Vietnam Journal of Science and Technology ***61*** *(1) (2023) 91-107*

doi:10.15625/2525-2518/16426

Evaluation of groundwater level, quality and recharge: a case study of Can Tho city, Viet Nam

Tran Van Ty[1], Trinh Trung Tri Dang[2], Nguyen Dinh Giang Nam[3], Huynh Vuong Thu Minh[3, *]

[1]*College of Engineering, Can Tho University, Viet Nam, Campus II, 3/2 street, Ninh Kieu District, Can Tho City*

[2]*Institute of Environmental Science and Technology, Tra Vinh University, Viet Nam, No. 126 Nguyen Thien Thanh - Block 4, Ward 5, Tra Vinh City, Tra Vinh Province*

[3]*College of Environment and Natural Resources, Can Tho University, Viet Nam, Campus II, 3/2 Street, Ninh Kieu district, Can Tho City*

[*]Emails: hvtminh@ctu.edu.vn

Received: 19 August 2021; Accepted for publication: 15 November 2021

Abstract. This study evaluated the groundwater levels (GWLs) and groundwater quality of Can Tho city using statistical analysis and a Groundwater Quality Index (GWQI). In addition, the groundwater recharge potential from rainfall was investigated for the period 2001-2009. The results show that GWLs decreased rapidly in the period 2000 - 2010 and gradually in the period 2012 - 2018 in both the Middle-upper Pleistocene ($qp_{2\text{-}3}$) and Upper Pleistocene (qp_3) aquifers. This is due to excessive withdrawals, especially to meet the demands of production facilities in the city's industrial zones. In this regard, Decree No. 2946/UBND-KT of the People's Committee of Can Tho City was issued and enacted in 2012, which resulted in a marked reduction in withdrawals and contributed to GWL stabilization. Groundwater quality in Can Tho was found to be mainly affected by coliform in both dry and wet seasons. However, groundwater quality improved during the wet season with the dilution of rainfall, as shown by the GWQI values. In addition to groundwater recharge from rainfall, other socio-economic factors such as urbanization, industrialization, and the influence of the Hau (Bassac) River on recharge potentials should be further investigated.

Keywords: Groundwater level, groundwater recharge, groundwater quality index (GWQI), Can Tho city.

Classification numbers: 3.4.2

1. INTRODUCTION

Water resources are central to socio-economic development and human health. It is estimated that 80 % of the world's population is currently facing water scarcity [1 - 4]. Hence, both water quantity and quality have become major issues in the current environmental discourse. In the Vietnamese Mekong Delta (VMD), water resources are affected by several factors, such as water use demands, climate change and inappropriate management, which create significant challenges for socio-economic development, poverty alleviation and livelihood diversification [5, 6]. Currently, the rapid rates of population growth, urbanization and industrialization transformation in the VMD have put considerable pressure on available water resources [7 - 9]. Furthermore, the development of dams, hydropower plants, as well as water withdrawals in upstream sections of the Mekong basin have also contributed to changes in the hydrological regime of the VMD downstream [6, 10]. In turn, increasing water demands in the VMD has caused over-exploitation not only for irrigation, aquaculture and industry, but also for domestic use [11, 12].

In view of these challenges, groundwater is considered as a valuable resource which accounts globally for 30 percent of freshwater demands [13]. In the VMD, groundwater plays an important role in meeting freshwater demands to sustain agricultural activities and the livelihood of residents. This is because annual rainfall is not uniformly distributed over the region, and groundwater is much less affected by climate variability, as well as from pollution than surface water resources. However, the hydrological regimes of the VMD have a direct impact on groundwater resources (GWR) through different routes, such as the disruption of natural flood regimes, groundwater exploitation and recharge, as well as salt intrusion into the groundwater aquifers [14]. Moreover, groundwater has been increasingly exploited for the purposes of irrigation, domestic use, and also industrial activities [15]. This has resulted in the reduction of groundwater levels (GWL) [16] and associated land subsidence [17]. Additionally, the absence of management policies and their enforcement has also contributed to decreasing groundwater quality [18]. Many studies have investigated the status of groundwater quantity and quality in many regions in the VMD [16, 17]; for example, the GWL in Soc Trang city had an average decrease of 0.30 to 0.39 m/year due to exploitation activities [19].

Can Tho city is the largest urban area in the VMD, currently undergoing rapid urbanization and population growth, which in turn has led to an increasing demand for fresh water resources. However, both the quantity and quality of surface water resources have decreased in recent years, causing a resultant over-exploitation of GWR. Recent studies on GWR in Can Tho city include Ty *et al.* (2021) [20], who studied the spatiotemporal variations of GWL and the connection to land subsidence. The results from a Mann Kendal test with Sen's slope indicated a decreasing trend of GWL and a significant change in GWL over an eighteen-year period from 2000 to 2018. The results showed significant downward trends of GWLs for all studied wells of aquifers qp_3 and $qp_{2\text{-}3}$, except for a few shallow wells. It was found that the trend of this dropdown in deep wells was highly associated with extraction rates. In addition, Ty *et al*. (2018) conducted research in the Tra Noc Industrial Zone of Can Tho city to assess the current status of exploitation, GWLs changes and management of GWR, from which a relationship between groundwater extraction, the water level in the Hau River (CTH-039803 station) and GWLs at monitoring stations/wells was established [21, 22]. The results showed that the extraction of groundwater in the Tra Noc Industrial Zone led to an over-exploitation of GWR. It is suggested that this may be a major cause of the marked decrease in GWLs of Pleistocene and Holocene aquifers of 4 m and 1 m from 2000 to 2015, respectively. Both rainfall and the Hau River were found to be the major source of recharge to the Holocene aquifer. In addition, the management of GWR was deemed not effective, and there was a lack of close coordination between enterprises and local GWR management agencies/departments. Besides, the GWL at the Tra Noc Industrial Zone in Can Tho city was seen to decrease at an average rate of 22.09, 41.24 and 37.64 cm/year in the Holocene aquifer (qh), the Middle-upper Pleistocene aquifer ($qp_{2\text{-}3}$), and the Upper Pleistocene aquifer (qp_3), respectively [23].

Therefore, GWR in Can Tho city has changed significantly with increasing water demands to meet the needs of both domestic and industrial activities. Moreover, changes in rainfall have also affected the potential groundwater recharge, which may lead to water scarcity in the future. For example, the impact of rainfall changes on shallow groundwater recharge under climate change scenarios in Hau Giang province was reported by [24]. Their work indicated a large imbalance between the amount of groundwater recharge (supply) and the exploitation (withdrawal). To the best of our knowledge, the evaluation of groundwater quality and recharge for the entire administrative area of Can Tho has been rarely documented in recent years. Moreover, the study on evaluating GWL, quality and recharge in Can Tho city is a pressing concern as it provides significantly practical information for improved management and reduction of GWR degradation. Therefore, the objective of this study was to evaluate the status of GWL and groundwater quality in eight representative districts of Can Tho city.

