty/brackish aquifers. Thus, the entire territory of Soc Trang province is subject to this regulation.

In Article 5, Chapter II of this Circular also stipulates responsibilities of the DONRE to implement the delineation of the registration compulsory areas for groundwater exploitation and announce the list of these areas. However, this has not been done in Soc Trang province despite the fact that this Circular has already been enforced for two years. The reason is that a scheme on investigation, assessment and delineation of the registration compulsory areas for groundwater exploitation in Soc Trang province is still pending for approval.

*Water resources financing*

As stipulated in Paragraph 1, Article 65 of the Water Resources Law 2012, agencies and individuals must pay permission fee for water resources exploitation in some cases mentioned therein. But so far, the calculation method, charging rates, charging methods for this fee; the management and disbursement mode for the resulting revenues have not yet been specified by the central level and therefore, the provincial government has not yet been able to implement this provision.

*Inspection, examination and handling of the legislation violatios in Water resources sector*

The inspection, examination and handling of law violations on water resources sector was done adequately by the Soc Trang DONRE. Many manufacturing enterprises, business companies were inspected and reminded on implementation of the legislation provisions on environmental and water resources protection. According to the "Review on groundwater resources management in Soc Trang province" done by CTU and Soc Trang DONRE in 2015, the management apparatus and the legal tools for groundwater resource management are tightly set from the central to local levels. The cooperation mechanism for groundwater management in Soc Trang province is basically functional. However, there is still duplication and ambiguity in the regular or irregular inspection of groundwater exploration, exploitation, utilisation and drilling work between the Soc Trang DONRE and the district People Committee and communial People Committee.

*Communication, dissemination, education on legislation in water resources sector*

The communication, dissemination and education on legislation in water resources sector are being focused by the Soc Trang DONRE. Many activities have been organized: collect garbage and clean roads; initiate the Cha Va canal dredging works in My Xuyen town; launch the contest "Learning the regulations on state management of water resources, mineral resources, hydrometeorology and climate change"; organize training courses on implementation of legal documents on water resources for environmental officials at district and commune levels and for enterprises and companies in the province; sign joint agreement with other organizations in the province (Farmers' Association, the Federation of Labour, Youth Union, Radio – Television of Soc Trang, Soc Trang press ...) in order to strengthen the communication and dissemination of legislation, policy on natural resource and environment protection in the province. The regulations and policies on groundwater management, exploitation and utilisation has been disseminated to local businesses and has been well implemented. However, the communication, dissemination of groundwater exploitation, protection and licensing to the local people has not been done adequately.

## 2. Objectives of the project “Improvement of Groundwater Protection in Vietnam”

The project “Improvement of Groundwater Protection in Vietnam” (IGPVN) is in frame of the German Technical Cooperation with Vietnam, which was started in 2009. The first two phases of the project focused on technical assistance component arts (construction of the groundwater monitoring network and handing over to the DONRE) and capacity building for Vietnam partners, and were implemented in Nam Dinh, Ha Nam, Hanoi, Quang Ngai and Soc Trang provinces.

Phase 3 of the project (2015-2017) was proposed with the overall objective of strengthening the groundwater resources management and protection in the Mekong Delta in order to prevent groundwater degradation and depletion, salt water intrusion under the impact of climate change. The project is under the priority areas “Environmental policies and sustainable use of natural resources" within the framework of bilateral development cooperation between the two governments. In addition, the project is part of the programme "Integrated coastal and mangrove forest management for climate change adaptation” by the Federal Ministry of Economic Cooperation and Development (BMZ) to support Green Growth Strategy (2011 - 2020) of Vietnam.

The current phase consists of 4 components:

- Policy advice at national and provincial levels (policy and legal documents development)
- Technical assistance to enhance understanding of the current status of groundwater resources and improve the groundwater management in the target provinces
- Capacity building for partners in the investigation, assessment, monitoring and forecasting of groundwater resources
- Public awareness raising on groundwater resources protection

There are about 4.5 million people in the Mekong Delta depending on groundwater sources. Population growth and social – economic growth have led to a strong increase in groundwater demand, arising many shortcomings: degradation, depletion of groundwater, increasing saltwater intrusion, water pollution and land subsidence.

In recent years, the coastal provinces of the Mekong Delta constantly faced with saltwater intruding far inland during the dry season and tidal flooding during the rainy season. During the past few months, almost all of the Mekong Delta were suffering from a severe historic drought and saltwater intrusion happening once in a 100 years-time. There were 8 provinces /cities in the Mekong Delta announcing the emergency state on drought and salinization.

Being implemented in Soc Trang province since 2010, the IGPVN project is reaching its aim of strengthening the capacity on groundwater monitoring, forecasting and management for the Soc Trang DONRE by conducting the following activities:

• New construction of 5 **groundwater monitoring stations** and handing over to the Soc Trang DONRE for management and operation

• Collecting available documents in conjunction with field survey and investigation to collect additional data; analysis and evaluation in order to build a **complete hydrogeological database**

• Analysis and evaluation based on relevant documents and development of a **consolidated final report** on the current state of groundwater exploitation, utilisation and management in Soc Trang and proposal of recommendations and measures for water resources management in Soc Trang.

• Support the Soc Trang DONRE on organizing **IWRM Workshop** to strengthen the networking and information sharing with other provinces and stakeholders in water resources sector; cooperating with the Soc Trang to organize **awareness raising communication** activities on water resources protection.

Details see in the next chapters of this report.

# 3. Approach and Study Methods

## 3.1. Construction of the monitoring wells

*Site selection*

Five monitoring wells in the $qp_{2-3}$ aquifer were built up in 5 districts of the Soc Trang province. More details see Table 5.

Table 5. IGPVN monitoring wells in Soc Trang province

| Well ID | Location | Coordinates (VN2000) | | Well depth (m) | Screening | | | aquifer | Static water level | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | X | Y | | length (m) | from (m) | to (m) | | 4/2013 | 5/2016 |
| ST1 | Thị trấn Phú Lộc, huyện Thạnh Trị | 526978 | 1042802 | 103 | 3 | 96 | 99 | $qp_{2-3}$ | 9.76 | 12.02 |
| ST3 | Xã An Thạnh I, huyện Cù Lao Dung | 565003 | 1077291 | 130 | 8 | 118 | 126 | $qp_{2-3}$ | 8.53 | 10.61 |
| ST4 | Thị trấn Trần Đề, huyện Trần Đề | 576892 | 1050551 | 150 | 8 | 138 | 146 | $qp_{2-3}$ | 7.53 | 9.9 |
| ST7 | Xã Thạnh Phú, huyện Mỹ Xuyên | 538203 | 1050657 | 120 | 10 | 106 | 116 | $qp_{2-3}$ | 10.13 | 12.58 |
| ST11 | Xã Vĩnh Tân, huyện Vĩnh Châu | 542286 | 1030035 | 110 | 8 | 98 | 106 | $qp_{2-3}$ | 9.46 | 11.84 |

*Drilling*

The monitoring boreholes were created by the DWRPIS from December 17, 2012 to January 25, 2013, using the rotary drilling method with core sampling. The drilling diameter was 90 mm.

The well logging was carried out at all the 5 monitoring wells after core –drilling. The well screening position was decided by the well logging results and the on-site description of core samples.

After well logging, the boreholes were enlarged. The well casing consisted of a PVC pipe with a diameter of 114 mm from 0 – 60 m depth of the borehole and another PVC pipe with a diameter of 90 mm for the remainders. A protection steel tube with a length of 1.5 m and a diameter of 140 mm was installed on the well head.

After casing, the boreholes were flushed for 3 shifts (equivalent to 24 hours) per each, using the airlift pump. Information on discharge rate, static water level, dynamic water level and EC were recorded during the flushing process (Table 6).

*Geodetic survey*

A geodetic survey was carried out to determine the coordinates of the monitoring wells and the elevations of the top of casing. Results shown in Table 7.

Table 6. Information recorded during the IGPVN monitoring well flushing in Soc Trang province

| Well ID | Static water level (m) | Pumping rate (l/s) | Electrical conductivity (µS/cm) |
|---|---|---|---|
| ST1 | 8.38 | 4,30 | 1058 |
| ST3 | 7,55 | 11,01 | 626 |
| ST4 | 5,37 | 7,56 | 519 |
| ST7 | 9,00 | 1,70 | 1170 |
| ST11 | 9,00 | 6,60 | 1809 |

Table 7. Coordinates and elevations of the monitoring wells determined by geodetic measurement

| No. | Well ID | X (m) | Y (m) | Hmo(m) | Hb (m) |
|---|---|---|---|---|---|
| 1 | ST1 | 1042802.532 | 526978.250 | 2.07 | 1.3 |
| 2 | ST3 | 1077291.328 | 565003.795 | 2.46 | 1.7 |
| 3 | ST4 | 1050551.868 | 576892.001 | 2.45 | 1.8 |
| 4 | ST7 | 1050657.014 | 538203.453 | 2.80 | 2.15 |
| 5 | ST11 | 1030035.430 | 542286.340 | 1.98 | 1.27 |

*Hmo: elevation of the top of casing
*Hb: elevation of the benchmark

### 3.2. Core sampling and analysis

The drilling core samples were collected along the entire depth of the borehole and placed into a storage tray. Core samples were taken for lithological description every 2 m depth or when the strata was observed to change.

The core samples along the well screening position were analyzed for grain size distribution at the Laboratory of the DWRPIS. Details see Table 7. The required sample amount for grain size analysis was 300 – 500 g. Sieving method (applicable for the coarse grain size with a diameter of > 0.075 m) with the following sieving size was applied:

0.005 – 0.01 – 0.05 – 0.1 – 0.25 – 0.5 – 1 – 2 – 5 – 10 (mm)

Table 8. List of the drilling core samples taken for grain size analysis

| No. | Well ID | Screen depth (m, bgl) | Sample ID | Depth of sampling (m, bgl) | Lithology | Formation |
|---|---|---|---|---|---|---|
| 1 | ST1 | 93-99 | ST1_64 - 66 | 64 - 66 | Fine Sand | qp3, Long Mỹ |
| 2 | | | ST1_86-88 | 86-88 | Fine Sand | qp2-3, Long Toàn |
| 3 | | | ST1_92-94 | 92-94 | Fine Sand | qp2-3, Long Toàn |
| 4 | | | ST1_95-97 | 95-97 | Fine Sand | qp2-3, Long Toàn |
| 5 | | | ST1_99-100 | 99-100 | Fine Sand | qp2-3, Long Toàn |
| 6 | ST3 | 118-126 | ST3_73-75 | 73-75 | Fine Sand | qp3, Long Mỹ |
| 7 | | | ST3_87-89 | 87-89 | Fine Sand | qp3, Long Mỹ |
| 8 | | | ST3_93-95 | 93-95 | Fine Sand | qp2-3, Long Toàn |
| 9 | | | ST3_99-101 | 99-101 | Fine Sand | qp2-3, Long Toàn |
| 10 | | | ST3_105-107 | 105-107 | Fine Sand | qp2-3, Long Toàn |
| 11 | | | ST3_112-114 | 112-114 | Fine Sand | qp2-3, Long Toàn |
| 12 | | | ST3_117-119 | 117-119 | Fine Sand | qp2-3, Long Toàn |
| 13 | | | ST3_121-123 | 121-123 | Fine Sand | qp2-3, Long Toàn |
| 14 | | | ST3_127-129 | 127-129 | Fine Sand | qp2-3, Long Toàn |
| 15 | ST4 | 138 - 146 | ST4_15-17 | 15-17 | Fine Sand | Q2 |
| 16 | | | ST4_37-39 | 37-39 | Fine Sand | qp3, Long Mỹ |
| 17 | | | ST4_72-74 | 72-74 | Sand, silty | qp3, Long Mỹ |
| 18 | | | ST4_96-98 | 96-98 | Fine Sand | qp3, Long Mỹ |
| 19 | | | ST4_111-113 | 111-113 | Fine Sand | qp3, Long Mỹ |
| 20 | | | ST4_117-119 | 117-119 | Fine Sand | qp3, Long Mỹ |
| 21 | | | ST4_127-129 | 127-129 | Fine Sand | qp2-3, Long Toàn |
| 22 | | | ST4_135-137 | 135-137 | Fine Sand | qp2-3, Long Toàn |
| 23 | | | ST4_141-143 | 141-143 | Fine Sand | qp2-3, Long Toàn |
| 24 | | | ST4_148-150 | 148-150 | Fine Sand | qp2-3, Long Toàn |
| 25 | ST6 | | ST6_36-38 | 36-38 | Fine Sand | Q2 |
| 26 | | | ST7_54-56 | 54-56 | Fine Sand | qp3, Long Mỹ |
| 27 | | | ST6_84-86 | 84-86 | Fine Sand | qp3, Long Mỹ |
| 28 | | | ST6_102-104 | 102-104 | Fine Sand | qp2-3, Long Toàn |
| 29 | | | ST6_120-122 | 120-122 | Medium Sand | qp2-3, Long Toàn |
| 30 | | | ST6_141-144 | 141-144 | Fine Sand | qp1 |
| 31 | | | ST6_159-161 | 159-161 | Fine Sand | qp1 |
| 32 | | | ST6_188-190 | 188-190 | Silt | qp1 |
| 33 | ST7 | 108-118 | ST7_31-33 | 31-33 | Sand, silty | qp3, Long Mỹ |
| 34 | | | ST7_46-48 | 46-48 | Sand, silty | qp3, Long Mỹ |
| 35 | | | ST7_60-62 | 60-62 | Silt | qp2-3, Long Toàn |
| 36 | | | ST7_73-75 | 73-75 | Fine Sand | qp2-3, Long Toàn |
| 37 | | | ST7_90-92 | 90-92 | Fine Sand | qp2-3, Long Toàn |
| 38 | | | ST7_96-98 | 96-98 | Fine Sand | qp2-3, Long Toàn |
| 39 | | | ST7_102-104 | 102-104 | Fine Sand | qp2-3, Long Toàn |

| No. | Well ID | Screen depth (m, bgl) | Sample ID | Depth of sampling (m, bgl) | Lithology | Formation |
|---|---|---|---|---|---|---|
| 40 | | | ST7_108-110 | 108-110 | Fine Sand | qp2-3, Long Toàn |
| 41 | | | ST7_113-115 | 113-115 | Fine Sand | qp2-3, Long Toàn |
| 42 | | | ST7_118-120 | 118-120 | Fine Sand | qp2-3, Long Toàn |
| 43 | ST11 | 98-106 | ST11_79-81 | 79-81 | Medium Sand | qp3, Long Mỹ |
| 44 | | | ST11_83-85 | 83-85 | Medium Sand | qp3, Long Mỹ |
| 45 | | | ST11_88-90 | 88-90 | medium - Coarse Sand | qp2-3, Long Toàn |
| 46 | | | ST11_93-95 | 93-95 | medium - Coarse Sand | qp2-3, Long Toàn |
| 47 | | | ST11_97-99 | 97-99 | medium - Coarse Sand | qp2-3, Long Toàn |
| 48 | | | ST11_102-104 | 102-104 | medium - Coarse Sand | qp2-3, Long Toàn |
| 49 | | | ST11_107-109 | 107-109 | medium - Coarse Sand | qp2-3, Long Toàn |

## 3.3. Water sampling and analysis

### *3.3.1. Sampling for hydrochemical analysis*

The IGPVN project carried out two sampling field trips in Soc Trang in April 2013 (dry season) and November 2013 (rainy season) to assess the hydrochemical characteristics and the connection between surface water and groundwater. The duplicated water samples collected during the two sampling campaigns in Soc Trang include:

- Groundwater samples at the five IGPVN monitoring wells in Soc Trang
- Groundwater samples at the three private tube wells in Tran De, Vinh Chau and My Tu districts in Soc Trang province
- Surface water samples collected at the Nhu Gia canal (My Xuyen district), Tran De estuary (Hau river, Tran De district), Tran De branch (Hau river, Cu Lao Dung district) and Phung Hiep canal (My Tu district)

Water sampling locations are mapped in Figure 2. Details on water samples collected are summarized in Table 9.

