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Assessment of groundwater's pressure by the water poverty index for Tien Giang province

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Abstract: *Tien Giang is a coastal province of the Mekong Delta with a high socio-economic development rate in the region. This means an increase in the demand for natural resources, including groundwater resources, from many economic sectors such as a living, industry, and cultivation. According to the groundwater monitoring results report from 2015 to 2021 of the Center for Natural Resources and Environment Monitoring of Tien Giang Province, the groundwater level in the main aquifers is decreasing at an average rate from 0.54 to 0.84 m/ year in the province. The quality of groundwater shows signs of salinity. In order to assess the current exploitation status, as well as the risk of decline in both quantity and quality of groundwater resources in Tien Giang Province, the study applies the water poverty index (WPI). This index synthesizes economic, social and environmental factors. Through WPI calculations, local groundwater resources are under moderate to severe pressure, especially in densely populated areas (Cities and towns in the province) and large industrial zones. The level of pressure increases in coastal districts, which are almost entirely dependent on groundwater with lower WPI values. The main reasons are the rapid increase in resource demand, easy access to exploitation sources and poor management.*
Keywords: *Groundwater; water poverty index (WPI); environment; water utilization; salinity*

1. Introduction

Groundwater is the most important source of supply for daily life and production, especially in locations with the surface water sources limited or polluted (WMO, 2022). Basically, Groundwater is a renewable resource through the infiltration of rainwater and snowmelt into rock layers (WMO, 2022). If the rate of groundwater utilization is lower than the regeneration rate, the groundwater utilization is sustainable. According to the United Nations (2022), groundwater will gradually become a leading factor in maintaining essential supplies for all living things on Earth. Groundwater plays a role in maintaining ecosystems, river flows, preventing land subsidence and salinity intrusion. It is an important part of measures to adapt to climate change and an important solution for places lacking safe water. The role of groundwater in agriculture and livestock is very large, especially in areas where surface water sources are affected by adverse conditions such as salinity intrusion, pollution or degradation, etc (WB, 2019). Groundwater will be an alternative (salvation) source of water for animals and crops.

According to the WMO report (2022), the total amount of freshwater on Earth is estimated to be from 11.1 million to 15.9 million km^3, of which the amount of freshwater in the layers located about 2 km deep in the Earth's crust accounts for 99% of the global reserves. However, the huge role of this groundwater resource is often not well understood or underestimated. According to UNESCO, groundwater utilization currently accounts for about 50% of the world's domestic water and 25% of the water used for irrigation. However, the management of this resource is often lax, coupled with limited technical expertise in some areas of the world, especially in sub-Saharan Africa (WMO, 2022).

The total volume of groundwater exploitation (freshwater) in Vietnam is currently about 10.5 million m^3/day and night, using about 17.2% of the exploitable fresh water reserves, concentrated in large urban areas (Hanoi City, about 1.78 million m^3/date, Ho Chi Minh City about 519 million m^3/day...) and the Mekong Delta provinces about 1.45 million m^3/day (MONRE, 2022).

The exploitation of groundwater is often concentrated in large quantities in urban areas such as Hanoi City, Ho Chi Minh City, urban areas in the Mekong Delta (Ca Mau City, Soc Trang City, Bac Lieu City...), and coastal provinces (Tien Giang Province, Ca Mau Province...) has caused a rapid and continuous decline in groundwater levels in aquifers. In addition to the exploitation of groundwater for domestic use, groundwater is also supplied to water-intensive economic sectors such as agriculture, industry and livestock. This will lead to the degradation of additional water resources with the water level continuing to decrease. The biggest problem with groundwater quality in the Mekong Delta is salinity and saltwater intrusion. The salinity concentration value is generally relatively high for water in shallow soil layers, with values fluctuating greatly in the range of 0.26 - 2.9 g/l, the value is mainly concentrated in the range of 0.4 - 1.4 g/l (DONRE of Tien Giang Province, 2022). Groundwater in all aquifers is widely saline and interwoven throughout the region. The salinity of groundwater tends to increase over time in some areas, showing that the encroachment of underground saltwater is still increasing. For groundwater flow at deep layers (n_1^{2-3}) - Porous aquifer of middle Pliocene sediments, in general, groundwater quality remains stable at a level that meets good water needs for daily life (DONRE of Tien Giang Province, 2022).