2. MATERIALS AND METHODOLOGY

2.1. Study area

Can Tho city has an average elevation of 1 to +3 m above the mean sea level and is located in the center of the VMD. It exhibits a tropical and monsoon climate, with a wet season from May to November and a dry season from December to April (Figure 1). The mean annual rainfall is 1,674 mm, while the average annual temperature and humidity are 27 ^{o}C and 83 %, respectively. In Can Tho city, groundwater exists in the pores of unconsolidated Cainozoic sediments with the different hydrographic geological units, including Holocene (qh), Upper Pleistocene (qp_3) and Upper-middle Pleistocene (qp_{2-3}). In the Holocene aquifer known as a source to recharge deeper aquifers, the groundwater level is stable, ranging from 0.1 to 1.6 m from the ground surface, with an average thickness of 25.4 m. Therefore, the seasonal changes in quantity and quality of water in the Holocene aquifer may be influenced by different recharge sources, such as rainfall and surface water [25].

Figure 1 shows that the groundwater monitoring network in Can Tho city includes 16 clusters covering eight districts; in which BS.01-BS.06 has been monitored since 2006, while QT1-QT6, QT8-QT12, and QT16-QT18 have been monitored since 2000. However, 8 out of 16 clusters were selected as the main representative of eight districts in Can Tho city as summarized in Table 1.

Table 1. The main representative of eight districts in Can Tho city.

No.	District	Abbreviation	Monitoring well
1	Cai Rang	CR	QT01
2	Binh Thuy	BT	QT08
3	O Mon	OM	QT09
4	Thoi Lai	TL	QT10
5	Thot Not	TN	QT11
6	Vinh Thanh	VT	QT17
7	Co Do	CD	QT18
8	Phong Dien	PD	BS03

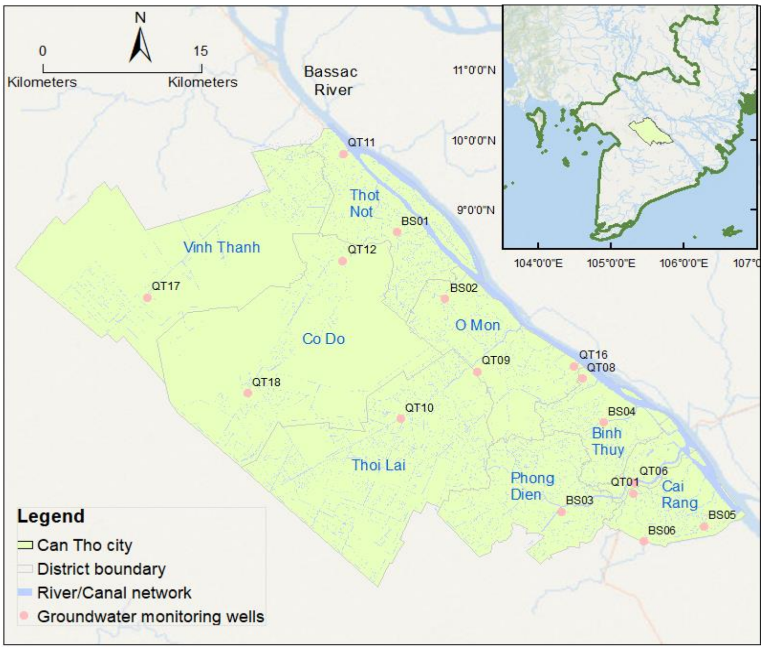

Figure 1. Location of groundwater monitoring wells in Can Tho city (QT- monitored since 2000; BS - Supplementally wells since 2006).

2.2. Data collection

The data series of groundwater levels was collected from the Department of Natural Resources and Environment of Can Tho city, and the Division for Water Resources Planning and Investigation for the South of Viet Nam. The rainfall data were provided from the Hydrometeorological station of Can Tho city. Table 2 outlines the data sources.

Table 2. Collected data series.

Data	Duration	Notes
Groundwater quality	2001 - 2016	10 monitoring wells Frequency 2 times/year
Groundwater level	2001 - 2018	16 monitoring wells Frequency 1 time/month
Groundwater exploitation	2004 - 2016	Yearly, in Tra Noc Industrial Zone
Rainfall	2001 - 2018	
Groundwater recharge	2001 - 2009	

2.3. Groundwater quality index

The Groundwater Quality Index (GWQI) method reflects the combined effects of different water quality parameters, depending on the characteristics of the study area and the target use. Groundwater quality is calculated using the GWQI formula (2001 - 2016) [26], which is compared with the permissive standard of the Vietnamese Regulation (QCVN 09-MT: 2015/BTNMT).

$$GWQI = \sum_{n}^{i=1} SI_i = \sum_{n}^{i=1} (W_i \times q_i) = \left[\left(\frac{W_i}{\sum_{n}^{i=1} W_i} \right) \times \left(\frac{c_i}{S_i} \times 100 \right) \right] \quad (1)$$

where n is the number of groundwater parameters; w_i is the weightage of the parameter i as presented in Table 3 (referenced from [27]); C_i is the measured value of the parameter i; and S_i is the maximum permissible standard of the parameter i (based on QCVN 09-MT: 2015/BTNMT).

After calculation, GWQI is classified as shown in Table 4. Besides, the probability of exceedance was also calculated by equation 2 to compare the GWQ between the dry and wet seasons.

$$\rho(x_i) = \frac{x_k}{n} \quad (2)$$

where $\rho(x_i)$ is the probability of exceedance value; x_k is the total number of samples with values higher than the standard values (compared to QCVN 09:2015/BTNMT); and n is the total number of samples observed.

Table 3. Weight, correlation weight and limit values of GWQI.

Parameter	**Unit**	**Weightage (w_i)**	**Correlation Weightage (W_i)**	**Limit values (S_i)** (QCVN 09-MT:2015/BTNMT)
pH	-	4	0.17	5.5 - 8.5
Hardness	mg/L	2	0.09	500
Cl^-	mg/L	3	0.13	250
NO_3^-	mg/L	5	0.22	15
SO_4^{2-}	mg/L	4	0.17	400
Fe^{2+}	mg/L	4	0.17	5
Coliform	MPN/100mL	1	0.04	3
		$\sum_{n}^{1} w_i = 21$	$\sum_{n}^{1} W_i = 1$	

Table 4. Water quality classification based on GWQI.