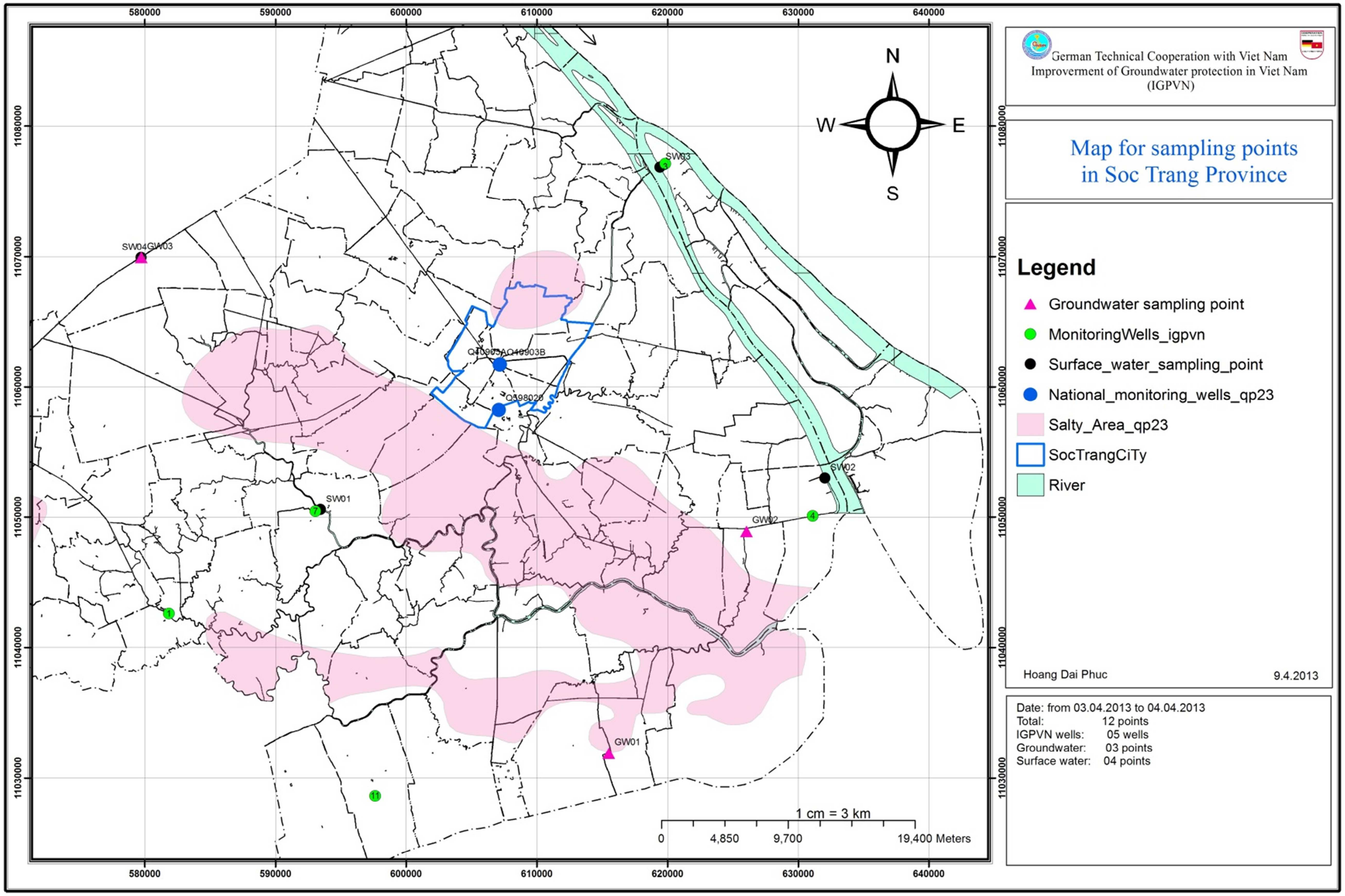


Figure 2. Map of the water sampling location in Soc Trang province in April and November, 2013

Table 9. Water samples collected in Soc Trang province in April and November 2013

| Sample ID | X | Y | Location |
|---|---|---|---|
| ST1 | 526978 | 1042802 | Phú Lộc town, Thạnh Trị district |
| ST3 | 565003 | 1077291 | An Thạnh I commune, Cù Lao Dung district |
| ST4 | 576892 | 1050551 | Trần Đề town, Trần Đề district |
| ST7 | 538203 | 1050657 | Thạnh Phú commune, Mỹ Xuyên district |
| ST11 | 542286 | 1030035 | Vĩnh Tân commune, Vĩnh Châu district |
| GW1 | 560389 | 1031900 | 7A village, Lai Hòa commune, Vĩnh Châu district |
| GW2 | 570941 | 1048950 | Lịch Hội Thượng town, Trần Đề district |
| GW3 | 524586 | 1069942 | Hưng Phú commune, Mỹ Tú district |
| SW1 | 538356 | 1050585 | Nhu Gia canal, Thạnh Phú commune, Mỹ Xuyên district |
| SW2 | 576897 | 1052995 | Trần Đề estuary, Trần Đề town, Trần Đề district |
| SW3 | 564363 | 1076776 | Trần Đề branch - Hậu river, An Thạnh I commune, Cù Lao Dung district |
| SW4 | 524586 | 1069942 | Phụng Hiệp canal, Hưng Phú commune, Mỹ Tú district |

At each monitoring well, the static water level was measured using a dipper before removing all the stagnant water in the monitoring well. Water in the monitoring well was pumped out (3 times of the well volume) using a specialized MP1 pump (Grundfos). The MP1 submersible pump is designed for the purging and sampling of contaminated groundwater in boreholes with an internal diameter of at least 50 mm. The pump is powered via an adjustable converter in the 25 to 400 Hz frequency range. At 400 Hz, the pump provides a flow rate of 1 $m^3/h$ at a 74 m water head.

The actual flow rate was measured by counting the amount of time it takes the extracted water to fill up the 18 L plastic bucket.

Water in the private tube well was pumped out for 5 minutes before sampling.

Surface water samples were taken at a depth around 50 cm from the water surface to minimize evaporation effect and from 1 – 2 m apart from the bank to ensure the representativeness of the samples.

Some in-situ parameters (pH, EC, ORP) were measured using WTW 340i.

A sample set collected at each sampling location includes one 500 mL PE bottle for anion analysis, one 100 mL PE bottle for cation analysis and one 100 mL PE bottle for stable isotope ($^{2}H$, $^{18}O$) analysis.

Sampling bottles were rinsed three times with the water sample solution before sampling. Groundwater sample for cation analysis was filtered on site using a 0.45 µm filter unit combined with a plastic syringe and then acidified with concentrated nitric acid (2% volume). Water samples after collected were packed and sent to the Water Laboratory in the

Federal Institute for Geosciences and Natural Resources (BGR, Hanover, Germany) for chemical analysis. The chemical analytical results of water samples collected in April and November 2013 are shown in Table 13 and Table 14, respectively.

The chemical analytical data was analyzed using AquaChem software to check for reliability (calculating the charge balance error) and create Piper diagram to determine the hydrochemical facies of water samples and illustrate the chemical variation in major ion compositions.

The charge balance error is calculated using the following formula:

$$CBE = \frac{\sum m_c Z_c - \sum \; m_a \, |Z_a|}{\sum m_c Z_c + \sum \; m_a \, |Z_a|} \times 100\ \%$$

The charge balance errors of the 24 water samples were within ±2%.

Relevant ratios between major ions were considered. Graphs showing the major ion contents, the relation between major ion ratios and stable isotope compositions were plotted using SigmaPlot software.

### 3.3.2. Sampling for groundwater dating and recharge

*Sampling location*

The IGPVN project in cooperation with Soc Trang Department of Natural Resources and Environment (DONRE) and the Institute for Nuclear Sciences and Technology (INST) conducted a field survey to collect water samples in Soc Trang province for the determination of groundwater age and origin using radioactive isotopes ($^{14}C$ and $^{3}H$) and stable isotopes ($^{2}H$, $^{18}O$). Groundwater samples were taken from 7 monitoring wells of the National Monitoring Network, 1 IGPVN monitoring well) and 5 production wells of the water treatment plants in the five districts of My Xuyen, Long Phu, Thanh Tri, Tran De and Vinh Chau. Surface water samples were collected from ponds or canals nearby the groundwater sampling locations. The sampling locations are mapped in Figure 3. The collected water samples are listed in Table 10.

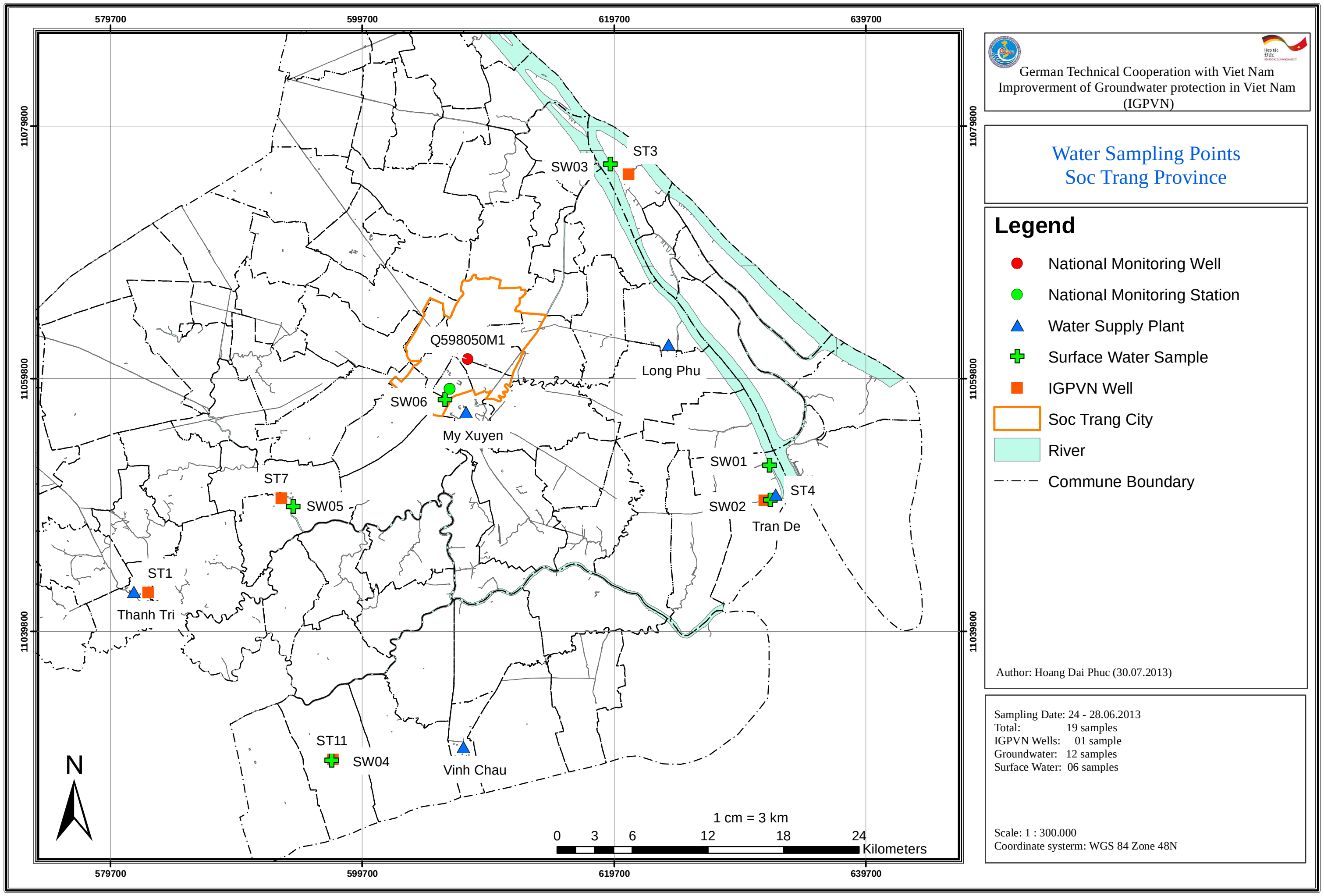


Figure 3. Location map of water sampling for radioactive isotopes ($^{14}C$ and $^{3}H$) and stable isotopes ($^{2}H$, $^{18}O$) in Soc Trang province in June, 2013.

Table 10. Water samples collected in Soc Trang province in 6/2013 for $^{14}C$ and $^{3}H$ dating

| Sample ID | Location | Well depth (m) | Aquifer | Target analytes |
|---|---|---|---|---|
| Q59801T | Trạm quan trắc Quốc gia NDĐ tại chùa Dơi | 4.5 | qh | $^{14}C$, $^{3}H$ |
| Q598020 | | 108 | $qp_{2-3}$ | $^{14}C$, $^{3}H$ |
| Q59804T | | 234.2 | $n_2^2$ | $^{14}C$, $^{3}H$ |
| Q59804Z | | 360.9 | $n_1^3$ | $^{14}C$ |
| Q598030 | | 154.4 | $qp_1$ | $^{3}H$ |
| Q59801Z | | 26.2 | qh | $^{3}H$ |
| Q598050M1 | Trạm quan trắc Quốc gia NDĐ Q598050 tại Trung tâm Thể dục thể thao Tp. Sóc Trăng | 439 | $n_1^3$ | $^{14}C$ |
| ST 3 | Trạm quan trắc ST3 của Dự án IGPVN | 130 | $qp_{2-3}$ | $^{14}C$, $^{3}H$ |
| PW1 | Trạm cấp nước Thạnh Trị | 140 | $qp_{2-3}$ | $^{14}C$, $^{3}H$ |
| PW2 | Trạm cấp nước Mỹ Xuyên | 475 | $qp_{2-3}$ | $^{14}C$, $^{3}H$ |
| PW3 | Trạm cấp nước Long Phú | 120 | $qp_{2-3}$ | $^{14}C$, $^{3}H$ |
| PW4 | Trạm cấp nước Trần Đề | 160 | $qp_{2-3}$ | $^{14}C$, $^{3}H$ |
| PW5 | Trạm cấp nước Vĩnh Châu | 300 | $qp_{2-3}$ | $^{14}C$, $^{3}H$ |
| SW5 | ao cạnh trạm cấp nước Trần Đề | | | $^{3}H$ |
| SW6 | kênh Vĩnh Tân (gần giếng ST11) | | | $^{3}H$ |
| SW7 | kênh Tà Lách (gần chùa Dơi) | | | $^{3}H$ |
| Total | $^{14}C$ | | | 11 |
| | $^{3}H$ | | | 14 |

*Sampling procedure and equipments*

Groundwater in the monitoring well was pumped out until pH or EC became stable using MP1 pump (Grundfos, Germany). Then, a staff of the INST conducted a sampling procedure to collect the total dissolved inorganic carbon (TDIC) in water for $^{14}C$ and $^{13}C$ determination. TDIC is defined as the total bicarbonate ($HCO_3^-$) and free carbon dioxide ($CO_{2,aq}$) if any, dissolved in groundwater. The $CO_{2aq}$ ultimately will become bicarbonate after the alkalization of water sample to pH 10 – 11.

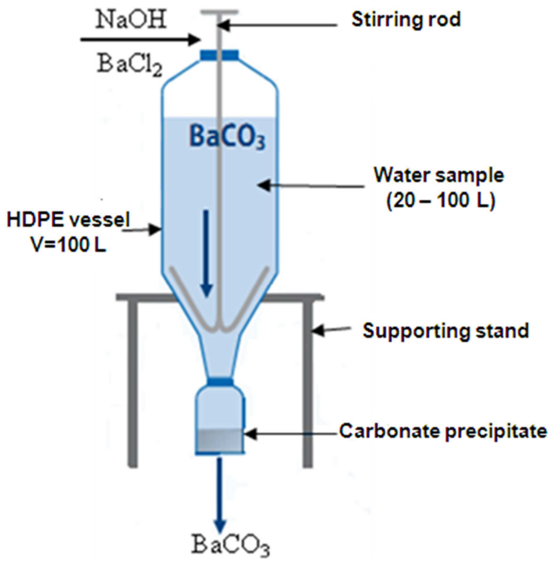


Figure 4. A device used to collect TDIC in groundwater samples

Approximately 80 L of groundwater was pumped into a special HDPE vessel of funnel-shaped bottom joined with one plastic bottle (Figure 4) and alkalized with NaOH ($CO_2$ free) to pH 10 – 11. The water was mixed well using a stirring rod and checked for the pH using pH paper. Then, the $BaCl_2$ solution was added in excess to the vessel in order to precipitate all the carbonate content in the form of $BaCO_3$. It was necessary to check whether all the bicarbonate has been precipitated by adding a small portion of $BaCl_2$ solution to the vessel. If no more precipitate appears upon adding $BaCl_2$ solution to the vessel, then TDIC has completely precipitated. The vessel was closed to prevent the mixing of $CO_2$ from the atmosphere and was left undisturbed for 1 hour so that all the $BaCO_3$ precipitate settled down to the bottom and entered the plastic bottle. Before removing the receiving bottle, a cap attached to the stirring rod was used to close the connection between the vessel and bottle. The precipitate was transferred from the plastic bottle to a 2L PE can which was tightly capped to avoid air contact. The amount of precipitate collected was at least 20 g (equivalent to 4 g Carbon). The TDIC samples should be preferably transported as soon as possible to the laboratory for analysis.

Groundwater samples for tritium and stable isotopes were taken directly into 500 mL PET bottles. Surface water samples were taken at a depth around 50 cm from the surface to minimize evaporation effect and when possible 1 – 2 m apart from the bank to ensure the representativeness of samples.

All precipitates and water samples were packed into boxes and sent to the Isotope Hydrology Laboratory in the Institute for Nuclear Science and Technology (179 Hoang Quoc Viet Street, Hanoi) for $^{14}C$ and $^{13}C$ determination.

*Laboratory sample treatment*

Carbonate precipitate samples were washed several times with hot distilled water (to eliminate dissolved $CO_2$ from the air), then subject to freeze drying for further analysis of $^{14}C$ and $^{13}C$ composition. Sample containing high salt content should be washed with hot distilled water several times until the chlorine content in the washing water is low.

Absorption method was applied to determine the $^{14}C$ activity in TDIC. The procedure is as follows (Quireshi, 1989):

$$Ba^{14}CO_3 + H_3PO_4 \rightarrow {}^{14}CO_2\uparrow + Ba^{2+} + PO_4^{3-} + H_2O \quad (1)$$

$$^{14}CO_2 + \text{ethanolamine} \rightarrow {}^{14}CO_2 \text{ in ethanolamine} \quad (2)$$

Figure 5 depicts a scheme of the $CO_2$ absorption device. The absorbed $^{14}CO_2$ in ethanolamine was mixed with a liquid scintillation cocktail and measured for $^{14}C$ activity.

Water samples to be analyzed for $^3H$ were distilled to eliminate all the minerals present till their electrical conductivity reduce to less than 10 µS/cm.

*$^{14}C$, $^{13}C$ và $^3H$ analysis*

5 mL of the $CO_2$ trapping solution was mixed with 15 mL of HP cocktail in a HDPE vial (20 mL capacity) for $^{14}C$ counting using a HP TriCarb 3170 TR (ultralow background). The background of the sampling instrument was checked with the cocktail for 86 000 seconds until it was lower than 0.1 Bq. The precision of the instrument is better than 10 % if the $^{14}C$ activity is in the range of 0.2 – 0.3 Bq $g^{-1}$ C (the standard used for the $^{14}C$ dating method). The mixture was counted for 24 hrs in order to achieve an uncertainty better than 7 %. Oxalic acid II was used as standard supplied by the International Atomic Energy Agency (IAEA).