Classification	**GWQI value**
Good	<50
Bad	50-100
Very bad	>100

2.4. Groundwater recharge

In this study, the groundwater recharge was estimated for the Holocene aquifer (qh) through the statistical relationship between the rainfall amount and the groundwater level (in qh aquifer) for the period 2001-2018 using the following equation [28].

$$\Delta H = a + b \times R_t \quad (3)$$

where ΔH is the recovery of groundwater level; R_t is the total precipitation during the wet period; a and b are the regression coefficients. The relationship between the two variables (R_t and ΔH) was established by a simple statistical technique, thereby the correlation equation between the amount of groundwater recharge and the rainfall at each monitoring well was estimated (or a and b were found).

3. RESULTS AND DISCUSSION

3.1. Fluctuation of GWR in Can Tho city

The fluctuation of rainfall and water level of the Hau River in Can Tho city from 2001 to 2018 is presented in Figure 2. Both monthly rainfall and river water levels show the same fluctuation trend. It suggests that in general, the water level of the river has not changed considerably over the last two decades.

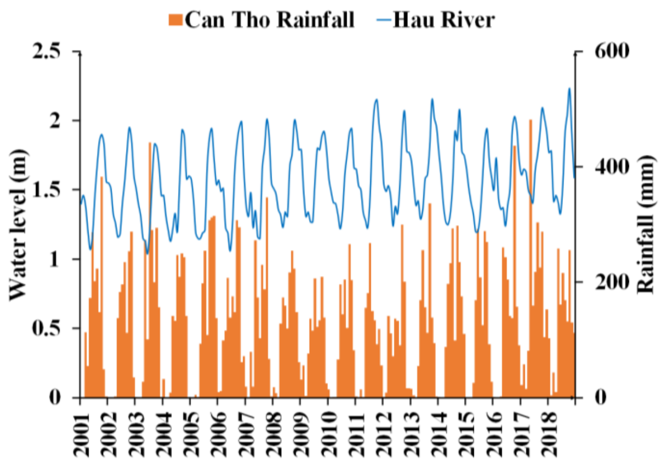

Figure 2. Rainfall and water levels in the period 2001-2018 of Can Tho city.

The trend of GWLs at Phong Dien (PD), Cai Rang (CR), Binh Thuy (BT), O Mon (OM), Thoi Lai (TL), Thot Not (TN), Vinh Thanh (VT), and Co Do (CD) districts versa the surface water level at the Can Tho station (2001 - 2018) is shown in Figure 3. It can be seen that the GWL in the Holocene aquifer was relatively stable during the majority of the last 20 years, while a gradual decrease in GWLs is found in the Upper Pleistocene (qp_3) and Upper-middle (qp_{2-3}) Pleistocene aquifers. The GWLs in Upper Pleistocene (qp3) and Upper-middle (qp2-3) Pleistocene aquifers both decreased approximately by 5 m. The possible reason is due to the increasing exploitation of GWR to meet the domestic (small driver) and industrial (dominant driver) demands as reported by [29]. However, it is also noted that the fluctuation of GWLs shows the same decreasing trend from 2001 to 2010, and then retains a certain stability as observed in districts such as CR, BT, OM, TL and VT. This may be the result of groundwater exploitation being gradually phased-out due to the expansion of the water supply network from surface water.

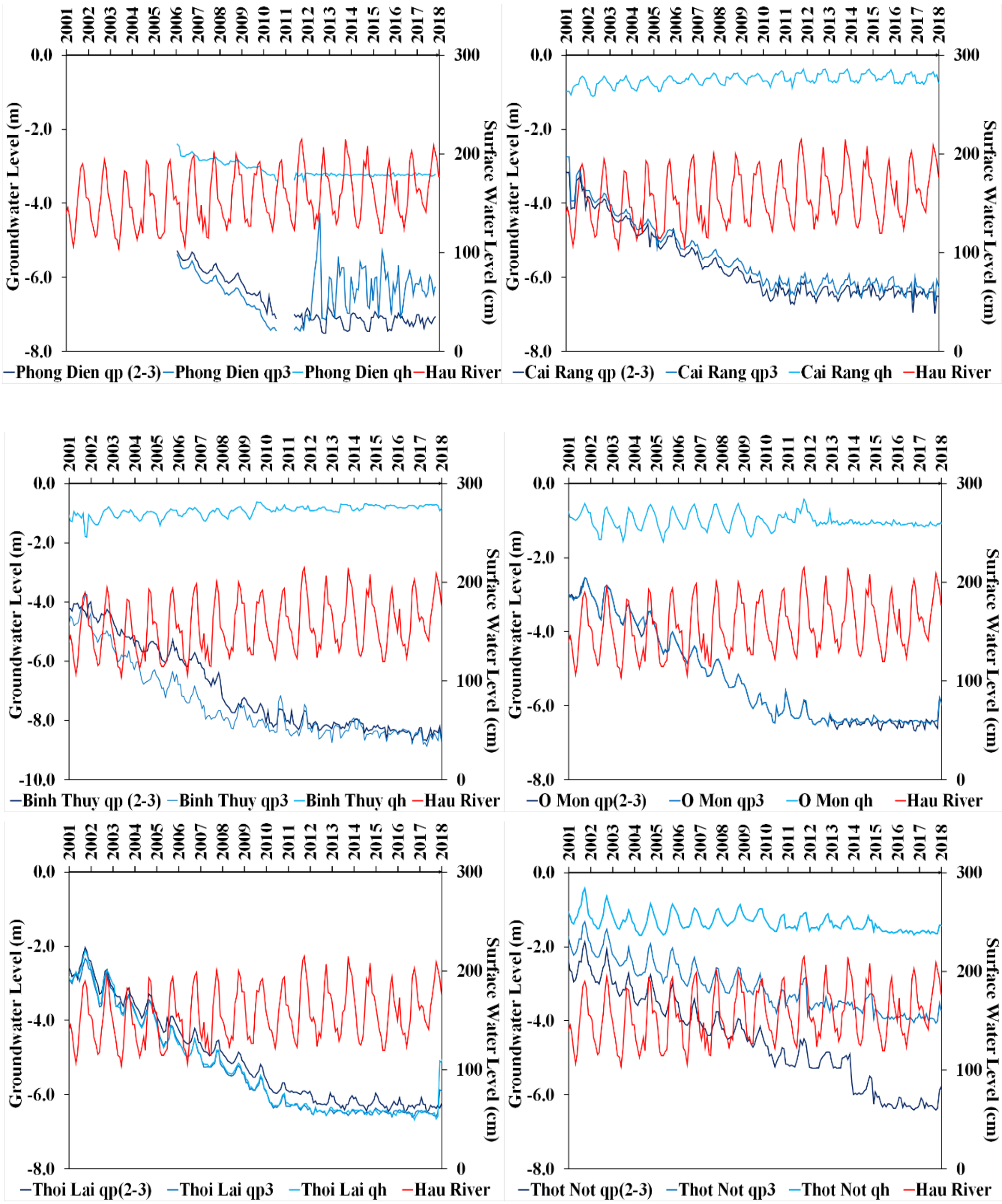

Figure 3. The trend of GWLs at districts vs surface water levels recorded at Can Tho station (2001-2018).

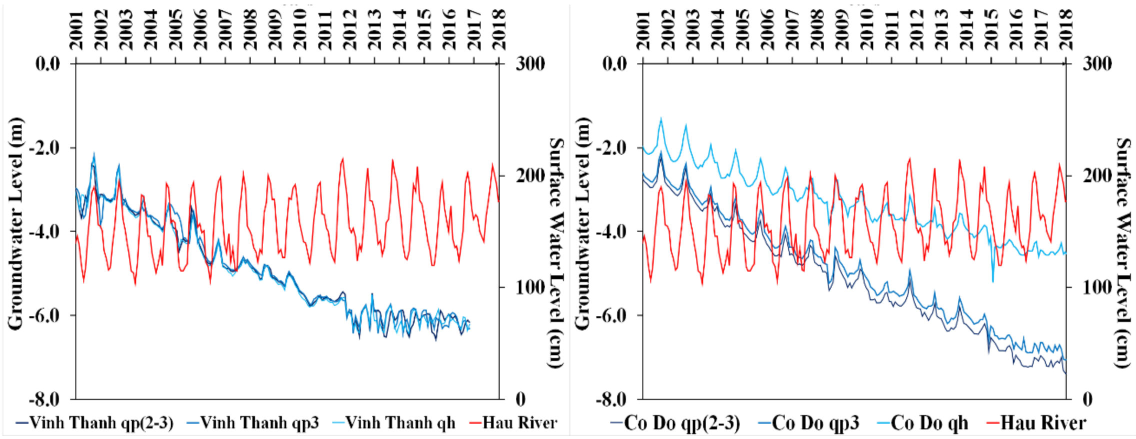

Figure 3 (*continue*). The trend of GWLs at districts vs surface water levels recorded at Can Tho station (2001-2018).

In addition, due to lack of data on GWR exploitation for the whole city, based on the assessment of the exploitation rate of GWR in Tra Noc Industrial Zone carried out by Ty *et al*. (2018) [22], a total exploitation rate of GWR from 2004 to 2016 is shown in Figure 4. The Figure shows that from 2004 to 2010, the policy of encouraging investment in the Tra Noc Industrial Zone led to a corresponding increase in GWR exploitation. The total GWR exploitation in 2004, 2009 and 2011 was 3,568 m^3/day, 18,876 m^3/day and 20,210 m^3/day, respectively. It is clear that the total exploitation of GWR increased by almost six times over this 7-year period. However, the enforcement of Decree No. 2946/UBND-KT dated June 23, 2010 of the People's Committee of Can Tho city on regulating the use of GWR reduced the exploitation in 2012, and thus GWLs became gradually stable [30]. In addition, the enterprises in Tra Noc Industrial Zone have used a combination of different water sources for production and daily needs. Only 18.18 % of enterprises used GWR, while other enterprises used main water with GWR accounting for 63.64 %; and the rest used combined sources (data not shown here). However, the exploitation of GWR for production nevertheless shows an increasing trend after 2012.

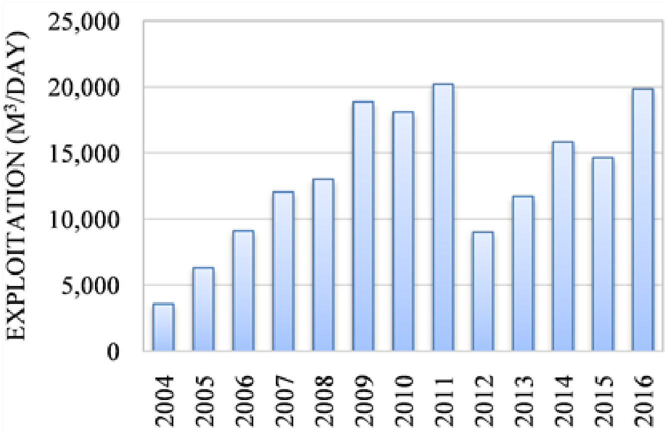

Figure 4. Total GWR exploitation rates in Tra Noc Industrial Zone (2004 - 2016).

3.2. Quality of groundwater

In this study, the groundwater quality was evaluated using basic water quality parameters, including pH, hardness, nitrate, sulfate, chlorine, and coliform. Generally, the values of pH, hardness and nitrate parameters were much lower than the standard values according to QCVN 09:2015/BTNMT.

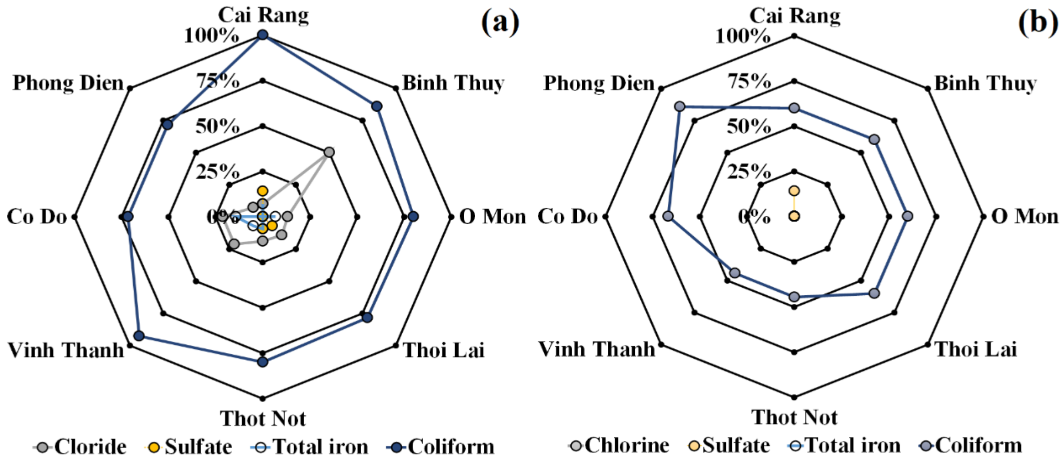

Figure 5. Comparative graph for GWQI parameters in both the dry (a) and wet (b) seasons.

Therefore, Figure 5 only shows the comparison of chlorine, total iron, sulfate and coliform contamination in the groundwater of the city between dry and wet seasons. It can be seen that the groundwater quality in Can Tho is contaminated mainly by coliform through both seasons. However, the contamination was reduced significantly due to the reduced exploitation of GWR and by rainwater dilution in the wet season. Moreover, chloride contamination was also observed during the dry season at most of the monitoring clusters. This is because the concentration of Cl^- may result from human activities (e.g., agricultural runoff, discharged wastewater, septic tank effluent, and landfill leachates) [31 - 34]. The groundwater pollution by sulfate was seen mainly in the wet season. This is because sulfate anions from fertilizers can be permeabilized easily into aquifers by rainfall runoff and infiltration. As a result, the increasing exploitation of groundwater for both domestic and industrial uses [29] can be considered as the main reason for the degradation of groundwater over the entire city.