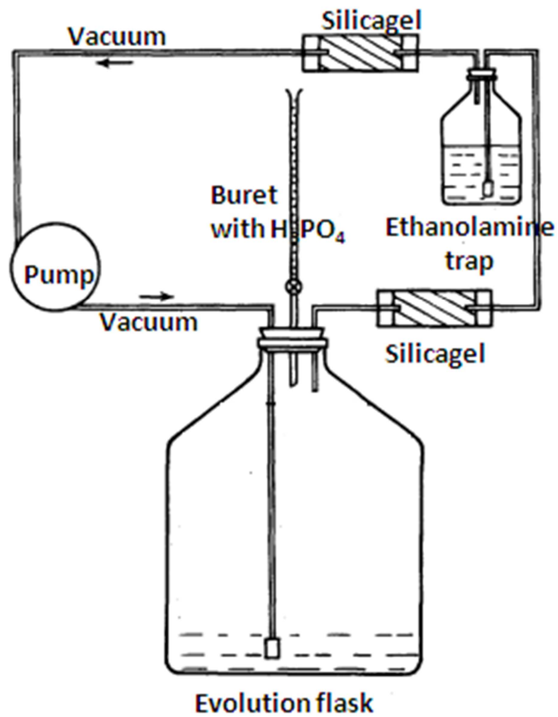


Figure 5. Scheme of the device used to trap $CO_2$ evolved from the reaction between $BaCO_3$ and $H_3PO_4$ 1M (adapted from H.R. Feltz and B.B. Handshaw, 1963)

The $^{13}C$ composition in TDIC was analyzed using a Gas Chromatography – Isotope Ratio Mass Spectroscopy (GC – IRMS by Micro mass, GV Instrument) equipped with a pyrolysis device (Eurovector, Italy). An amount of the freeze dried carbonate precipitate of around 50 µg C was wrapped into tin capsules and then loaded in an autosampler of IRMS and dropped into an oven of 1050 $^oC$ to decompose carbonate into $CO_2$. This gas will pass through a gas chromatographic column to purify off any contaminant before entering an ionization source chamber and then an electro-magnetic field to separate by mass numbers 44 ($^{12}CO_2$) and 45 ($^{13}CO_2$). The standard used for $^{13}C$ composition in TDIC is VDPB (Vienna Dee Pee Belemnite). The precision of the measurement was ±0.2 ‰.

Before counting for $^3H$ activity, the purified water sample was electrochemically enriched by reducing its initial 500 mL to 10 mL and then mixed with 10 ml HP cocktail with a low Tritium level. The mixture was counted for $^3H$ using a HP TriCarb 3170 TR. The counting time was 1000 seconds, breaking into 10 cycles, 100 minutes for each cycle. The Limit of Detection (LOD) of the method was ±0.46 TU (tritium unit) (1 TU = 0.118 Bq/L). The accuracy of the analysis was better than 5 % in a range of $^3H$ activity within 1 – 4 TU as verified by the TRI-004/TRI-2008 matching program of IAEA.

*Groundwater dating using $^3H$:*

Tritium (T or $^3H$) is a radioactive isotope of hydrogen (H) which is produced naturally in small amounts by the interaction of cosmic rays with the Earth's atmosphere. Cosmogenic $^3H$ enters groundwater by way of rainfall at a concentration of approximately 3-5 TU (Kaufman and Libby, 1954; Robertson and Cherry, 1989). With the onset of atmospheric nuclear testing in 1953, the $^3H$ concentration in rainfall at some places increased to as high as 700 TU in 1963 and gradually decreased afterward. Because of the difference in $^3H$ concentration in rainwater before and after 1953, $^3H$ has been used as a hydrologic tracer to date recent groundwater (Coplen, 1988).

- Groundwater contains $^3H$ activity comparable to that of surface water is considered to be young. In this case, surface water has concentration of $^3H$ within a range of 1.0 – 1.5 TU.
- Groundwater contains $^3H$ activity lower than the LOD of the procedure is considered to be older than 70 years, i.e. it occurred before 1950.

The half-life of $^3H$ is 12.43 years, which means that the $^3H$ concentration decreases by a half after every 12.43 years.

*Groundwater dating using $^{14}C$:*

Carbon-14 is a radioactive isotope of carbon (C) formed by the reaction between cosmic rays and nitrogen in the atmosphere. $^{14}C$ combines with oxygen (O) to form carbon dioxide ($CO_2$), which is taken up by plants or absorbed by rain and is found in surface water bodies. When plants, animals and groundwater are no longer exposed to the atmospheric $CO_2$, the $^{14}C$ content begins to decay radioactively. The radiocarbon content of groundwater decreases at a rate controlled by the half-life of $^{14}C$, which is 5,715 years (Coplen 1993). Therefore, water that has been underground for an extended period of time will have a lower concentration of $^{14}C$ than water that has only recently entered the ground and is isolated from atmospheric $CO_2$.

The measured $^{14}C$ content of groundwater is expressed as a percentage of the modern $^{14}C$ content of groundwater, or percent modern carbon (pmC). Because the content of $^{14}C$ in the atmosphere increased after the above-ground nuclear testing in 1953, 1950 is the base year for modern $^{14}C$. The standard for modern $^{14}C$ content is oxalic acid II.

The formula applied to estimate the age of a groundwater sample by $^{14}C$ activity in TDIC is:

$$t_{^{14}C} = 8268 \ln \frac{^{14}a_{in}^{0}}{^{14}a_{sample}} \text{ (year)} \qquad (1)$$

where ${}^{14}a_{in}^{0}$ is initial ${}^{14}C$ activity. It is the relative (to the NIST oxalic acid II standard) activity of ${}^{14}C$ in TDIC (in pmC) at the moment when water entered an interested aquifer; and ${}^{14}a_{sample}$ is the relative activity of ${}^{14}C$ in TDIC (in pmC) of the taken water sample.

The ${}^{14}a_{in}^{0}$ is estimated using a model suggested by Gonfiantini et al. (1980) with ${}^{13}C$ composition correction. The model is as follows:

$$ {}^{14}a_{in}^{0} = \frac{\left(\delta^{13}C_{TDIC} - \delta^{13}C_{CaCO_3}\right)}{\delta^{13}C_{CO_2} - \delta^{13}C_{CaCO_3} + \varepsilon_{CO_2/CaCO_3}} .100 \text{ (pmC)} \qquad (2) $$

where $\delta^{13}C_{TDIC}$ (in ‰)derived from experimental measurement is the difference in ${}^{13}C/{}^{12}C$ ratios between the TDIC samples and the standard VDPB:

$$ \delta^{13}C_{TDIC} = \frac{{}^{13}R_{sample} - {}^{13}R_{std}}{{}^{13}R_{std}} \times 1000 $$

$\delta^{13}C_{CaCO_3}$ is the ${}^{13}C$ composition of calcite in the aerated zone; $\delta^{13}C_{CO_2}$ is the ${}^{13}C$ composition of carbon dioxide in the aerated zone; $\varepsilon_{CO_2/CaCO_3}$ is a factor corrected for isotopic fractionation of ${}^{13}C$ between carbon dioxide and calcite when the mineral dissolved.

Gonfiantini and his co-workers proposed that the values of $\delta^{13}C_{CaCO_3}$, $\delta^{13}C_{CO_2}$ and $\varepsilon_{CO_2/CaCO_3}$ to be respectively 2‰, -23‰ and 7‰.

In formula (2) with the value of $\delta^{13}C_{TDIC}$ that has been derived from experimental measurement one can estimate ${}^{14}a_{in}^{0}$ . Then with formula (1) and the value of ${}^{14}a_{sample}$ , the age (in years) of the water sample can be calculated.

Groundwater dating using ${}^{14}C$ with correction for ${}^{13}C$ composition in TDIC is applied for the cases when ${}^{14}C$ activity in TDIC was low (${}^{14}a_{sample} \leq 80$ pmC). If ${}^{14}a_{sample}$ in TDIC is close to 100 pmC, the Gonfiantini model is not recommended to use. In that case, the age of the water sample is simply estimated by the following formula:

$$ t_{TDIC} = 8268 \ln \frac{100}{{}^{14}a_{sample}} \text{ (year)} \qquad (3) $$

The uncertainty of the age estimate by the ${}^{14}C$ dating method in the case of ${}^{14}a_{sample} \geq$ 80 pmC was 6 – 7%. This figure was estimated based on the fact that the uncertainty of the half-live of ${}^{14}C$ was 3%, the uncertainty of ${}^{14}a_{sample}$ measurement in the lab was 5% and the uncertainty of ${}^{14}a_{in}^{0}$ was 5%.

In cases of low or very low $^{14}a_{sample}$ ($\leq 60$ pmC), the uncertainty of the half-live of $^{14}C$ was 3%, the uncertainty of $^{14}a_{sample}$ measurement in the lab was 7% and 3% of $^{13}C$ composition correction for $^{14}a_{in}^{0}$. The resulting total uncertainty for age estimation for old and very old water samples is usually in the range of 8 – 9%.

### 3.4. Groundwater level monitoring

*Monitoring equipment*

A semi-automatic monitoring device (Diver) is installed in the monitoring well to measure a number of physical parameters of groundwater: pressure, temperature, electrical conductivity.

There are several types of Divers that can be used in different water environments. The IGPVN project is using the Diver of **Schlumberger Water Services** © as below:

- Mini-Diver: use for fresh water
- Cera-Diver, CTD-Diver: use for brackish water
- Baro-Diver: measure air pressure within the radius of 15 – 20 km.

The Baro-diver is installed in four out of five monitoring wells in Soc Trang. The air pressure needs to be measured simultaneously with the hydrostatic pressure for barometric compensation and then, calculation of the height of the water column above the Diver and the static water level (above sea level) in the monitoring well. The Diver was dropped into the monitoring well after attached to a segment of plastic cable (fishing line) instead of metallic cable in order to prevent the cable from corrosion. The supporting cable that suspends the Diver was attached near the top of casing to provide access to the Diver when needed.

*Data extraction device*

- laptop, desktop
- Handheld Trimble Nomad
- Diver USB Reading Unit Type AS330: to connect a Diver to a desktop, laptop or Trimble to:

  + set up a monitoring program for a Diver

  + Start/Stop a Diver

  + download the monitoring data

*Diver-Office software*

The Diver-Office 2013 released by **Schlumberger Water Services** © is the software to go with the Diver and has the following main functions:

- Read the monitoring data of Diver
- Set up the monitoring programs for Diver
- Start/Stop Diver in different ways
- Import and Export monitoring data in different formats (CSV, MON)
- View timeline monitoring data in table or graph
- Compensate barometeric pressure to calculate static water level (above sea level)

Details on Diver and Diver-Office manual can be seen in the IGPVN Guidebook on Diver-Office utilization and Diver-Office database management.

*Periodical check and extraction of the monitoring data*

The Diver and Baro-Diver were installed in the IGPVN monitoring wells in Soc Trang sin April 2013. Since then, the IGPVN project in cooperation with Soc Trang DONRE checked the monitoring wells, Diver and extracted the monitoring data every 3-4 months. Static water levels in the monitoring wells were also measured using a dipper in order to compare and verify the water levels recorded by Diver.

Generally, the monitoring data of ST1 and ST11 were almost continuous since April 2013. However, the monitoring data of the other three monitoring wells (ST3, ST4, ST7) were discontinuous due to the malfunctioned Divers were not uncovered and replaced immediately.

*Calculation of the static water level (asl)*

The static water level was calculated from the hydrostatic pressure using the air pressure for barometric compensation. The air pressure recorded at ST3, ST7 and ST11 was not continuous; therefore, we had to interpolate those data sets using the continuous data set of ST4. The air pressure at ST7 was used for the calculation of the static water level at ST1 due to their close distance.

### 3.5. Capacity building for Soc Trang DONRE

*Equipment*

The equipments necessary for groundwater monitoring was handed over to the Soc Trang DONRE:

- Diver, Baro-Diver
- 01 Trimble, 01 notebook EEC touch, 01 laptop, Diver USB reading unit
- MP1 pump and converter
- Honda Power generation

*Training*

Training for staff in charge of the monitoring well operation was organized on site and in office in order to make them possible to use the necessary equipments and software.

*Study tour on water resource management*

The IGPVN project supported the Soc Trang DONRE to organize a study tour for their staff to Nam Dinh DONRE to learn about implementation of the project activities, water resource planning, operation of groundwater monitoring network and organization of IWRM workshop.

By doing this study tour and field visit in Nam Dinh, the Soc Trang DONRE staff aquired valuable experiences:

+ the need to develop a monitoring plan and to supervise the implementation and compliance of the plan in order to ensure the accuracy, continuity and consistency of the monitoring data

+ the need to coorperate with the local people in groundwater monitoring

+ the need for specialized training for the staff in charge of operating the monitoring wells

+ operating and checking the monitoring equipment (Diver)

*IWRM workshop*

In frame of IGPVN project 2015 – 2017, as agreed between Soc Trang DONRE and the IGPVN project, the Soc Tran DONRE will organize 2 IWRM workshop with the support of IGPVN in order to enhanced networking in water resource sector with other provinces; especially with the coastal provinces of similar natural conditions with Soc Trang to share information, experiences on water resource management, and with the upstream provinces to share the rights and responsibilities related to the inter-provincial river water.

*Guide book*

The IGPVN project supported and cooperated with Soc Trang DONRE to develop 2 Guide books:

- Guide book on water resource management – for local authorities

- Guide book on application of the legal documents on water resource exploitation, utilization and protection – for enterprises and companies

# 4. Study results

## 4.1. Grain size analysis results

The results of the grain size analysis are shown in Table 11. The hydraulic conductivity was calculated basing on the grain size analysis results using Sizeperm. The calculation results are shown in Table 12. More details see Technical Report No. 39.

Table 11. Grain size analysis results

| No. | Well | Formation | Depth of sampling (below ground) (m) | Passing (%) | | | | | | | | | | | Soil Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Gravel | | | Sand | | | | Silt | | Clay | | |
| | | | | Particle Diameter ( mm ) | | | | | | | | | | | |
| | | | | > 10 | 10 - 5 | 5 - 2 | 2 - 1 | 1 – 0.5 | 0.5 – 0.25 | 0,25 – 0.10 | 0.10 – 0.05 | 0.05 – 0.01 | 0.01-0.005 | < 0.005 | |
| 1 | ST1 | qp3 | 64-66 | | | | | | 54.3 | 21.8 | 10.7 | 13.2 | - | - | Medium-grain Sand |
| 2 | | qp2-3 | 86-88 | | | | | | 43.1 | 46.9 | 2.6 | 7.4 | - | - | Fine Sand |
| 3 | | qp2-3 | 92-94 | | | | | 2.1 | 16.5 | 53.7 | 13.4 | 14.3 | - | - | Silty Sand |
| 4 | | qp2-3 | 95-97 | | | | | | 54.6 | 24.1 | 6.7 | 14.6 | - | - | Fine Sand |
| 5 | | qp2-3 | 99-100 | | | 8.9 | 7.2 | 16.8 | 25.1 | 25.3 | 2.9 | 13.8 | - | - | Medium-grain Sand |
| 6 | ST3 | qp3 | 73-75 | | | | | 0.9 | 9.8 | 61.2 | 18.7 | 9.4 | - | - | Silty Sand |
| 7 | | qp3 | 87-89 | | | | | 1.1 | 24.7 | 53.8 | 7.9 | 12.5 | - | - | Fine Sand |
| 8 | | qp2-3 | 93-95 | | | | 0.8 | 1.2 | 26.4 | 49.2 | 9.6 | 12.8 | - | - | Fine Sand |
| 9 | | qp2-3 | 99-101 | | | | | 1.9 | 47.6 | 35.1 | 4.5 | 10.9 | - | - | Fine Sand |
| 10 | | qp2-3 | 105-107 | | | | | 1.8 | 42.9 | 39.8 | 5.4 | 10.1 | - | - | Fine Sand |
| 11 | | qp2-3 | 112-114 | | | | | 1.5 | 35.4 | 43.2 | 7.5 | 12.4 | - | - | Fine Sand |

| No. | Well | Formation | Depth of sampling (below ground) (m) | Passing (%) | | | | | | | | | | | Soil Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Gravel | | | Sand | | | | | Silt | | Clay | |
| | | | | Particle Diameter ( mm ) | | | | | | | | | | | |
| | | | | > 10 | 10 - 5 | 5 - 2 | 2 - 1 | 1 – 0.5 | 0.5 – 0.25 | 0,25 – 0.10 | 0.10 – 0.05 | 0.05 – 0.01 | 0.01-0.005 | < 0.005 | |
| 12 | | qp2-3 | 117-119 | | | | | 1.6 | 47.9 | 34.7 | 4.3 | 11.5 | - | - | Fine Sand |
| 13 | | qp2-3 | 121-123 | | | | | 2.1 | 57.2 | 30.6 | 2.5 | 7.6 | - | - | Medium-grain Sand |
| 14 | | qp2-3 | 127-129 | | | | 0.7 | 6.9 | 28.5 | 34.7 | 10.8 | 8.3 | 4.9 | 5.2 | Clayey Sand |
| 15 | ST4 | Q2 | 15-17 | | | | | | 8.3 | 45.9 | 21.4 | 9.2 | 5.4 | 9.8 | Clayey Sand |
| 16 | | qp3 | 37-39 | | | | | | 3.9 | 59.6 | 22.7 | 13.8 | - | - | Silty Sand |
| 17 | | qp3 | 72-74 | | | | 0.9 | 1.2 | 6.1 | 49.5 | 13.7 | 12.1 | 6.8 | 9.7 | Clayey Sand |
| 18 | | qp3 | 96-98 | | | 0.9 | 2.1 | 4.1 | 14.8 | 42.7 | 23.5 | 11.9 | - | - | Silty Sand |
| 19 | | qp3 | 111-113 | | | 2.1 | 2.3 | 3.5 | 7.6 | 39.8 | 32.1 | 12.6 | - | - | Silty Sand |
| 20 | | qp3 | 117-119 | | | 5.4 | 15.7 | 33.8 | 25.7 | 10.9 | 2.4 | 6.1 | - | - | Coarse Sand |
| 21 | | qp2-3 | 127-129 | | | 1.5 | 3.8 | 12.1 | 21.3 | 34.1 | 14.3 | 12.9 | - | - | Silty Sand |
| 22 | | qp2-3 | 135-137 | | | 1.6 | 3.4 | 12.9 | 34.8 | 35.2 | 5.6 | 6.5 | - | - | Medium-grain Sand |
| 23 | | qp2-3 | 141-143 | | | | 0.9 | 1.8 | 25.4 | 47.6 | 9.5 | 14.8 | - | - | Fine Sand |