The total water quality values to evaluate GWQI based on the permissive standard of QCVN 09:2015/BTNMT in the wet and dry seasons are presented in Figure 6. As mentioned, the GWQI of Can Tho city was affected mainly by the high value of coliform, hence the GWQI value was usually at a high level (> 100) in the dry season between 2001 to 2016. However, the GWQI improved significantly in the wet season with increased rainfall dilution. It is also noted that the groundwater pollution remained quite high in some districts that are considered as the suburbs of Can Tho city, where domestic waste may be discharged directly into the aquatic environment. Furthermore, the growth of population and production also contributes to the pollution of groundwater quality from 2005 onwards. On the other hand, rapid urbanization may help to reduce the groundwater pollution from 2016 thanks to the replacement of GWR by the surface domestic water supply, and improved technologies for water treatment.

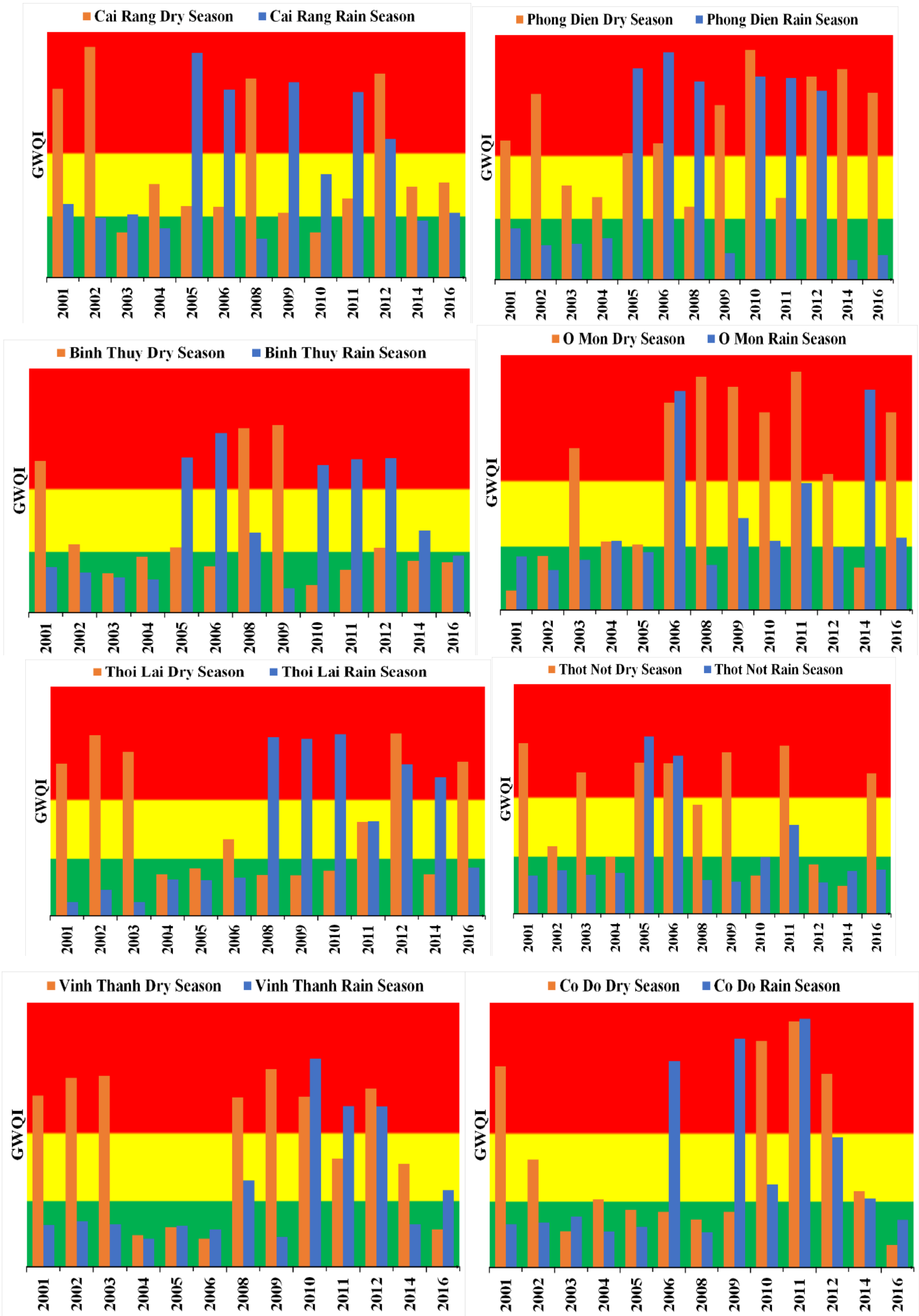

Figure 6. GWQI in the dry and wet seasons over eight districts of Can Tho city.

3.3. Groundwater recharge

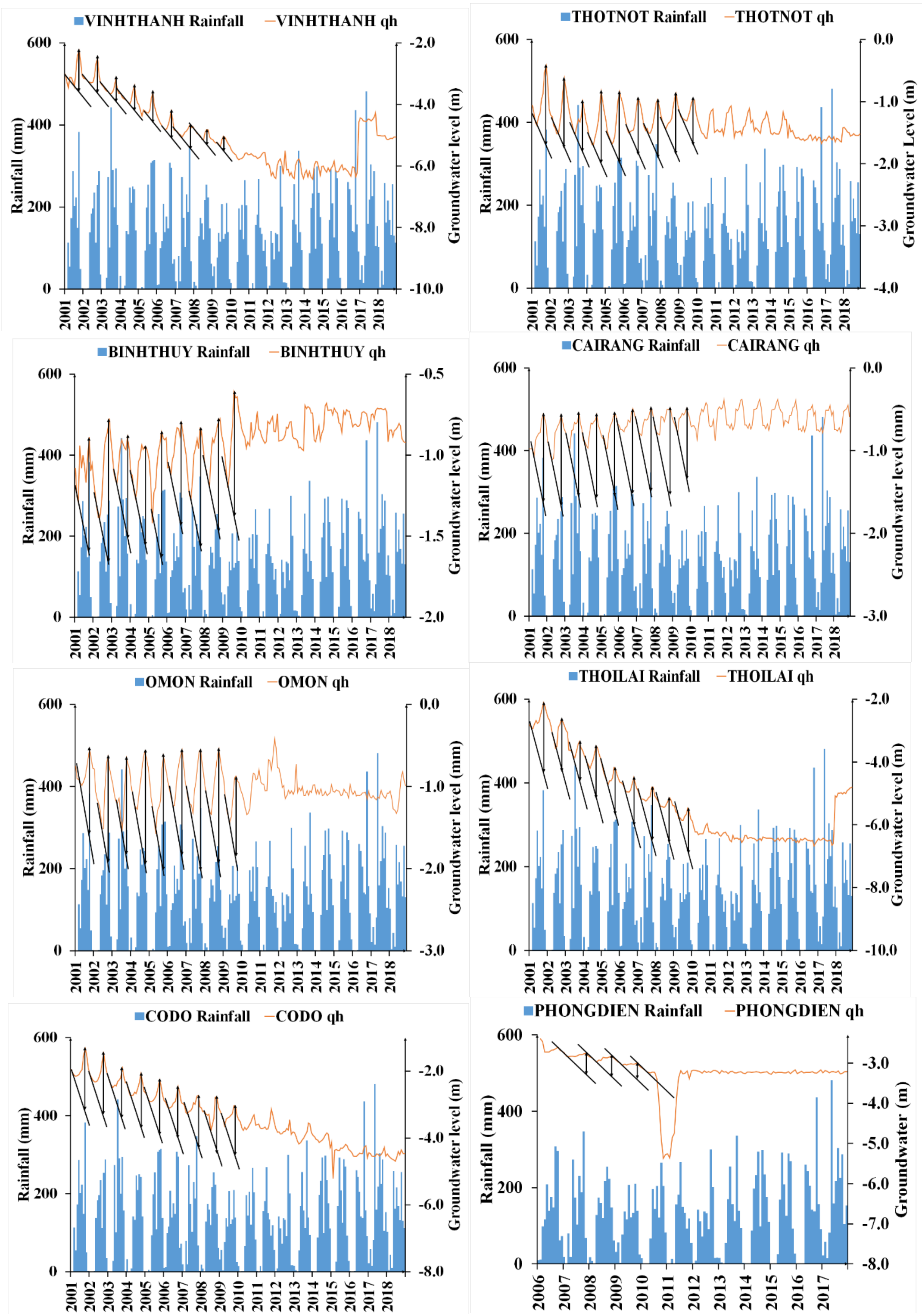

Figure 7. Groundwater recharge in 8 districts of Can Tho city.

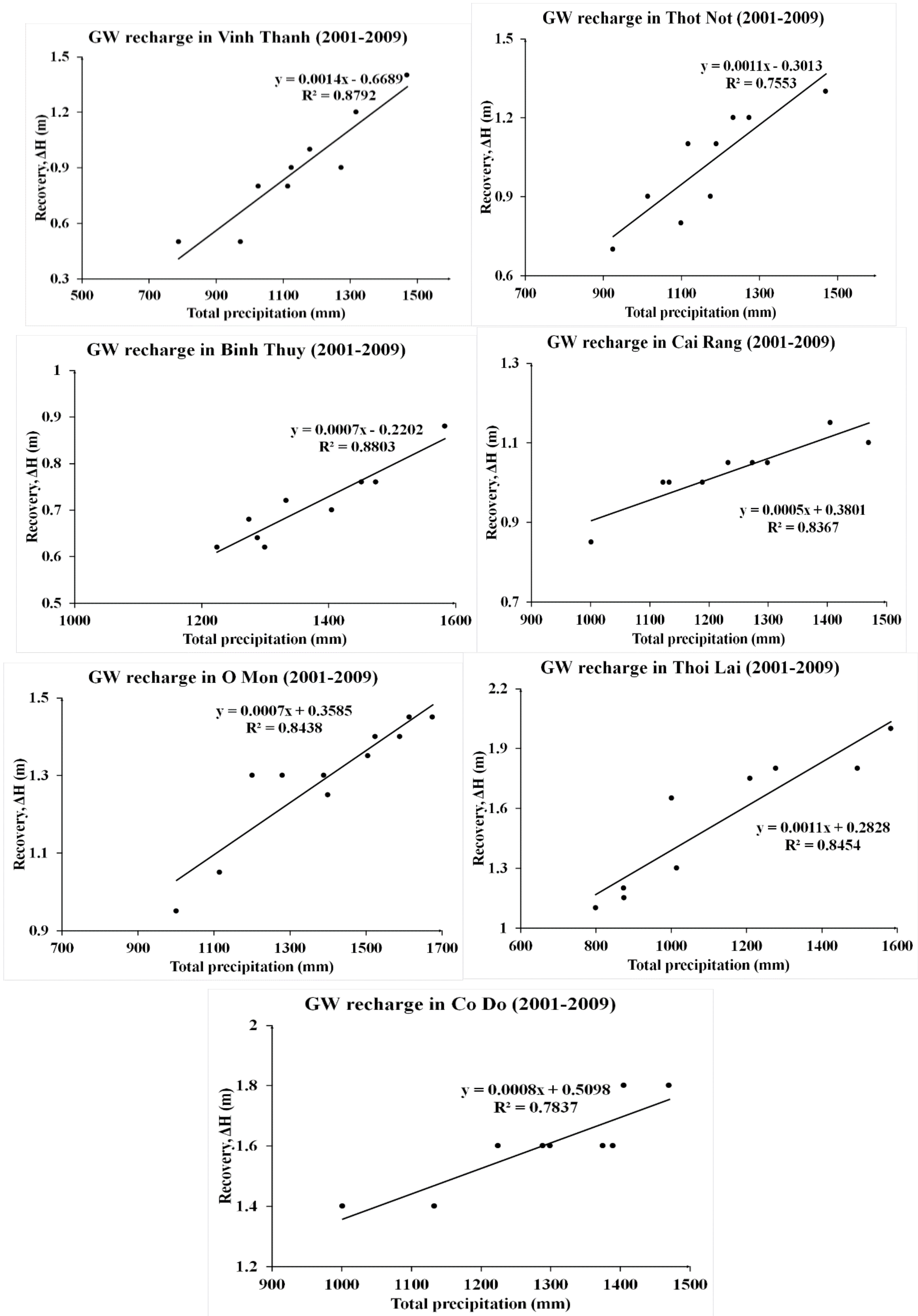

Figure 8. Correlative equation of GW recharge and rainfall in selected districts of Can Tho city.

Figure 7 presents the hydrograph of groundwater recharge from annual rainfall to the Holocene aquifer in Vinh Thanh, Thot Not, Binh Thuy, Cai Rang, O Mon, Thoi Lai, Co Do, and Phong Dien districts for the period 2001-2018. Overall, there is a certain recharge from rainfall to qh aquifer in Can Tho city. However, it is clearly seen that the GWL graph has different trends over the two periods of 2001 - 2009 and 2010 - 2018. The results show that the groundwater recharge in Can Tho city was relatively stable in the period 2001 - 2009, but became unpredictable in the years 2010 - 2018. This suggests an imbalance between the rate of exploitation and recharge. Therefore, the groundwater recharge from rainfall over the entire Can Tho administrative area is only calculated from 2001 to 2009.