| No. | Well | Formation | Depth of sampling (below ground) (m) | Passing (%) | | | | | | | | | | | Soil Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Gravel | | | Sand | | | | | Silt | | Clay | |
| | | | | Particle Diameter ( mm ) | | | | | | | | | | | |
| | | | | > 10 | 10 - 5 | 5 - 2 | 2 - 1 | 1 – 0.5 | 0.5 – 0.25 | 0,25 – 0.10 | 0.10 – 0.05 | 0.05 – 0.01 | 0.01-0.005 | < 0.005 | |
| 24 | | qp2-3 | 148-150 | | | | 1.1 | 2.3 | 20.7 | 53.4 | 7.8 | 14.7 | - | - | Fine Sand |
| 25 | ST6 | Q2 | 36-38 | | | | | 1.9 | 46.5 | 42.7 | 3.1 | 5.8 | - | - | Fine Sand |
| 26 | ST6 | qp3 | 54-56 | | | | | 0.7 | 0.8 | 54.9 | 21.8 | 9.7 | 5.4 | 6.7 | Clayey Sand |
| 27 | ST6 | qp3 | 84-86 | | | | | 12.1 | 68.2 | 14.6 | 1.9 | 3.2 | - | - | Medium-grain Sand |
| 28 | ST6 | qp2-3 | 102-104 | 7.4 | 5.2 | 6.8 | 3.9 | 41.3 | 19.4 | 2.5 | 1.4 | 12.1 | - | - | Coarse Sand and gravel |
| 29 | ST6 | qp2-3 | 120-122 | | | | 18.1 | 50.4 | 19.1 | 6.4 | 1.3 | 4.7 | - | - | Coarse Sand |
| 30 | ST6 | qp1 | 141-144 | | | | 2.5 | 33.2 | 29.5 | 27.6 | 2.7 | 4.5 | - | - | Medium-grain Sand |
| 31 | ST6 | qp1 | 159-161 | | | | 1.3 | 42.5 | 37.2 | 11.7 | 1.4 | 5.9 | - | - | Medium-grain Sand |
| 32 | ST6 | qp1 | 188-190 | | | 0.8 | 0.9 | 1.5 | 8.6 | 54.2 | 14.9 | 9.8 | 4.1 | 5.2 | Clayey Sand |
| 33 | ST7 | qp3 | 31-33 | | | | | | | 0.8 | 29.3 | 31.2 | 7.8 | 30.9 | Sandy clay |
| 34 | ST7 | qp3 | 46-48 | | | | | | | 1.6 | 34.5 | 28.9 | 5.6 | 29.4 | Sandy clay |
| 35 | ST7 | qp2-3 | 60-62 | | | | | | 5.4 | 28.9 | 21.8 | 6.5 | 6.9 | 30.5 | Sandy clay |

| No. | Well | Formation | Depth of sampling (below ground) (m) | Passing (%) | | | | | | | | | | | Soil Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Gravel | | | Sand | | | | | Silt | | Clay | |
| | | | | Particle Diameter ( mm ) | | | | | | | | | | | |
| | | | | > 10 | 10 - 5 | 5 - 2 | 2 - 1 | 1 – 0.5 | 0.5 – 0.25 | 0,25 – 0.10 | 0.10 – 0.05 | 0.05 – 0.01 | 0.01-0.005 | < 0.005 | |
| 36 | | qp2-3 | 73-75 | | | | | 1.0 | 17.6 | 50.4 | 14.9 | 6.2 | 4.8 | 5.1 | Clayey Sand |
| 37 | | qp2-3 | 90-92 | | | | | 0.6 | 1.5 | 19.8 | 48.7 | 14.1 | 6.9 | 8.4 | Clayey Sand |
| 38 | | qp2-3 | 96-98 | | | | | 0.7 | 2.1 | 35.6 | 29.8 | 17.8 | 7.1 | 6.9 | Clayey Sand |
| 39 | | qp2-3 | 102-104 | | 1.8 | 4.9 | 1.5 | 3.2 | 10.3 | 41.2 | 17.1 | 11.5 | 3.7 | 4.8 | Clayey Sand |
| 40 | | qp2-3 | 108-110 | | | | | | 3.8 | 58.1 | 16.2 | 9.7 | 4.6 | 7.6 | Clayey Sand |
| 41 | | qp2-3 | 113-115 | | | | | 1.6 | 8.1 | 63.8 | 13.1 | 13.4 | - | - | Silty Sand |
| 42 | | qp2-3 | 118-120 | | 5.9 | 2.3 | 1.2 | 6.9 | 34.6 | 24.7 | 10.9 | 13.5 | - | - | Fine Sand |
| 43 | | qp3 | 79-81 | | | | 0.7 | 2.4 | 38.7 | 34.9 | 10.6 | 12.7 | - | - | Fine Sand |
| 44 | | qp3 | 83-85 | | 2.6 | 4.5 | 2.3 | 3.1 | 26.4 | 41.2 | 7.8 | 12.1 | - | - | Fine Sand |
| 45 | ST11 | qp2-3 | 88-90 | | | | | | 27.3 | 48.5 | 12.3 | 11.9 | - | - | Fine Sand |
| 46 | | qp2-3 | 93-95 | | | | | | 14.7 | 57.6 | 11.8 | 5.7 | 4.3 | 5.9 | Clayey Sand |
| 47 | | qp2-3 | 97-99 | | | 1.8 | 1.3 | 4.7 | 46.3 | 21.5 | 11.9 | 12.5 | - | - | Fine Sand |

| No. | Well | Formation | Depth of sampling (below ground) (m) | Passing (%) | | | | | | | | | | | Soil Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Gravel | | | Sand | | | | | Silt | | Clay | |
| | | | | Particle Diameter ( mm ) | | | | | | | | | | | |
| | | | | > 10 | 10 - 5 | 5 - 2 | 2 - 1 | 1 – 0.5 | 0.5 – 0.25 | 0,25 – 0.10 | 0.10 – 0.05 | 0.05 – 0.01 | 0.01-0.005 | < 0.005 | |
| 48 | | qp2-3 | 102-104 | | | | | 3.5 | 47.2 | 25.1 | 11.4 | 12.8 | - | - | Fine Sand |
| 49 | | qp2-3 | 107-109 | | | 1.2 | 2.1 | 18.9 | 50.8 | 10.3 | 2.5 | 14.2 | - | - | Medium-grain Sand |

Table 12. Hydraulic conductivities (m/day) calculated for each aquifer using various methods by SizePerm

| Method | Results | Unit | Aquifer | | |
|---|---|---|---|---|---|
| | | | qh | $qp_3$ | $qp_{2-3}$ |
| Hazen | Min | m/ng | 76.1 | 66.4 | 31.5 |
| | Max | | 76.1 | 114.9 | 146 |
| | Mean | | 76.1 | 64 | 79.3 |
| Slitcher | Min | m/ng | 0 | 0 | 0 |
| | Max | | 28.6 | 42.2 | 45.8 |
| | Mean | | 14.3 | 5.3 | 7 |
| Terzaghi | Min | m/ng | | 32.6 | 1.1 |
| | Max | | | 32.6 | 79.6 |
| | Mean | | | 32.6 | 40.3 |
| Beyer | Min | m/ng | 67.9 | 0.01 | 2.2 |
| | Max | | 67.9 | 102.8 | 140 |
| | Mean | | 67.9 | 21.8 | 13 |
| Sauerbrei | Min | m/ng | | 0.2 | 0.5 |
| | Max | | | 0.6 | 2.2 |
| | Mean | | | 0.4 | 1.4 |
| Kruger | Min | m/ng | | 1.7 | 1.9 |
| | Max | | | 1.7 | 2 |
| | Mean | | | 1.7 | 2 |
| Kozeny | Min | m/ng | | 152.1 | 31.2 |
| | Max | | | 152.1 | 298.1 |
| | Mean | | | 152.1 | 164.6 |
| Zunker | Min | m/ng | | 14.3 | 12.4 |
| | Max | | | 17.2 | 49.5 |
| | Mean | | | 16 | 18 |
| USBR | Min | m/ng | | 73 | 21.1 |
| | Max | | | 73 | 24.6 |
| | Mean | | | 73 | 22.9 |

## 4.2. Water sample analysis results

### 4.2.1. Hydrochemical characteristics of water samples in Soc Trang

*Water type*

The Piper diagram shows hydrochemical facies of the water samples collected in Soc Trang (Figure 6). Among four surface water sampling locations investigated, three locations (SW1, SW2 and SW3) showed strong variations in major ion concentrations between the two sampling dates, one in dry season and the other in the rainy season. Accordingly, those water samples shifted from Na-Cl type in dry season (indicated by the red circle on Figure 6) to mixed water type or bicarbonate Ca-Na-Mg type in rainy season.

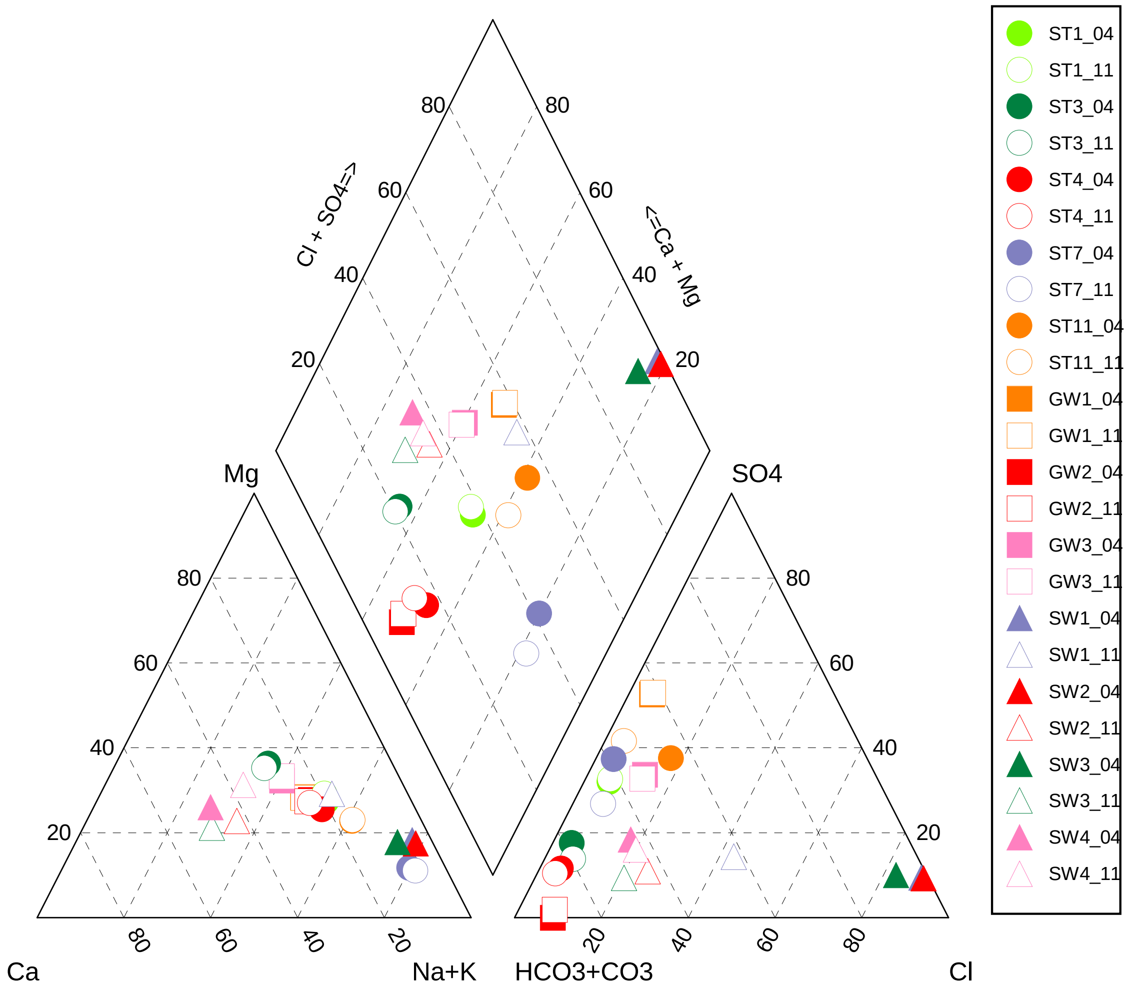


Figure 6. Piper diagram visualizing hydrochemical facies of water samples in Soc Trang. Samples in dry season indicated by filled symbols; samples in rainy season indicated by unfilled symbols.

Generally, there was no difference in major ion contents of groundwater samples (both IGPVN monitoring wells and private tube wells) between dry season and rainy season with the exception of ST7 and ST11. The ST7 tends to shift from mixed water type in dry season to fresh water type in rainy season. The variation in major ion compositions of ST7 and ST11 may indicate the desalination process occurring in the aquifer during rainy season. The ST4 and GW2 samples located close to the Tran De estuary are of Na-Mg-Ca-$HCO_3$ water type for both dry and rainy season (indicated by the green circle on Figure 6) reflecting no or a negligible effect of salt water intrusion. The ST1, GW1 and GW3 samples are of mixed water type while ST3 is of temporary hard water type. The concentrations of major ions in water samples in Soc Trang Province are plotted on graphs shown in Figure 7 to Figure 13.

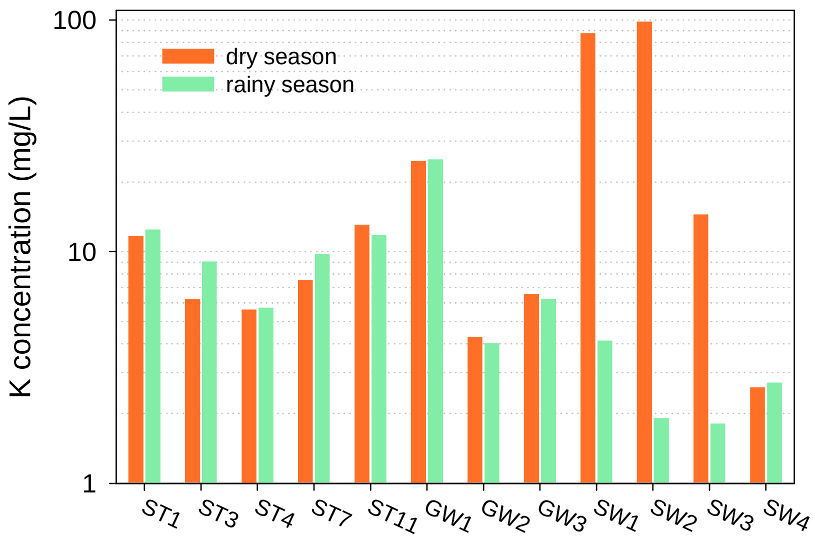


Figure 7. Potassium concentration in water samples in Soc Trang province in 2013

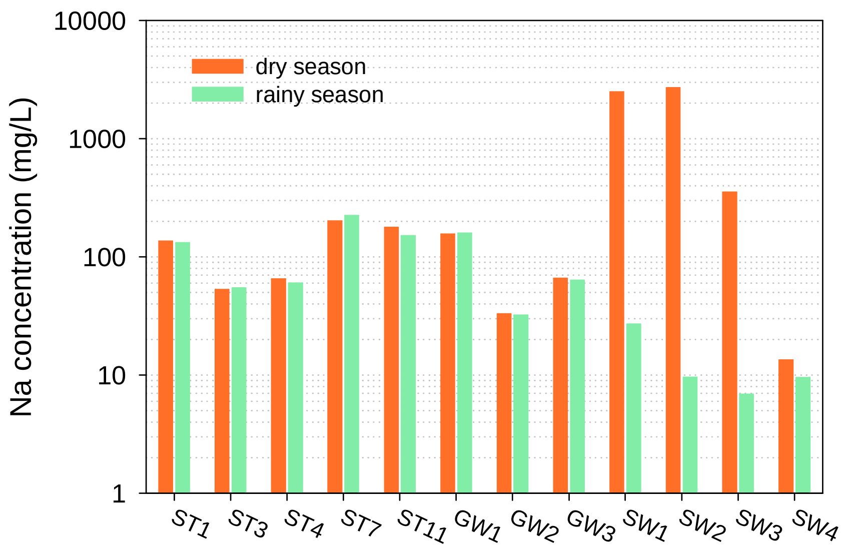


Figure 8. Sodium concentration in water samples in Soc Trang province in 2013

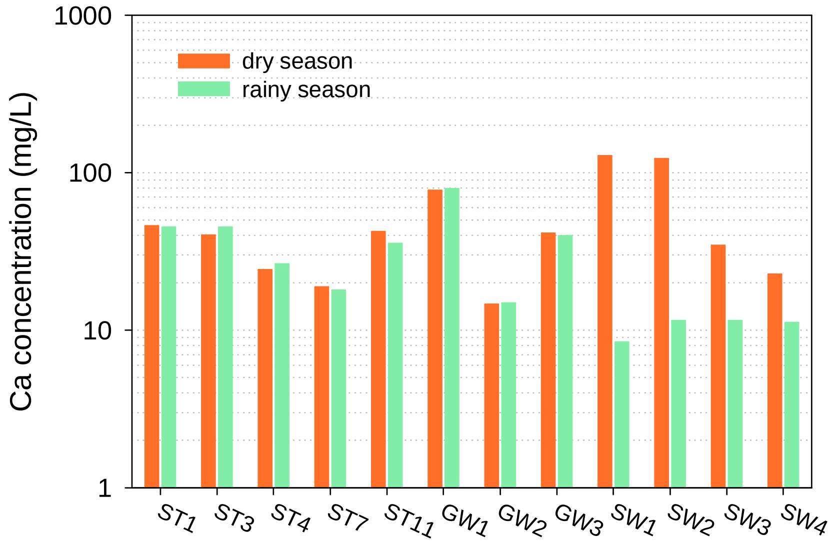


Figure 9. Calcium concentration in water samples in Soc Trang province in 2013

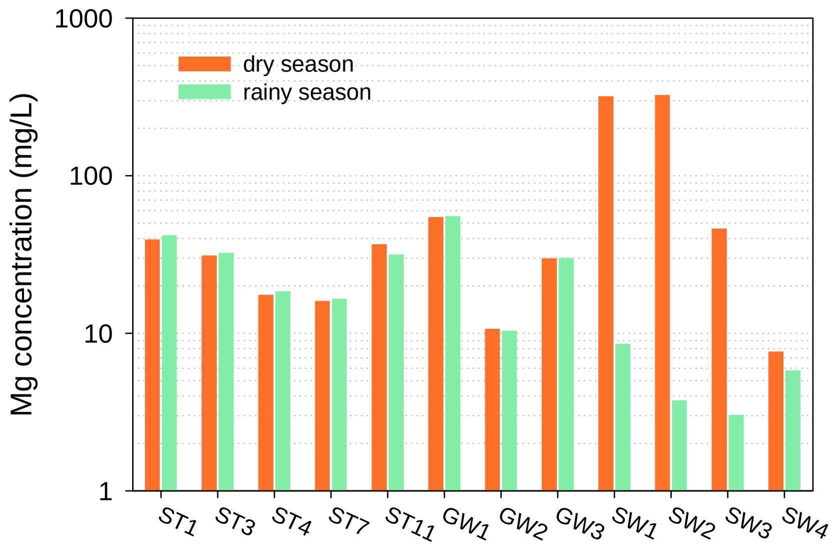


Figure 10. Magnesium concentration in water samples in Soc Trang province in 2013

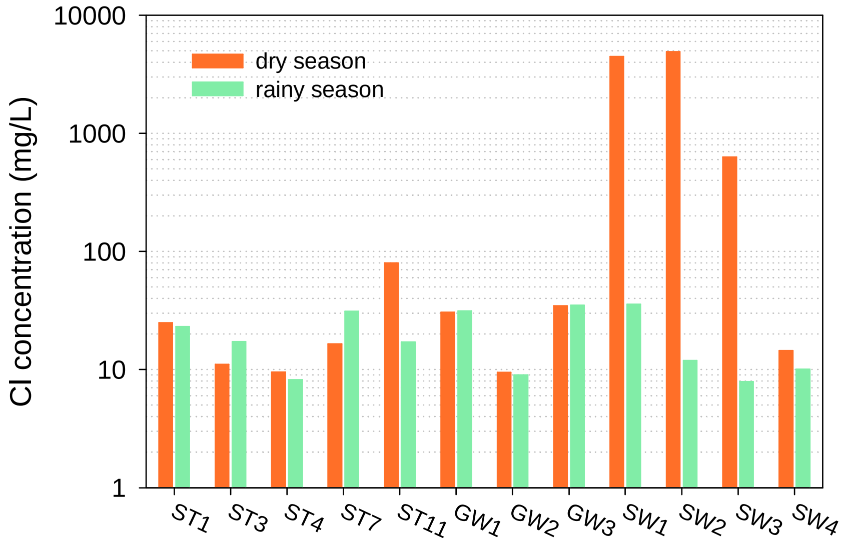


Figure 11. Chloride concentration in water samples in Soc Trang province in 2013

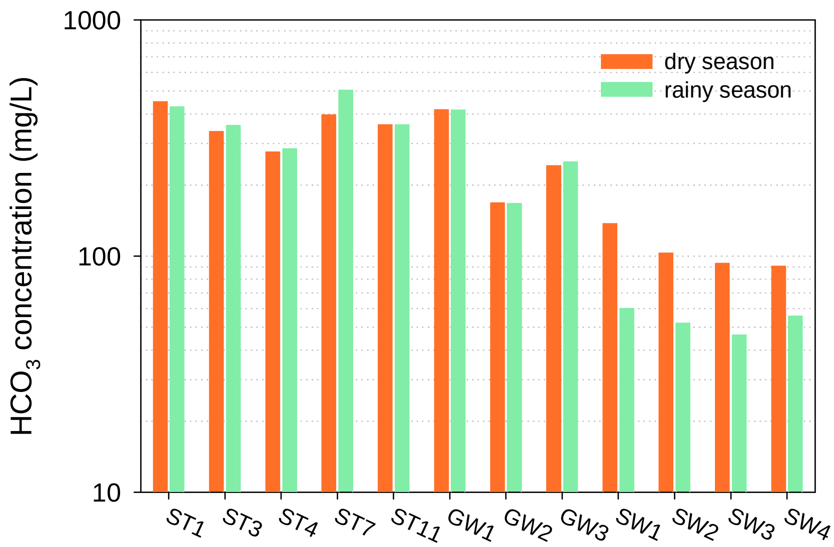


Figure 12. Bicarbonate concentration in water samples in Soc Trang province in 2013

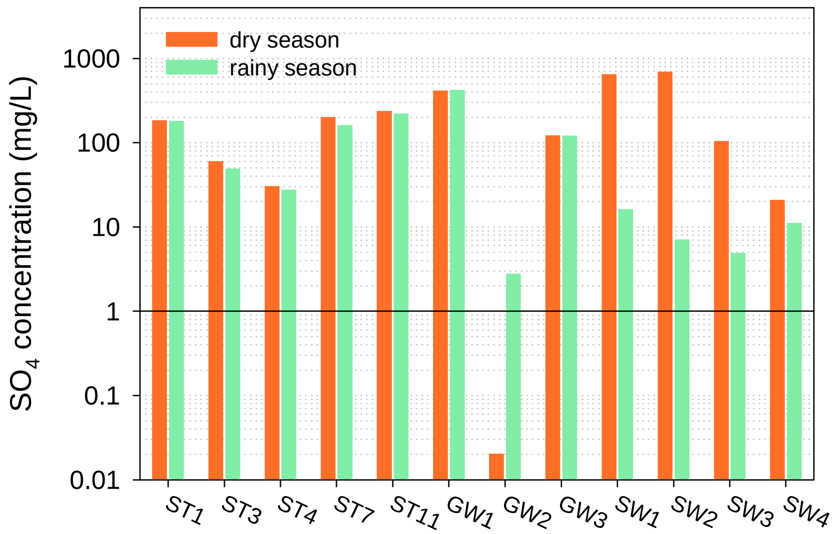


Figure 13. Sulfate concentration in water samples in Soc Trang province in 2013

The variation in major ion compositions of water samples in Soc Trang province by time and location is shown in Figure 14. The Stiff diagrams show the major ion compositions of water samples in meq/L. The Stiff diagram shapes of surface water samples are different for dry and rainy season whereas groundwater samples take almost similar shapes. This demonstrates that there is no hydraulic connection between surface water and groundwater in Soc Trang Province. In Figure 14, well ST7 shows slight increases in Na and $HCO_3$ contents in rainy season compared to the dry season. ST11 shows a moderate decrease in Cl content in rainy season compared to dry season.

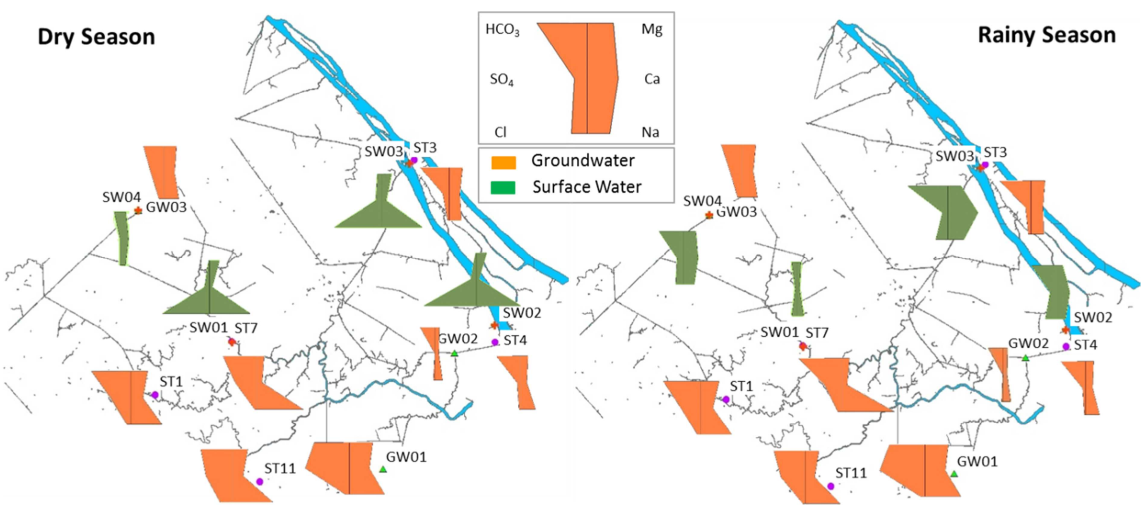


Figure 14. Spatial and temporal variation in the major ion compositions of surface water and groundwater in Soc Trang province

*Major ion ratios*

The Mercado diagram displays the Na/Cl ratio and Cl content of water samples (Figure 15). The river water sample SW1 from the dry season 2013 collected far from the coastal line shows a low Na/Cl ratio (0.55) together with a high Cl content (4910 mg/L) that may indicate salt water intrusion. However, this is not the case for river water sample SW4 as well as other groundwater samples far from the coast. Most of the groundwater samples display high Na/Cl ratios and low Cl contents (ST7, ST4, ST1, ST3, GW1, GW2) indicating desalination process in which freshwater is dominant and Na is released from the replacement of $Na^+$ by $Ca^{2+}$ in the aquifer; or both low Na/Cl ratios and low Cl contents (ST11, GW3) indicating mixed processes in which, neither salt water intrusion nor desalination process is dominant. Generally, the chemical compositions of groundwater samples collected from the IGPVN monitoring wells in $qp_{2-3}$ aquifer demonstrate the dominance of desalination process.

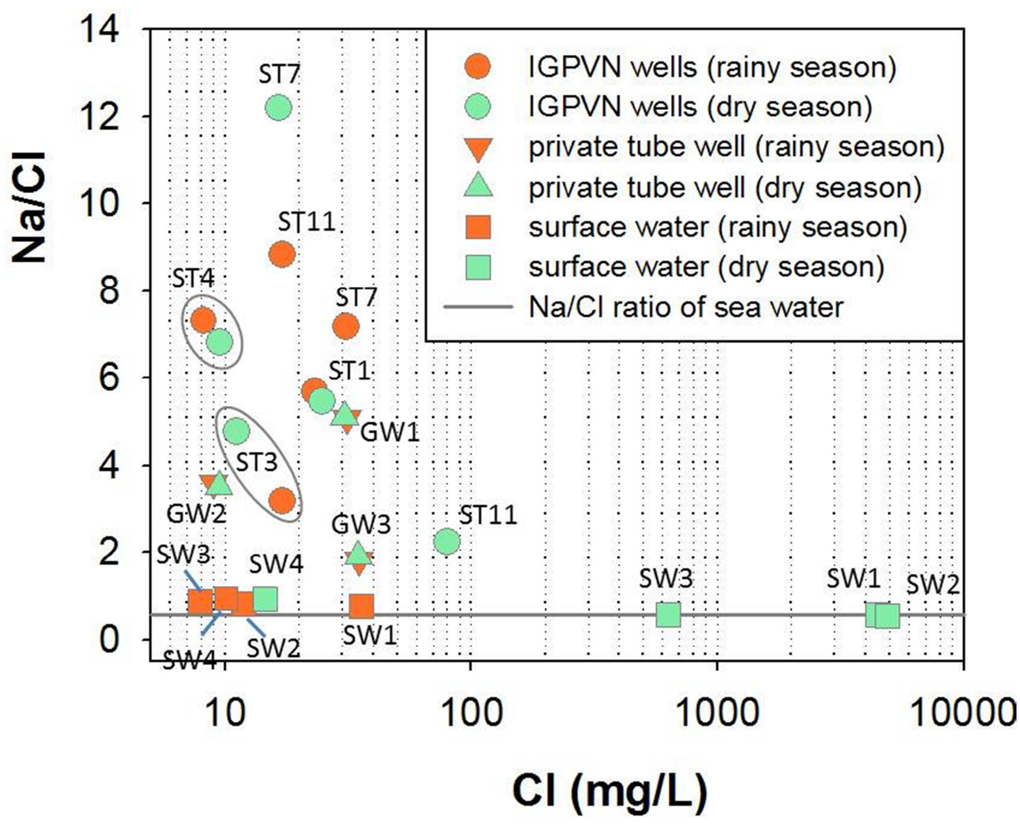


Figure 15. Mercado diagram showing the relationship between Na/Cl ratios and Cl contents from water samples in Soc Trang province in 2013

Analytical results of surface water samples collected in the rainy season 2013 do not show any high Cl content with a maximum value of only 35.7 mg/L. No salt water intrusion process was inferred from rainy season data for surface water and mixed processes are typical. Groundwater samples display high Na/Cl ratios and low Cl contents indicating desalination process. Only groundwater sample GW3 may indicate a mix of salt and freshwater.

The water composition of groundwater sample ST11 varies greatly. From dry to rainy season the Cl and Br content changes by a factor of 5. The change in Cl may originate from salt water intrusion.

The groundwater sample GW2 in the dry season display high $Ca/SO_4$ and low $SO_4/Cl$ ratios that indicate $SO_4$ reduction or precipitation. The groundwater samples ST1, ST7 and GW1 in both dry and rainy season display high $SO_4/Cl$ and similar $Fe/SO_4$ ratios that indicate the source of $SO_4$ from pyrite oxidation. The groundwater samples ST3 and ST4 in both dry and rainy season display high $SO_4/Cl$ ratios and their $Ca/SO_4$ ratios close to 1 indicating $SO_4$ and Ca as sources from gypsum dissolution.

### 4.2.2. Water quality

*Surface water*

The analytical results of the surface water samples taken in the dry season show a high $PO_4$ content of 0.25 mg/L in SW1 (Figure 16). The Vietnamese Technical Regulation for surface water in column B1 (states that a concentration higher than 0.3 mg/L is only suitable for irrigation or other purposes requiring similar water quality. Elevated concentrations of Cl in SW1, SW2 and SW3 samples in the dry season (Figure 11) make these water sources unsuitable for irrigation purposes. Very high Cl concentrations found in the Nhu Gia cannal (SW1) and in the Tran De estuary (SW2) indicate a strong effect of sea water not only at the river mouth but also far inland. This corresponds to other reports where sea water goes up to until 60 km upstream in the dry season.

Ammonium is not detected in surface water samples collected in the dry season. The $NO_3$ contents in surface water samples taken in the dry season meet the Vietnamese Technical Regulation for surface water in column A1 of 2 mg/L (see Figure 17). $NO_2$ was only detected in SW3 (0.12 mg/L) and exceeds the guideline value in column B2 of 0.05 mg/L.

Generally, the chemical compositions (except for $PO_4$ and $NO_3$, see Figure 16 and 17) of surface water in Soc Trang Province in the rainy season are much lower than those taken in the dry season showing the dilution effect from rainwater. $NO_2$ was not detected while Cl is lower than the guideline value in column A1 of 250 mg/L that is suitable for domestic water supply. The $NO_3$ content in SW1 meets the Vietnamese Technical Regulation for surface water in column A2 of 5 mg/L that is suitable for domestic water supply but only with prior treatment. The $PO_4$ concentration in SW3 (0.07 mg/L) is lower than the guideline value in column A1 of 0.1 mg/L. The $PO_4$ concentrations in SW2 (0.14 mg/L) and SW4 (0.17 mg/L) are lower than the guideline value in column A2 of 0.2 mg/L) while that in SW1 (0.51 mg/L) still slightly exceeds the guideline value in column B2 of 0.5 mg/L (see Figure 16). Higher concentrations of $PO_4$ and $NO_3$ in surface water samples taken in the rainy season compared to those in the dry season indicate an increase of fertilizer application in agriculture.