Moreover, the observed data in Phong Dien district is not enough to calculate groundwater recharge, hence Figure 8 only shows the correlative equation of groundwater recharge and rainfall in Vinh Thanh, Thot Not, Binh Thuy, Cai Rang, O Mon, Thoi Lai, and Co Do districts. Additionally, the average riverbed level of the Hau River is about -25 to -33 m MSL, while all of the well depths in the Pleistocene aquifer are from 50 to 150 m. Therefore, the possibility of groundwater recharge from rivers to the Pleistocene aquifer is very low [21]. Groundwater in this aquifer might be, however, recharged by vertical penetration from the Holocene aquifer. That is the reason why this study only considers the groundwater recharge from rainfall to the Holocene aquifer.

Table 5. Summary of groundwater recharge of Can Tho city in 2001 - 2009.

Clusters	**Groundwater recharge (mm)**								
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Vinh Thanh	777.8	634.9	349.2	420.6	492.1	420.6	349.2	134.9	134.9
Thot Not	655.7	473.9	201.2	564.8	564.8	473.9	292.1	292.1	110.3
Binh Thuy	254.6	511.7	140.3	140.3	340.3	168.9	283.1	226.0	340.3
Cai Rang	839.8	939.8	739.8	739.8	739.8	639.8	639.8	639.8	339.8
O Mon	187.9	616.4	473.6	687.9	687.9	545.0	759.3	759.3	45.0
Thoi Lai	921.1	739.3	102.9	739.3	193.8	693.8	284.7	148.4	602.9
Co Do	2087.3	2087.3	1837.3	1837.3	1837.3	1837.3	1587.3	1837.3	1587.3

In addition, Table 5 shows the calculated quantity of groundwater recharge from rainfall in the districts of Can Tho city for the years 2001 - 2009. Generally, the amount of groundwater recharge over the whole city decreased gradually from 2001 to 2009, while the recharge levels showed a large spatial variation due to different land uses and functions between districts. Based on the recent research results of [35] documenting urbanization processes in Can Tho, the NDVI value in Can Tho city tended to decrease gradually over the period 1990 - 2020, this is especially true in the core central city area and the surrounding suburban areas. For example, in Ninh Kieu district, NDVI values from negative 1 to 0 (water system objects) had the highest spatial coverage (23.4 %) in 2005, yet reduced to relatively stable values of about 11.0 % thereafter. At the same time, the NDVI from 0 to 0.2 (impermeable surfaces) tended to increase gradually over the periods of 1990, 2005, 2015 and 2020, measured at 16.27 %, 20.05 %, 53.04 % and 58.29 % spatial coverage, respectively.

4. CONCLUSIONS

The increased demand of GWR for both domestic and industrial purposes has resulted in the widespread overexploitation of resources in Can Tho. This study shows that GWLs in the study area reduced rapidly from 2000 to 2011 in the Middle-upper Pleistocene ($qp_{2\text{-}3}$) and Upper Pleistocene (qp_3) layers due to the over-withdrawal of GWR. This is markedly seen in almost all the designated industrial areas. The reduction rate of GWLs slowed from 2012-2018 as Decree No. 2946/UBND-KT of the People's Committee of Can Tho City was issued and enacted in the year 2012. It is found that groundwater quality in Can Tho city is affected mainly by coliform in both dry and wet seasons. However, the quality of groundwater also improved as a result of dilution with rainfall. Moreover, it is noted that groundwater recharge has been decreasing gradually, which may lead to groundwater scarcity in the near future. In addition to the groundwater recharge from rainfall, other factors such as the effects of urbanization and industrialization, the water level of the Hau River on groundwater recharge should be investigated and evaluated in future studies. The obtained results are useful as a preliminary reference in planning, managing and protecting the groundwater resources of Can Tho city.

Acknowledgements. This study is partially funded by the Can Tho University Improvement Project VN14-P6, supported by a Japanese ODA.

CRediT authorship contribution statement. Tran Van Ty: Methodology, Investigation, Data analysis. Trinh Trung Tri Dang: Data analysis, Manuscript preparation. Nguyen Dinh Giang Nam: Investigation, Data analysis. Huynh Vuong Thu Minh: Methodology, Investigation, Data analysis, Manuscript editing. All authors have read and agreed to the published version of the manuscript.

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

REFERENCES

1. Minh H. V., Avtar R., Kumar P., Tran D. Q., Ty T. V., Behera H. C., and Kurasaki M. - Groundwater quality assessment using fuzzy-AHP in An Giang province of Viet Nam - Geosciences **9** (8) (2019a). doi:10.3390/geosciences9080330
2. Vörösmarty C. J., Sahagian D. - Anthropogenic Disturbance of the Terrestrial Water Cycle - BioScience **50** (9) (2000) 753-765, https://doi.org/10.1641/00063568 (2000)050 [0753:ADOTTW]2.0.CO;2
3. Vörösmarty C. J., Peter B. M., Mark O. G., Dudgeon D., Alexander P., Pamela G., Stanley G. - Global threats to human water security and river biodiversity - Nature **467** (7315) (2010) 555-561.
4. Woodhouse P. and Muller M. - Water governance-An historical perspective on current debates - World development **92** (2017) 225-241.