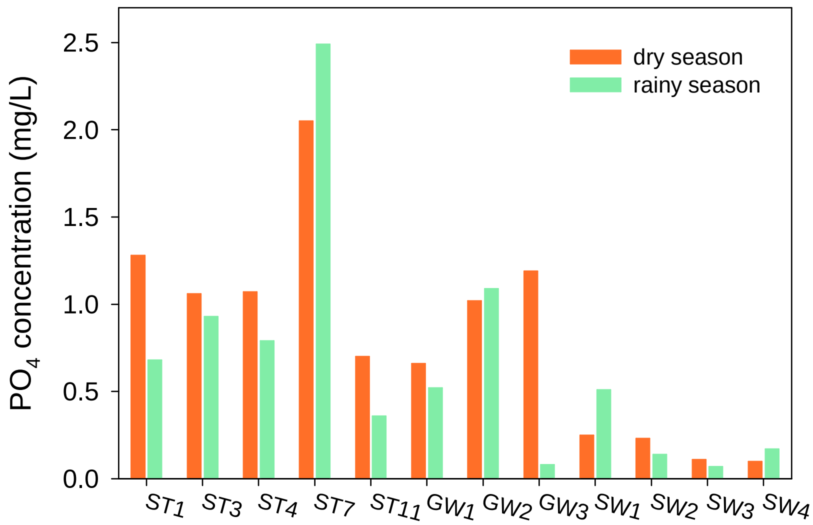


Figure 16. Phosphate concentration in water samples in Soc Trang province in 2013

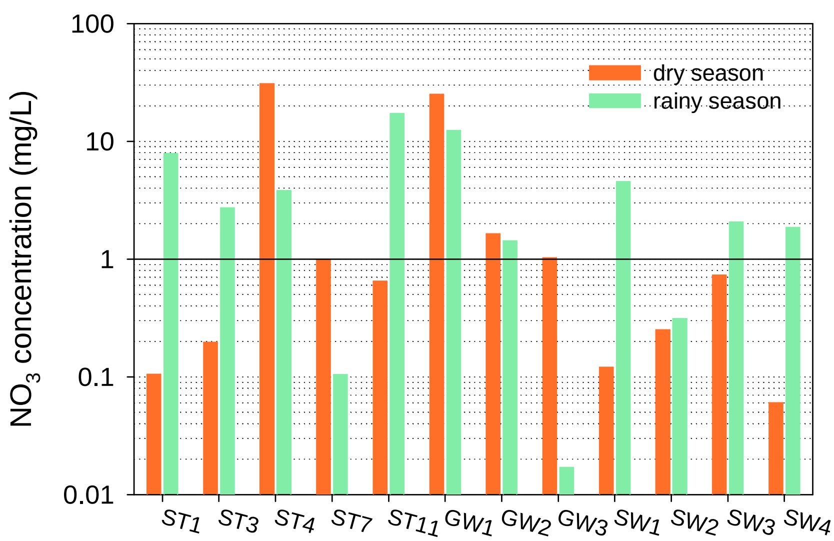


Figure 17. Nitrate concentration in water samples in Soc Trang province in 2013

Table 13. Chemical analytical results of water samples collected in Soc Trang Province in April 2013

| Sample ID | K | Na | Cl | Mg | Ca | SO4 | HCO3 | Fe(II) | Mn | NO3 | NO2 | NH4 | Br | F | PO4 | BO2 | Ba | SiO2 | Sr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| ST1 | 11.6 | 136 | 24.9 | 39.0 | 46.1 | 182 | 450 | 0.049 | 0.126 | 0.11 | 0.861 | 1.75 | 0.120 | 0.356 | 1.28 | 1.29 | 0.074 | 33.8 | 0.466 |
| ST3 | 6.22 | 53.0 | 11.1 | 30.9 | 40.2 | 59.3 | 336 | 1.30 | 0.225 | 0.20 | 0.011 | 0.73 | 0.057 | 0.317 | 1.06 | 0.44 | 0.149 | 48.4 | 0.367 |
| ST4 | 5.58 | 65.0 | 9.53 | 17.4 | 24.3 | 30.0 | 276 | 0.739 | 0.151 | 30.7 | ND | 0.30 | 0.045 | 0.193 | 1.07 | 0.41 | 0.052 | 41.9 | 0.213 |
| ST7 | 7.51 | 201 | 16.5 | 15.9 | 18.8 | 199 | 396 | 0.047 | 0.129 | 0.99 | 6.42 | ND | 0.069 | 0.352 | 2.05 | 1.61 | 0.153 | 31.4 | 0.183 |
| ST11 | 13.0 | 178 | 80.0 | 36.5 | 42.3 | 235 | 360 | 0.448 | 0.141 | 0.65 | 3.25 | ND | 0.352 | 0.249 | 0.70 | 1.23 | 0.034 | 26.5 | 0.450 |
| GW1 | 24.5 | 156 | 30.6 | 54.3 | 77.4 | 409 | 416 | 0.137 | 0.105 | 25.0 | 0.060 | 4.79 | 0.147 | 0.008 | 0.66 | 1.99 | 0.036 | 21.7 | 0.746 |
| GW2 | 4.26 | 33.1 | 9.45 | 10.6 | 14.6 | 0.02 | 168 | 0.007 | 0.001 | 1.63 | ND | ND | 0.036 | 0.209 | 1.02 | 0.28 | 0.047 | 60.7 | 0.123 |
| GW3 | 6.53 | 65.8 | 34.7 | 29.6 | 41.4 | 120 | 241 | 5.15 | 0.159 | 1.02 | 2.74 | 1.15 | 0.134 | 0.141 | 1.19 | 0.36 | 0.086 | 58.2 | 0.372 |
| SW1 | 87.3 | 2491 | 4460 | 317 | 128 | 640 | 137 | 0.480 | 0.307 | 0.12 | ND | ND | 15.9 | 0.45 | 0.25 | 4.08 | 0.035 | 7.4 | 1.82 |
| SW2 | 97.9 | 2690 | 4910 | 323 | 123 | 687 | 103 | 0.078 | 0.003 | 0.25 | ND | ND | 16.7 | 0.33 | 0.23 | 4.37 | 0.032 | 2.7 | 1.83 |
| SW3 | 14.4 | 354 | 631 | 45.9 | 34.6 | 103 | 93.2 | 0.009 | 0.002 | 0.73 | 0.121 | ND | 2.02 | 0.052 | 0.11 | 0.71 | 0.023 | 2.4 | 0.368 |
| SW4 | 2.58 | 13.4 | 14.5 | 7.60 | 22.7 | 20.5 | 90.7 | 0.029 | 0.061 | 0.06 | ND | ND | 0.028 | 0.132 | 0.10 | 0.12 | 0.023 | 2.4 | 0.131 |

ND: not detected, concentrations below the detection limit of the analytical method

Table 14. Chemical analytical results of water samples collected in Soc Trang Province in November 2013

| Sample ID | K | Na | Cl | Mg | Ca | SO4 | HCO3 | Fe(II) | Mn | NO3 | NO2 | NH4 | Br | F | PO4 | BO2 | Ba | SiO2 | Sr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L | mg/ L |
| ST1 | 12.4 | 132 | 23.2 | 41.6 | 45.2 | 178 | 428 | 0.017 | 0.168 | 7.87 | 7.39 | ND | 0.086 | 0.387 | 0.68 | 1.15 | 0.062 | 27.9 | 0.485 |
| ST3 | 9 | 54.7 | 17.2 | 32.1 | 45.2 | 48.7 | 357 | 0.006 | 0.066 | 2.71 | 1.97 | ND | 0.059 | 0.326 | 0.93 | 0.36 | 0.164 | 37.7 | 0.42 |
| ST4 | 5.7 | 60 | 8.2 | 18.3 | 26.4 | 27.3 | 285 | 0.045 | 0.131 | 3.8 | ND | ND | 0.026 | 0.204 | 0.79 | 0.34 | 0.055 | 35.3 | 0.223 |
| ST7 | 9.7 | 224 | 31.2 | 16.4 | 18 | 160 | 503 | 0.008 | 0.12 | 0.104 | 0.173 | 6.74 | 0.107 | 0.623 | 2.49 | 1.54 | 0.079 | 23.5 | 0.187 |
| ST11 | 11.7 | 151 | 17.1 | 31.3 | 35.6 | 218 | 360 | 0.013 | 0.099 | 17.2 | ND | 0.01 | 0.068 | 0.252 | 0.36 | 1.07 | 0.032 | 21.3 | 0.405 |
| GW1 | 24.9 | 159 | 31.3 | 55 | 79.1 | 416 | 415 | 0.028 | 0.111 | 12.3 | 11.8 | 11.2 | 0.115 | 0.023 | 0.52 | 1.8 | 0.039 | 17.8 | 0.791 |
| GW2 | 4 | 32.2 | 9 | 10.3 | 14.9 | 2.74 | 167 | 0.009 | ND | 1.42 | 0.048 | 0.01 | 0.019 | 0.14 | 1.09 | 0.22 | 0.051 | 47.7 | 0.131 |
| GW3 | 6.2 | 63.6 | 35.1 | 29.8 | 39.9 | 119 | 250 | 0.341 | 0.154 | 0.017 | ND | 2.89 | 0.125 | 0.155 | 0.08 | 0.29 | 0.075 | 44 | 0.382 |
| SW1 | 4.1 | 26.9 | 35.7 | 8.48 | 8.4 | 16 | 60 | 2.62 | 0.013 | 4.52 | ND | 0.04 | 0.09 | 0.241 | 0.51 | 0.13 | 0.005 | 10.1 | 0.063 |
| SW2 | 1.9 | 9.6 | 11.9 | 3.73 | 11.5 | 7 | 51.9 | 0.784 | 0.017 | 0.311 | ND | 0.03 | 0.004 | 0.016 | 0.14 | 0.03 | 0.014 | 8.6 | 0.066 |
| SW3 | 1.8 | 6.9 | 7.9 | 3 | 11.5 | 4.85 | 46.3 | 0.13 | 0.002 | 2.06 | ND | ND | 0.011 | 0.09 | 0.07 | 0.01 | 0.026 | 7.8 | 0.062 |
| SW4 | 2.7 | 9.5 | 10.1 | 5.76 | 11.2 | 11 | 55.7 | 0.334 | 0.008 | 1.85 | ND | ND | 0.026 | 0.158 | 0.17 | 0.05 | 0.009 | 8.6 | 0.066 |

ND: not detected, concentrations below the detection limit of the analytical method

*Groundwater*

The Cl contents in groundwater samples collected in Soc Trang Province in both dry and rainy season are below the Vietnamese Technical Regulation for groundwater of 250 mg/L (see Table 13, Table 14 and Figure 11). The $SO_4$ concentrations range between 0.02 – 409 mg/L in the dry and 2.74 – 416 mg/L in the rainy season (see Table 13, Table 14 and Figure 13). This is not much different from the $SO_4$ concentration range of fresh water in $qp_{2-3}$ aquifer with 0.39 – 436 mg/L (Report on Assessment of Groundwater Resource in Soc Trang Province, DWRPIS 2010). Only GW1 showed $SO_4$ concentrations (409 and 416 mg/L) slightly exceeding the guideline value of 400 mg/L.

The $NH_4$ concentrations in groundwater samples collected from the IGPVN monitoring wells and private tube wells in both dry and rainy season were not detected or did not exceed the Vietnamese Technical Regulation for groundwater of 0.1 mg/L. Groundwater samples ST4 and GW1 in the dry season were contaminated by $NO_3$ with concentrations of 30.7 and 25 mg/L, respectively (Figure 17). This exceeds the level stated in the Vietnamese Technical Regulation for groundwater of 15 mg/L. Meanwhile, only one groundwater sample taken in the rainy season (ST11) shows a $NO_3$ concentration exceeding the guideline value. The $NO_2$ concentrations in ST7, ST11, and GW3 in the dry season and in ST1, ST3, and GW1 in the rainy season are 2 – 12 times higher than the Vietnamese Technical Regulation for groundwater of 1.0 mg/L.

Generally, heavy metals and trace elements were not detected in water samples collected in Soc Trang province or are observed at low concentrations.

### 4.2.3. Stable isotopes analysis results

The stable isotopic compositions $\delta^2H$ and $\delta^{18}O$ (in permil (‰) difference in $^2H/^1H$ and $^{18}O/^{16}O$ ratios between the samples and the Vienna Standard Mean Ocean Water (VSMOW)) were determined for water samples from Soc Trang Province. The $\delta^2H$ and $\delta^{18}O$ values of the groundwater ranged from -47.7 to -34.7 ‰ and from -6.82 to -3.77 ‰ in dry season and from -47.7 to -34.2 ‰ and from -7.01 to -3.84 ‰ in rainy season, respectively; and those of the surface water ranged from -54,5 to -14,5 ‰ and from -7,11 to -0,44 ‰ in dry season, and from -53.5 to -35.8 ‰ and from -7.31 to -4.7 ‰ in rainy season, respectively (Table 15).

The stable isotope composition of water samples collected in Soc Trang Province are shown in Figure 18 in parallel to the Global Meteoric Water Line (GMWL) derived from the equation: $\delta^2H = 8.2* \delta^{18}O + 11.27$ (Rozanski *et al.*, 1993) and the IAEA/WMO Global Network for Isotopes in Precipitation (GNIP) data set for Bangkok from 1968 – 2009. The stable isotope compositions of rain water samples collected in Soc Trang Province using a rain collector installed at the Soc Trang DONRE are also included in the graph. Rain water sampling period was from July to November 2013. The water samples collected in the rainy season are indicated by unfilled symbols and the samples collected in the dry season by filled symbols of the same color. Groundwater and surface water samples assigned with the same color indicate their close sampling location. The stable isotope analysis results of water samples collected in the Mekong River Delta (Southern Plain) in frame of the IAEA VIE/8/003 project are shown on the graph by the small dark red unfilled circles.

Table 15. Stable isotope composition of water samples collected in Soc Trang in 2013

| Sample ID | 4/2013 | | | | 11/2013 | | | |
|---|---|---|---|---|---|---|---|---|
| | d$^{18}$O | SD | d$^{2}$H | SD | d$^{18}$O | SD | d$^{2}$H | SD |
| ST1 | -6.68 | 0.05 | -46.6 | 0.6 | -6.65 | 0.02 | -45.5 | 0.1 |
| ST3 | -5.17 | 0.05 | -40.8 | 0.1 | -5.13 | 0.18 | -39.9 | 0.7 |
| ST4 | -4.72 | 0.06 | -38.2 | 0.2 | -4.6 | 0.13 | -37.3 | 0.6 |
| ST7 | -6.34 | 0.02 | -45.5 | 0.2 | -6.33 | 0.17 | -44.1 | 0.6 |
| ST11 | -6.76 | 0.02 | -46.4 | 0.2 | -6.75 | 0.12 | -46.4 | 0.5 |
| GW1 | -6.82 | 0.13 | -47.7 | 0.4 | -7.01 | 0.13 | -47.7 | 0.6 |
| GW2 | -3.77 | 0.04 | -34.7 | 0.2 | -3.84 | 0.11 | -34.2 | 0.5 |
| GW3 | -6.31 | 0.05 | -46.8 | 0.3 | -6.48 | 0.06 | -47.2 | 0.5 |
| SW1 | -0.44 | 0.14 | -14.5 | 0.3 | -4.7 | 0.05 | -35.8 | 0.3 |
| SW2 | -5.30 | 0.09 | -41.7 | 0.5 | -7.31 | 0.07 | -53.5 | 0.2 |
| SW3 | -7.11 | 0.07 | -54.4 | 0.3 | -7.25 | 0.12 | -53.1 | 0.8 |
| SW4 | -7.04 | 0.10 | -54.5 | 0.4 | -6.27 | 0.08 | -46.1 | 0.2 |

From Figure 18, it is clear that the rain water samples collected in Soc Trang province and the IAEA VIE/8/003 water samples locate along the Bangkok Meteoric Water Line.

Generally, the stable isotope compositions of groundwater samples show little differences between the dry and rainy season indicating no or a negligible dilution effect of groundwater which might be caused by a direct hydraulic connection with surface water.

Surface water samples except SW3 showed great differences in their stable isotope compositions between the dry and rainy season. Sample SW1 in the dry season is shifted far towards the direction of less negative $\delta^{18}$O values, displaying a strong enrichment in $^{18}$O that may indicate a strong evaporation effect and an intrusion of seawater. However, this is not the case in the rainy season. Sample SW2 in the dry season is enriched in $^{18}$O because of the mixing between river and seawater at the estuary. The SW3 and SW4 samples in the dry season are depleted in stable isotopes comparing them to sample SW2 indicating a lesser effect of salt water intrusion from sea water.

The higher river discharge during the rainy season causes a decreasing effect of seawater mixing at the estuary leading to a strong reduction in the stable isotope compositions of the estuarine sample SW2. Accordingly, the stable isotope compositions of sample SW2 are equivalent to those of SW3 that was taken further upstream in Cu Lao Dung district. Only surface water sample SW4 shows a higher stable isotope composition in the rainy season compared to the dry season.

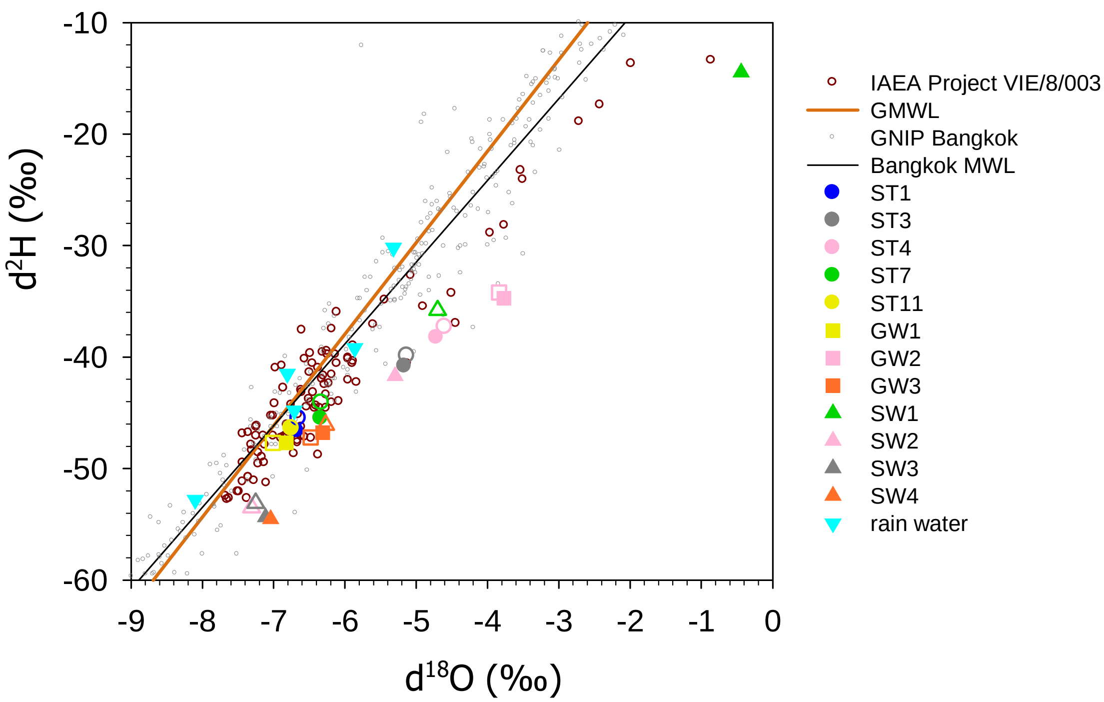


Figure 18. Stable isotope compositions ($^{2}H$, $^{18}O$) in water samples taken in the rainy (unfilled symbols) and dry season (filled symbols) in Soc Trang Province in 2013. Rainwater samples were collected from July to November 2013. Groundwater samples collected from the IGPVN monitoring wells are indicated by circles and groundwater samples collected from private tube wells are indicated by squares; surface water samples are indicated by upwards triangles.

Groundwater samples ST1, ST11 and GW1 in both dry and rainy season show a similar stable isotope composition being placed along the Bangkok MWL. This might indicate the meteoric origin of the corresponding aquifers.

The differences in stable isotope compositions in dry season between ST7 and SW1 despite their close sampling locations indicate no hydraulic connection between groundwater and surface water. Similarly, the differences in stable isotope compositions in the dry season between ST4 and SW2 in Tran De district, between ST3 and SW3 in Cu Lao Dung district, and between GW3 and SW4 in My Tu district also indicate no hydraulic connection between groundwater and surface water there.

The enrichment of $^{18}O$ in the ST4 and GW2 samples to a higher degree than in the SW2 sample (Tran De estuary) suggest that samples ST4 and GW2 might be located in a paleo-salinized area and the enhanced seawater intrusion through Hau River during the dry season does not affect the adjacent aquifers.

#### 4.2.4. Groundwater dating

*$^{3}$H activity of water samples in Soc Trang province*

The $^{3}$H activity of water samples in Soc Trang ranged from below the LOD (0.46 TU) to 1.05 TU and from 1.14 TU to 1.53 TU for groundwater and surface water, respectively (Table 16).

The seven groundwater samples showing $^{3}$H activity below the LOD were most likely recharged with water prior to 1953, or older than 70 years. The other four groundwater samples with $^{3}$H activity from 0.57 – 1.05 TU are a mixture of pre- and post-1953 water. The $^{3}$H activity of surface water samples were quite low indicating exchange process of surface water with groundwater which has lower $^{3}$H activity.

Table 16. $^{3}$H activity of water samples collected in Soc Trang province in June 2013

| No. | Sample ID | 3H ±σ (TU) |
|---|---|---|
| 1 | Q59801T | 0.94 ± 0.22 |
| 2 | Q598020 | <0.46 |
| 3 | Q59804T | <0.46 |
| 4 | Q598030 | <0.46 |
| 5 | Q59801Z | <0.46 |
| 6 | ST3 | 0.57 ± 0.49 |
| 7 | PW1 | <0.46 |
| 8 | PW2 | 0.6 ± 0.4 |
| 9 | PW3 | 1.05 ± 0.22 |
| 10 | PW4 | <0.46 |
| 11 | PW5 | <0.46 |
| 12 | SW5 | 1.40 ± 0.48 |
| 13 | SW6 | 1.53 ± 0.40 |
| 14 | SW7 | 1.14 ± 0.42 |

*Groundwater dating in Soc Trang using $^{14}$C*

The $^{14}$C age of groundwater of the qp and n aquifers ranged from 10,700 years to 22,500 years and from 15,300 years to over 40,000 years, respectively (Table 17).

Among the seven groundwater samples from $qp_{2-3}$ aquifer, the two samples collected from My Xuyen and Long Phu WTPs showed younger ages than the others, indicating that younger (ground)water from the upper layers may be drawn down as a result of over exploitation at those WTPs and that vertical contamination from the surface may eventually occur. This may imply that the abstraction rate at those wells exceeds the potential reserve of the aquifer. However, this can be confirmed by annual monitoring data for $^{14}C$ to see whether there is any decrease in groundwater absolute age; and a closer assessment of groundwater level behavior to see whether there is any sudden increase in groundwater level.

The other three production wells did not show abnormally younger ages, indicating that the aquifers are completely confined, with no hydrogeological windows apparent; thereby, reducing the risk of overlying younger water to percolate into the lower lying aquifer. Still no information about abstraction rate can be inferred from these dating results.

Among three National monitoring wells of n aquifer, the well Q59804T ($n^2_2$) showed much younger age (15,300 years) than the other 2 wells, probably because the well was not perfectly sealed off and younger water from overlying aquifers could leak down into the well, or the casing could be cracked. It might also be possible that this well is part of different aquifer.

Table 17. $^{13}C$, $^{14}C$ activity and groundwater age in Soc Trang province

| No. | Sample ID | Analytical results | | |
|---|---|---|---|---|
| | | δ13C (‰) | 14C (pmC) | Age (year) |
| 1 | Q59801T | -15.5 | 98.8 ± 0.3 | < 100 year |
| 2 | Q598020 | -13.1 | 55 ± 0.5 | 22,500 |
| 3 | Q59804T | -10.2 | 10.6 ± 0.3 | 15,300 |
| 4 | Q598050 | -11.4 | 0.4 ± 0.2 | > 40,000 |
| 5 | Q59804Z | -13.7 | 1.4 ± 0.5 | 34,000 |
| 6 | ST3 | -13.3 | 8.7 ± 0.5 | 18,800 |
| 7 | PW1 | -14.1 | 6.4 ± 0.4 | 21,800 |
| 8 | PW2 | -8.2 | 15.5 ± 0.3 | 10,700 |
| 9 | PW3 | -9.3 | 12.4 ± 0.4 | 13,400 |
| 10 | PW4 | -12.7 | 8.8 ± 0.5 | 18,400 |
| 11 | PW5 | -13.0 | 9.7 ± 0.3 | 18,000 |

### 4.2.5. Groundwater flow direction and groundwater transit velocity

Static water level monitoring data from National monitoring wells of the $qp_{2-3}$ aquifer in Soc Trang province provided by DWRPIS were selected and input to ArcGIS to draw a contour map (Figure 19). The groundwater flow direction in the $qp_{2-3}$ aquifer was defined as the direction from higher water level to lower water level indicated by the arrows.

Based on the $^{14}C$ dating data of the $qp_{2-3}$ aquifer and the apparent groundwater flow direction, three sampling locations (LP, MX, VC) corresponding to the production wells at Long Phu, My Xuyen and Vinh Chau WTPs were used to determine the groundwater transit velocity basing on the following criteria:

- Groundwater flows from the location of higher water level to the location of lower water level
- Groundwater flows from the location of younger age to the location of older age

The groundwater transit velocity in the $qp_{2-3}$ aquifer located in Soc Trang Province was calculated by considering the distance between each couple of sampling points (Long Phu – Vinh Chau and My Xuyen – Vinh Chau, indicated by the red lines on the map, see Figure 4) and the differences between the $^{14}C$ ages of the water samples there. Accordingly, the groundwater transit velocities in the $qp_{2-3}$ aquifer between Vinh Chau and the other two WTPs were 2.3 m/yr and 7.8 m/yr, respectively.

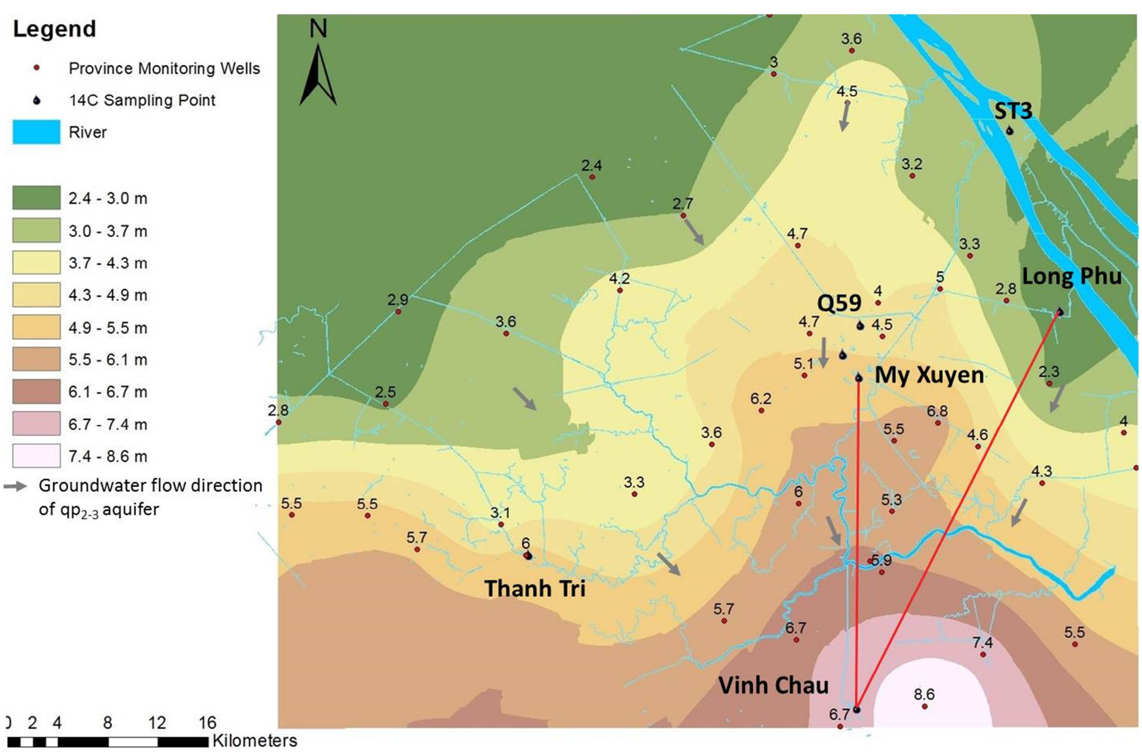


Figure 19. Groundwater contour line and flow direction in $qp_{2-3}$ aquifer in Soc Trang province according to the monitoring data in 2005 from the National Monitoring Network provided by DWRPIS

### 4.3. Groundwater level monitoring results

The daily static water levels at 12:00 AM was filtered out from the water level time series and plotted on a graph together with the daily rainfall data at the Soc Trang station.

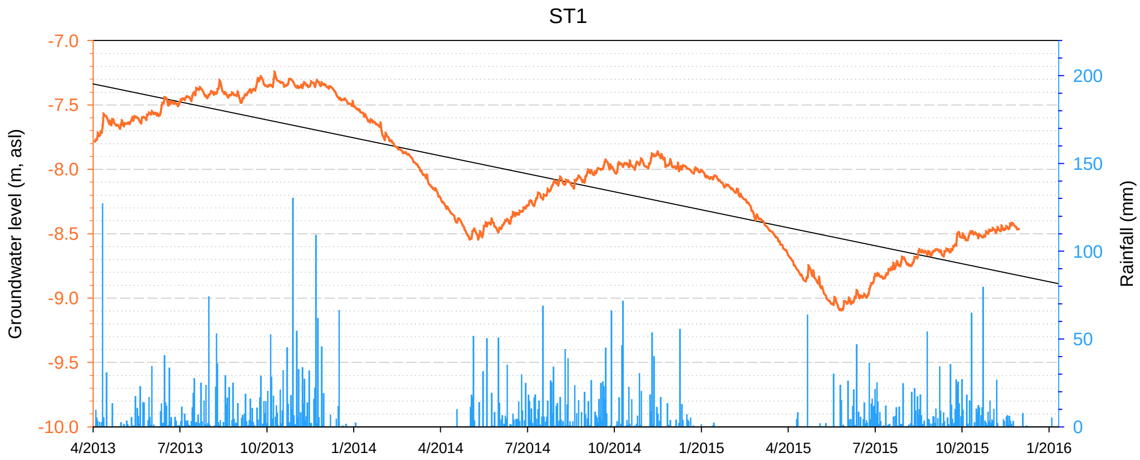


Figure 20. Fluctuation of groundwater level at ST1 (Phú Lộc town, Thạnh Trị district, Sóc Trăng province)

The groundwater level monitoring data of ST1 is continuous since April 2013 uptil December 2015. During this period, groundwater level has decreased from -7.34 m to -8.85 m; averaged at 0.55 m/year. The groundwater level fluctuates by season and varies by rainfall.

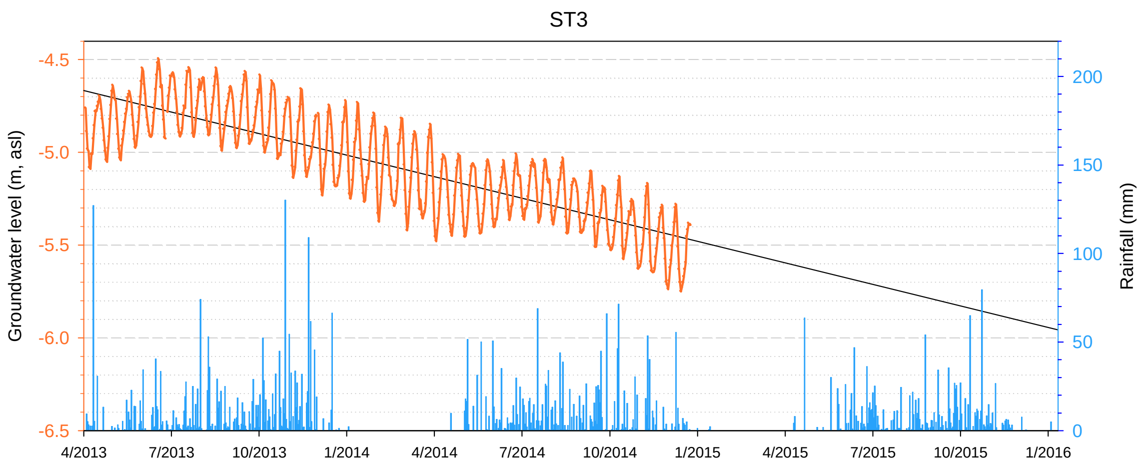


Figure 21. Fluctuation of groundwater level at ST3 (An Thạnh I commune, Cù Lao Dung district, Sóc Trăng province)

The groundwater level monitoring data of ST3 is continuous since April 2013 uptil December 2014. During this period, groundwater level has decreased from -4.67 m to -5.47 m; averaged at 0.29 m/year; expected to decrease to -5.94 m by January 2016. The groundwater level fluctuates by season and tidal regime.

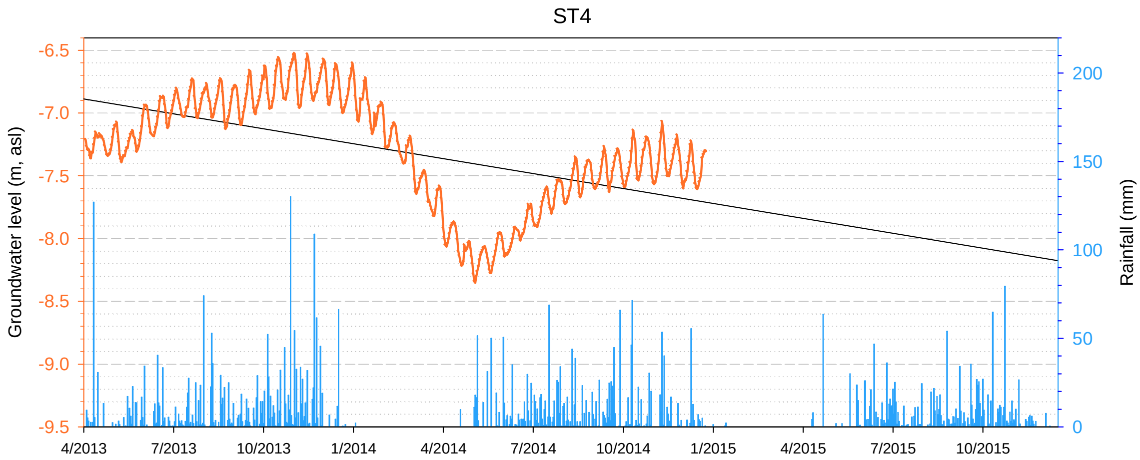


Figure 22. Fluctuation of groundwater level at ST4 (Trần Đề town, Trần Đề district, Sóc Trăng province)

The groundwater level monitoring data of ST4 is continuous since April 2013 uptil December 2014. During this period, groundwater level has decreased from -6.89  m to -7.7 m; averaged at 0.47 m/year; expected to decrease to -8.17 m by Jannuary 2016.

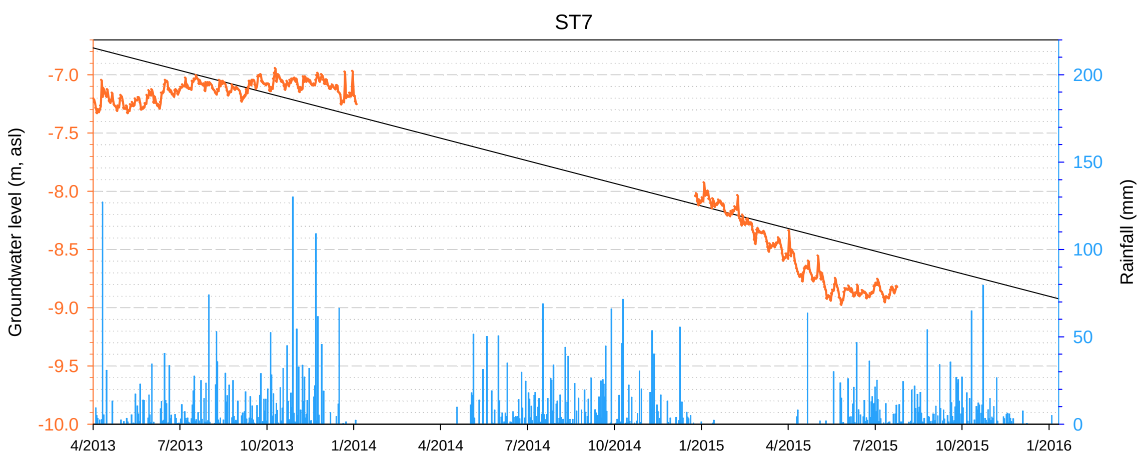


Figure 23. Fluctuation of groundwater level at ST7 (Thạnh Phú commune, Mỹ Xuyên district, Sóc Trăng province)

The groundwater level monitoring data of ST7 is unavailable from Jannuary 2014 to December 16th, 2014. Groundwater level has decreased from -6.78 m to -8.6 m by July 15th, 2015; averaged at 0.77 m/year; expected to decrease to -8.9 m by Jannuary 2016.

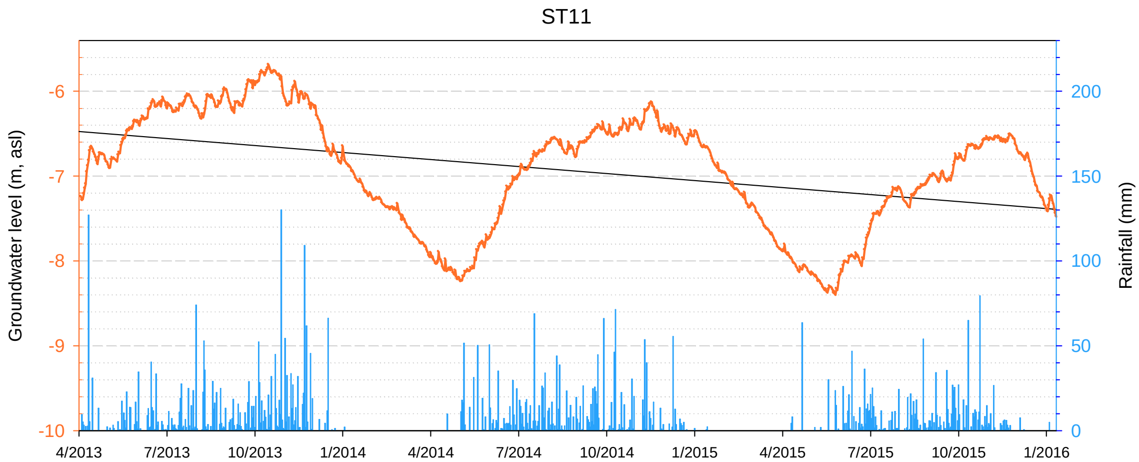


Figure 24. Fluctuation of groundwater level at ST11 (Vĩnh Tân commune, Vĩnh Châu district, Sóc Trăng province)

The groundwater level monitoring data of ST11 is continuous since April 2013 uptil Jannuary 2016. During this period, groundwater level has decreased from -6.48 m to -7.4 m; averaged at 0.33 m/year. Similar to ST1, the groundwater level fluctuates by season and varies by rain fall.