5. Todd M. C., Taylor R. G., Osborn T. J., Kingston D. G., Arnell N. W., and Gosling S. N. - Uncertainty in climate change impacts on basin - scale freshwater resources – preface to the special issue: the QUEST-GSI methodology and synthesis of results - Hydrol. Earth Syst. Sci. **15** (3) (2011) 1035-1046. doi:10.5194/hess-15-1035-2011
6. Anh D. T., Hoang L. P., Bui M. D., and Rutschmann P. - Simulating future flows and salinity intrusion using combined one- and two-dimensional hydrodynamic modelling - The case of Hau river, Vietnamese Mekong delta - Water **10** (7) (2018) https://doi:10.3390/w10070897
7. Keskinen M., Chinvanno S., Kummu M., Nuorteva P., Snidvongs A., Varis O., and Västilä K. - Climate change and water resources in the Lower Mekong River Basin: putting adaptation into the context, Journal of Water and Climate Change **1** (2) (2010) 103-117. https://doi.org/10.2166/wcc.2010.009. doi:10.2166/wcc.2010.009
8. Piman T., Lennaerts T., and Southalack P. - Assessment of hydrological changes in the lower Mekong Basin from Basin-Wide development scenarios - Hydrological Processes **27** (15) (2013) 2115-2125. https://doi.org/10.1002/hyp.9764
9. Varis O., Kummu M., and Salmivaara A. - Ten major rivers in monsoon Asia-Pacific: An assessment of vulnerability - Applied Geography **2012** (2) (2012) 441-454. https://doi.org/10.1016/j.apgeog.2011.05.003
10. Västilä K., Kummu M., Sangmanee C., and Chinvanno S. - Modelling climate change impacts on the flood pulse in the Lower Mekong floodplains - Journal of Water and Climate Change **1** (1) (2010) 67-86. https://doi.org/10.2166/wcc.2010.008.
11. Kalhor K., Ghasemizadeh R., Rajic L., and Alshawabkeh A. - Assessment of groundwater quality and remediation in karst aquifers: A review - Groundwater for Sustainable Development **8** (2019) 104-121. https://doi.org/10.1016/j.gsd.2018.10.004
12. Minh H. V., Kurasaki M., Ty T. V., Tran D. Q., Le K. N., Avtar R., Osaki M. - Effects of multi-dike protection systems on surface water quality in the Vietnamese Mekong delta - Water **11** (5) (2019). doi:10.3390/w11051010
13. Siebert S., Burke J., Faures J. M., Frenken K., Hoogeveen J., Döll P., and Portmann F. T. - Groundwater use for irrigation – a global inventory – Hydrol, Earth Syst. Sci. **14** (10) (2010) 1863-1880. https://doi:10.5194/hess-14-1863-2010
14. Renaud F. G. and Kuenzer C. - The Mekong delta system: Interdisciplinary analyses of a river delta (F. G. Renaud & C. Kuenzer Eds.), Springer, 2012, Dordrecht.
15. Danh V. T. and Khai H. V. - Household demand and supply for clean groundwater in the Mekong Delta, Viet Nam - Renewables: Wind, Water, and Solar, **2** (1) (2015) 4. https://doi.org/10.1186/s40807-014-0004-7. doi:10.1186/s40807-014-0004-7
16. Erban L. E., Gorelick S. M., and Zebker H. A. - Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Viet Nam. Environmental Research Letters **9** (8) (2014) 084010. http://doi:10.1088/1748-9326/9/8/084010
17. Minderhoud P. S. J., Erkens G., Pham V. H., Bui V. T., Erban L., Kooi H., and Stouthamer E. - Impacts of 25 years of groundwater extraction on subsidence in the Mekong delta, Viet Nam - Environmental Research Letters, **12** (6) (2017), 064006. http://doi:10.1088/1748-9326/aa7146

18. Howard G., Bartram J., Pedley S., Schmoll O., Chorus I., and Berger P. - Groundwater and public health, Protecting groundwater for health: managing the quality of drinking-water sources - London, International Water Association Publishing, 2006, pp. 3-19.
19. Minh H. V. T., Trung N. H., Ngan H. Y. N., and Tuan D. D. - Analysis of factors affecting declined groundwater level in the Soc Trang city - Can Tho University Scientific Journal, 2015, pp. 129-138.
20. Ty T. V., Minh H. V. T., Avtar R., Pankaj K., Hiep H. V., Masaaki K. - Spatiotemporal variations in groundwater levels and the impact on land subsidence in CanTho, Viet Nam, Groundwater for Sustainable Development **15** (2021) 100680.
21. Vang N. T. and Ty T. V. - Groundwater Exploitation, Head Change and Management at Tra Noc Industrial Zone, Can Tho City: Current State and Challenges, Can Tho University Journal of Sciences **52a** (2017) 80-90
22. Ty T. V., Phat L., and Hiep H. V. - Groundwater Level Prediction Using Artificial Neural Networks: A Case Study in Tra Noc Industrial Zone, Can Tho City, Viet Nam, Journal of Water Resource and Protection **10** (2018) 870-883. http://doi:10.4236/jwarp.2018.109050.
23. Minh H. V. T., Ngoc D. T. H., Ngan H. Y., Men H. V., Van T. N., and Ty T. V. - Assessment of groundwater level and quality: A case study in O Mon and Binh Thuy districts, Can Tho city, Viet Nam, Naresuan University Engineering Journal **11** (1) (2016) 25-33.
24. Day P. M., Nam N. D. G., Tri V. P. D., Trung N. H., and Thanh D. Q. - Impact of rainfall changes on the shallow groundwater recharge-A case study in Hau Giang province, Can Tho University Journal of Science **54** (6) (2018) 1-11. https://doi:10.22144/ctu.jvn.2018.089
25. Hiep H. V., Hung N. T., and Long P. V. - Evaluating the saltwater intrusion to aquifer upper-middle pleistocene (qp2–3) in coastal area of Tra Vinh province due to groundwater exploitation, Paper presented at the Proceedings of the International Conference on Advances in Computational Mechanics, Singapore, 2018.
26. Nguyen Binh N. T., Tham N. T. M., and Quang V. B. - Assessment of groundwater quality based on principal component analysis and pollution source-based examination: A case study in Ho Chi Minh City, Viet Nam, Environmental Monitoring and Assessment **192** (2020) 1-13.
27. Nguyen A., Hoang T., Pham N., Tat V., Phan N., and Nguyen Q. - Application of groundwater quality index (GWQI) and principal component analysis (PCA) to assess the groundwater quality of Pleistocene aquifer in Tan Thanh district, Ba Ria – Vung Tau province, Science & Technology Development Journal Science of The Earth & Environment **2** (2) (2019) 107-115.
28. Korkmaz N. - The estimation of groundwater recharge from water level and precipitation data - Medical Journal of Islamic World Academy of Sciences **1** (2) (1988) 87-93. https://dx.doi.org/.
29. Nam D. G. N., Goto A., Vermeulen P., Trung H. N., and Truc T. T. N. - Modeling for analyzing impacts of rapidly growing groundwater exploitation in Cantho city, Viet Nam, Paper presented at the First Sustainability Environmental Leader Summit, Hokkaido University, 2013.

30. People's Committee of Can Tho City - Official Letter No. 2946/UBND-KT of the People's Committee of Can Tho City, 2010 (in Vietnamese)
31. Edzwald J. - Water quality & treatment: a handbook on drinking water - McGraw-Hill Education, 2011.
32. Sharma S. and Bhattacharya A. - Drinking water contamination and treatment techniques, Applied Water Science **7** (3) (2017) 1043-1067. https://doi.org/10.1007/s1320101604557.
33. Spellman F. R. - The drinking water handbook - CRC Press, 2017.
34. Summers J. K. - Water Quality: Science, Assessments and Policy, BoD–Books on Demand, 2020.
35. Thinh L. H., Minh H. V. T., Nam N. D, G., Thanh V. Q., and Ty T. V. - Landsat image application to evaluate the change of surface temperature distribution in Can Tho City in the period 1990 – 2020, Proceedings of the Fifth Scientific Conference Management of Environmental Resources for Sustainable Development in Industry 4.0, 2021, pp. 75-86. (in Vietnamese).