Among 5 monitoring wells in Soc Trang province, the groundwater level at ST1 can decrease down to 9 m below sea level; meanwhile, the groundwater level at ST3, of which, the lowest level was as much as 6 m below sea level, is much higher than those at the other monitoring wells.

# 5. Observations and Conclusions

## 5.1. Groundwater reserve and quality of the $qp_{2-3}$

The groundwater level of the $qp_{2-3}$ has been decreasing continuously since April 2013. The average decreasing rate was 0.29 – 0.77 m/year. The groundwater level varies by seasons and tidal regime.

Generally, groundwater of the qp2-3 shows good quality, no heavy metals, trace elements were observed. Therefore, groundwater of the qp2-3 can be extracted for domestic water supply with relevant water treatment technology applied. The influent water quality should be monitored continually due to the variation of chemical components by time.

## 5.2. Salt water intrusion

The stable isotope composition of water samples collected in Soc Trang in 2013 showed that salt water from the sea was going upstream to some exten on Hau River during the dry season but it did not affect the adjacent aquifers.

## 5.3. Groundwater source, recharge and the surface water – groundwater interaction

Major ions and stable isotope data of both groundwater and surface water samples in dry season showed no hydraulic connection between the rivers and the corresponding aquifers in Soc Trang province. Any recharge from surface water to aquifers in Soc Trang should occur outside the vicinity of Soc Trang province. Some groundwater sampling points are located in previously occurred salty area.

## 5.4. Issues related to the centralized Water supply station

The pump rate at the two water supply stations (My Xuyen and Long Phu districts) were exceeding the maximum sustainable yield of the aquifer and contamination from surface water may eventually occur. It is necessary to control the pump rate at these WTPs to prevent any possible contamination.

# 6. Proposal of the Recommendations and Solutions for Groundwater Management in Soc Trang province

## 6.1. Review and assessment of the implementation of legal documents, secondary regulations in water resource sector

According to the "Review of the groundwater resources management in Soc Trang province" implemented by CTU and Soc Trang DONRE in 2015, the management apparatus and the legal tools for groundwater resource management are tightly set from the central to local levels. The legal documents, secondary regulations in water resources sector in general and groundwater in particular have been issued under the authority by the Government, the MONRE and Soc Trang PPC; and were implemented by Soc Trang DONRE (see Section 1.2.3). Therefore, Soc Trang DONRE should conduct a review and evaluation of the implementation of those documents to clarify any disadvantages to overcome in the near future; propose orientations and implementation plan.

## 6.2. Water resources planning

The project "Planning for groundwater resource exploitation, utilization and protection in Soc Trang province to 2020" was completed in 2010 and was approved by the Soc Trang PPC in the beginning of 2011. To date, the results of this planning is still being applied as a basis for management of groundwater exploitation licensing in Soc Trang. In the context of seriously increasing drought and salinization in the Mekong Delta; and the provisions of the Water Resources Law dated on 21/06/2012, the Circular 42/2015/TT-BTNMT dated on 29/9/2015 of the MONRE regulating water resources planning techniques; the Soc Trang PPC should carry out a general water resources planning, submit to the MONRE for comments before submission to the Provincial People Council for approval. In details, surface water resource planning should be newly carried out; groundwater resource planning since 2010 needs to be adjusted and supplemented. Analysis and evaluation of the implementation of this planning are needed to point out the contents to be adjusted and the factors affecting the planning adjustment.

The general water resources planning will be the basis for the Soc Trang DONRE to perform the tasks of water resources management, exploitation licensing and allocation.

Currently Soc Trang is carrying out the project "Planning for surface water resource exploitation, utilization and protection in Soc Trang province to 2020, orienting to 2030" (currently processing the survey data, collected data, running the water quality model, topographical mapping of some major rivers), which is expected to be completed at the end of 2016 and will be sent to MONRE for comments and then, submitted to the Provincial People Council for approval.

### 6.3. Specific tasks regarding to water resouces planning

*Groundwater exploitation licensing*

In the mean time while an updated water resources planning is not yet available, the Soc Trang DONRE still has to apply the groundwater resource planning 2010. However, the groundwater resource exploitation licensing should be done with the following remark: limit the abstraction rate in the $qp_{2-3}$ aquifer, especially in Thanh Tri, My Xuyen, Vinh Chau districts where quick drawdown of groundwater levels are observed as a monitoring result of the IGPVN project (see Section 4.4).

The Soc Trang DONRE needs to review and sum up all the licensed abstraction rates for each aquifer. The newly granted licensing of new groundwater abstraction works must not exceed the sustainable yield of each aquifer. However, there still may be the case when the actual abstraction rate did not exceed the sustainable yield of the aquifer but still resulted in groundwater level drawdown. This demonstrates the need to investigate, evaluate and calculate the sustainable yield of the corresponding aquifers; and the need to cut down the abstraction rate.

The Soc Trang DONRE should notify the District People Committee on groundwater dynamic in their district and request for coordinating in management and supervision of the qp2-3 exploitation restriction.

*Investigation for updates of groundwater exploitation and utilization*

The Soc Trang DONRE should conduct an investigation to update groundwater exploitation and utilization in the whole province; assess the implementation of the Decision No. 11/2008/QD-UBND dated on 14/4/2008 issued by the Soc Trang PPC on registration for groundwater exploitation and utilization at household scale.

The Soc Trang DONRE should introduce concrete measures to end the household arbitrary drillings (many households drilled tens of wells, one new well will be drilled as soon as the previously drilled well is dry out); for example, the PPC should issue regulation on administrative punishment for household arbitrary drillings, requirement to fill up any household tubewell that is no longer in use before drilling any new well.

Budget allocation is needed to support local people to fill up abandoned wells, saline wells those are no longer usable; supervision of well filling up is needed to assure that it is in accordance with the relevant regulations and standards (Decision No. 14/2007/QD-BTNMT dated on 4/9/2007).

*Water resources Allocation*

The Soc Trang DONRE should allocate water resources according to the following priorities: 1) water for domestic use; 2) water for agricultural production; 3) water for aquaculture; then for other purposes.

Water for domestic use must be guaranteed by a stable water supply from the centralized water supply plants. The Soc Trang PPC should develop a plan for construction of water supply plants in the province which points out how many water supply plants are needed to meet the water demand. There should be an appropriate roadmap to completely switch from household tube well water to tap water and rainwater. The local people should be encouraged and supported to switch to tap water. They also need to be trained how to collect, store and handle rain water for domestic use and supported instruments for that. It is advisable to develop distillation technology using solar energy for surface saline water treatment for domestic water supply during dry season.

Fresh aquifers should not be exploited for agriculture and aquaculture uses and should be reserved for domestic use. Water from the salty aquifer can be exploited and used for this purpose provided that the wells are registered and licensed and the water is consistent with the salinity tolerance of plants and animals. The Soc Trang DONRE should control the pumping rate that is allowable for the saline aquifer and make public the water quality data. The Soc Trang DARD and the relevant agencies should advise people how to use saline water for this purpose (direct use or mix with other water sources), or which plants and animals fit this water source.

The local people should use surface water for agricultural production and aquaculture with the following note: water should be taken at low tide not at high tide to minimize the tidal impact. For this, people not only need to understand the tidal regime, but also need to actively update the weather forecast and salinity forecast for the river system to accordingly make their own irrigation plan. The Soc Trang PPC should make policies to develop scientific irrigation technology to help save water and ensure crop yields.

*Protection of fresh/slightly saline aquifers*

The fresh deep aquifers need to be conserved as a strategic water reserve for domestic use and for prolonged drought or extreme water scarcity. The Soc Trang DONRE should restrict groundwater exploitation licensing for the deep aquifers ($qp_1$, $n_2^2$, $n_2^1$).

Additionally the Soc Trang DONRE need to investigate and make a list of the abandoned wells (broken, saline, not usable any more...) and make plan for filling up those wells. Appropriate policy is needed to support the local people on filling up those wells and the well filling up should be supervised to assure the quality.

The Soc Trang DONRE should properly control the drilling quality. Drilling licensing should be done adequately to assure the licensed agency/individual must have sufficient equipments and technical capacity. While drilling a well, various aquifers/layers must be tightly sealed off to prevent any leakage that may result in aquifer contamination. The well owner should report to the DONRE or the district people committee about unusual problems occuring while using the well so that those information will be put into a factual record of the corresponding drilling agency. The factual record is open access so that people can refer to any relevant information when selecting a drilling agency. The drilling license will be revoked or will not be extended for the drilling agency if the number of the broken wells in their factual records exceed a certain number (possibly 5).

*Management of saline aquifer*

As mentioned above, the saline aquifers (qh, $qp_3$) are possible to be exploited for agricultural production and aquaculture if and only if the salinity is consistent with the salinity tolerance of plants and animals. Moreover, the abstraction rate of the saline aquifers regarding this purpose must be tightly controled.

The saline water is not suitable for domestic use as the MOH guideline value for Cl in domestic water is 250 mg/L. Therefore, the Soc Trang DONRE should disseminate information on saline aquifer to the local people to prevent and stop drilling into the saline aquifers for exploitation of groundwater for domestic use. There should be an appropriate roadmap to completely switch from household tube well water to tap water. The residents in the saline aquifer areas should be encouraged and supported to switch to tap water. They also need to be trained how to collect, store and handle rain water for domestic use and supported instruments for that.

The saline aquifers should only be exploited by the water treatment plant with appropriate treatment technologies, using nanofiltration (NF) membrane in combination with reverse osmosis (RO) or distillation. The pumping rate must be tightly controled to ensure the aquifers' sustainable yield are not exceeded so as not to lower the groundwater level or enhance the salinisation process. The Soc Trang DONRE should update the annual monitoring data of groundwater dynamic and adjust the licensed pumping rate of the corresponding water treatment plant. The Soc Trang DONRE needs to coordinate/consult DOST to learn about saline water/seawater treatment technology to qualify their licensing capacity and supervising capacity on the operation of the corresponding water treatment plan. Especially when all the water sources (including surface and groundwater) in Soc Trang province are affected by salt water intrusion, then the only solution is to build up the centralized water treatment plants of saline water/seawater treatment technology. A rational development orientation is to build up centralized water treatment plants of saline water treatment technology using influent water of alternative surface water/rainwater and saline groundwater to ensure stable operation; increasing surface water/rainwater exploitation during the rainy season from May to November. It is recommended to facilitate the water supply company to build up rainwater harvesting system and reservoir to cut down groundwater pumping rate during the rainy season; and to develop distillation technology using solar energy for surface water treatment to cut down groundwater pumping rate during the dry season. The Soc Trang PPC should direct the water supply company in Soc Trang to update water treatment technology and prepare for the $qp_{2-3}$ water treatment plants to switch to saline water treatment technology.

*Artificial recharge*

In the mean time when a detailed guideline of the MONRE on artificial recharge is yet available, the Soc Trang DONRE together with the district People Committee and the communal People Committee should make plan for a tight control on this issue in combination with awareness raising for the local people to avoid "spontaneous recharge": people let rainwater and surface water runoff freely flow into the wells leading to risk of serious pollution.

The Soc Trang DONRE should cooperate with the DOST, research institutes, universities to do research and development on aquifer artificial recharge in accordance with the specific conditions of Soc Trang province. The Soc Trang PPC should have guidelines and policies to encourage this activity: call for investment from the Soc Trang water supply company, industrial zones and water stakeholders. The Soc Trang PPC and Soc Trang DONRE should actively seek for any external resources, either scientific, technical or financial resources to implement this solution.

However, artificial recharge is recommended for long term measure. Currently, under the context of severe drought and salinization in the Mekong Delta, this measure does not have high priority as any water source that may be used for artificial recharge should be allocated for domestic use. Moreover, artificial recharge requires a recovery step to pump out and treat the previously recharged water and therefore, it is not cost effective and not appropriate for Soc Trang at current state.

*Groundwater monitoring*

In phase 2 of the IGPVN project, 5 groundwater monitoring wells of the $qp_{2-3}$ aquifer have been built in 5 districts of Soc Trang province and groundwater monitoring started since April 2013 (see 3.4). After taking over the monitoring wells, the Soc Trang DONRE should develop an annual monitoring plan and submit to the PPC to apply for funding. Monitoring data should be taken regularly for every 3 months. Simultaneously, the monitoring wells should be inspected during each visit to detect any problem occurring, develop maintenance plan and submit for approval. Details on the maintenance of the monitoring well are outlined

in the "Short list for implementation of maintenance for groundwater monitoring works" by the IGPVN project based on Article 13 Circular 19/2013/TT-BTNMT and handed over to the Soc Trang DONRE along with the monitoring wells. Details as follows:

- Regularly clean, clear up the surrounding area and the entrance to the monitoring work to ensure a safe and convenient performance of the monitoring task.
- Check the protection fence, gate and lock of the monitoring work; lubricate, repaint, repair, replace if necessary.
- Check if the basemen of the monitoring well sinks or flooded, then it should be lifted up to a reasonable extent. If necessary, the well pad and the well protection tube must also be lifted up and the atteched benchmark must be leveled again.
- Check the signboard, the well protection tube, cap and lock. The signboard must be kept clean to clearly see the printed text. Well head must always be closed tightly. The well protection tube, cap and lock must be repaired, replaced promptly if they are rusted or damaged.
- During pumping for water sampling, if the water is mixed with mud and/or sand, then the well depth is very likely to be silted up; if the output flow rate is too low, then the well screening is very likely to be clogged. In this case, it is recommended to flush the well to restore its depth and clear up its screening.
- The depth of the monitoring well should be checked every 3 months to immediately detect the sedimentation at the bottom of the well or obstacles falling into the well, if any.
- The monitoring well should be flushed every 3-5 years.
- If severe damage of the well casing is detected, then decision on repairing or filling up the well should be made.

### 6.4. Development of the Guidebooks on water resources sector

Currently, the Guide book on water resource management (for local authorities) and the Guide book on water resource exploitation, utilization and protection (for enterprises and companies) are being compiled by the Soc Trang DONRE with the support of the IGPVN project.

In 2012, the Soc Trang DONRE has compiled a Guide book on management of water resources - minerals (for local authorities) which codified the legal documents and secondary regulations in order to provide basic knowledge and professional guidance to officials in charge of natural resources and environment management and officials of relevant departments in the province. To date, there are more legal documents are enacted; therefore, it is in need to compile a guide book on water resources management based on some of the contents of the previous Guide book to conform with the new regulations in water resources sector.

The Guide book on water resource exploitation, utilization and protection (for enterprises and companies) will be compiled in order to provide necessary knowledge to support enterprises and companies in implementation of the legislation in water resources sector.

The project IGPVN has been cooperating with the Soc Trang DONRE to compile these two Guide books to release on schedule.

### 6.5. Strengthening the integrated water resources management, networking and information sharing

Soc Trang is a coastal province which locates in the most downstream part of the Mekong River. The tidal regime of the East sea and the hydrological regime of the Mekong River have a great influence on groundwater resource of the province. In the context of global climate change and increasing drought and salt intrusion in the whole Mekong Delta, Soc Trang province is one of the most heavily affected area. Three estuaries in Soc Trang province make good condition for sea water intrusion further inland causing many difficulties for production and people's lives. Locating in the coastal estuaries, tidal-enhanced saltwater intrusion has affected large portion of the province area. In some places, salty water can intrude as far as 60 km inland. Meanwhile, drought also occurs in Soc Trang more seriously than in other provinces.

As a province of quite low per capita income and revenues are mainly from aquaculture and vegetables, Soc Trang is facing many difficulties especially in financial resources while implementing the legislation in water resources sector.

In order to overcome these difficulties and challenges, Soc Trang needs to be proactively connect with the neighboring provinces in the Mekong Delta, especially the upstream provinces to share information on water resources, the right and responsibility to protect inter-provincial river water and related resources (upstream protection forests, riverbed sand ...); connect with the provinces in coastal estuaries of similar natural conditions to share information and learn experiences on water resource management. The approach of integrated water resource management, regional linkage management with a regional coordination mechanism are especially in need.

### 6.6. Awareness raising on water resources

So far, water resource exploitation, utilization and protection has been clearly stipulated in the Water Resources Law 2012 and many other legal documents as well as secondary regulations. However, in order to ensure these regulations will come to life and will be enforced, it is the responsibility of the authorities to carry out communication for dissemination of these regulations and policies to the people. Appropriate awareness raising communication forms are necessary for each object in order to promote the efficiency.

For the local people, the most effective form of communication and information dissemination is evidence-based. People will learn about the issue and gain deeper understanding when witnessing the consequences of over exploitation, indiscriminate use of water resources which their neighbors are incurring; from that, people will understand that it is only a matter of time for them to become similar victims.

For the school children, it is recommended to integrate relevant content into the school curriculum. The development of education materials on water resources for school children is essential. This is one of the work packages that is being implemented by the IGPVN project.

For students who are subjected to formal training, have basic knowledge, independent thinking and problem-solving ability; it is recommended to facilitate to students to contribute ideas and solutions for water resources issues in particular and for natural resources and environment issues in general. It is necessary to strengthen the connection between the local authorities and the students of Soc Trang province who are studying at various universities across the country to make the students better understand the current state of the local issues, so that they will have better career orientation and can contribute to the improvement of the situation in the province.

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