In addition, another reason leading to the decline in both quantity and quality of groundwater resources is low efficiency of utilization, waste,... For example, the agricultural sector is the largest water user and the water use efficiency of this sector will determine the water supply for other uses in the economy. However, the current water use efficiency in the agricultural sector, according to international organizations, is still low. Specifically, according to the WB's assessment in 2019 (WB. 2019), water used in agriculture accounts for 81% of Vietnam's total water volume but currently only generates 17-18% of GDP and creates jobs for 45% of the workforce. In 2021, Vietnam used about 3.83 billion m^3 each year (accounting for 4.7% of the total amount of water exploited and used), the efficiency of water use is still low, only generating 2.37 USD GDP/m^3 of water, lower than the Philippines 2.58 USD/m^3 of water (WMO, 2022).

Thus, with the increasing pressure on both quantity and quality of groundwater demand for urban development and production, groundwater resources are facing the risk of degradation. In water resources management, groundwater resources need to be studied to assess the level of water quality as well as the pressure in exploitation and use to provide complete and timely information for management levels to make decisions on protection or investment in exploitation. (Feitelson and Chenoweth, 2002).

In the research as well as in water resources management, to determine the level of pressure on resources such as water resources, the poverty index is always used as an assessment tool, determining many indicators related to the sustainability of resources and their impacts on people (Sullivan, 2002). For water resources, Sullivan (2002) developed the WPI to reflect five components: Resources (R), Access (A), Capacity (C), Use (U) and Environment (E). The components represent broad issues but do not follow direct measurement. Instead, each component was made up of a number of sub-components or in different ways. The water poverty index is intended to create a comprehensive policy tool, based on both physical and social science aspects (Sullivan. 2002). In addition, WPI also shows disadvantages in some issues such as water distribution and water supply. The main limitations of WPI (Gleick, 2002) are that the index does not consider fluctuations in water supply and does not address issues related to water allocation among users. Feitelson and Chenoweth (2002) argued that WPI does not reflect social resources to cope with water scarcity and the use of weights may not be objective. Lawrence et al., 2002 pointed out that WPI combines information (and often correlates) with arbitrary weights, leading to non-objective results. Therefore, to minimize the above disadvantages, the water poverty index (WPI) will be applied together with assessment models such as DPSIR (Drivers - Pressures - Status - Impacts - Responses). DPSIR will dissect the areas (Drivers) that put pressure on groundwater resources and identify the types of responses currently being applied to minimize environmental impacts in the study area (Ha, 2016).

In our study, the WPI index is used to assess groundwater resource pressure based on the types of community activities identified through the DPSIR model in Tien Giang Province, Vietnam in the period of 2019-2022.

2. Methodology

2.1. Research area

Within the framework of the study, the area conducts an assessment of groundwater resource pressure in districts, towns and cities of Tien Giang Province, Vietnam with data collected on socio-economic development of the province in the period 2019-2022. The research area is shown in Figure 1 below.

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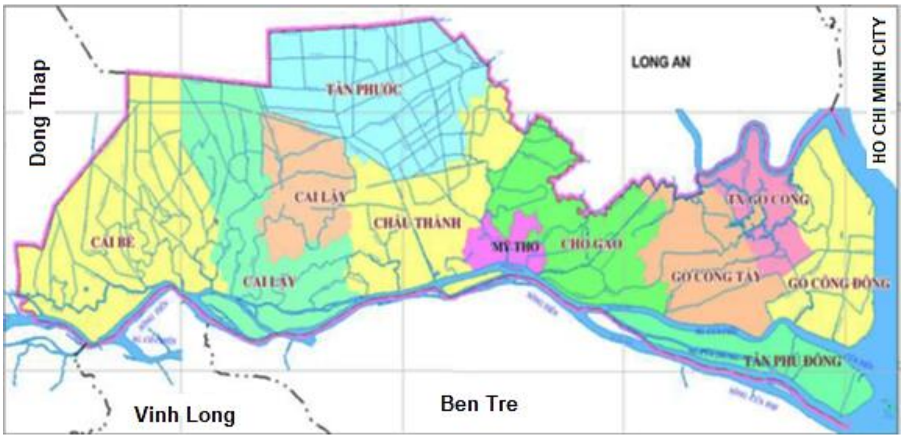

Fig. 1. Administrative map of Tien Giang Province

2.2. Data collected for the study period 2019-2022

Based on the parameter components in the WPI index formula, the data will come from the following sources (see table below)

Tab. 1. Data sources collected for the study

No	Parameter types	Source of documents
1	Average annual water consumption per capita (m^3/year)	National Environmental Report 2012, 2021. Department of Natural Resources and Environment of Tien Giang Province (2022); Falkenmark, 1989
2	Coefficient of variation of rainfall (mm/year)	Department of Irrigation and Flood and Storm Prevention (2022) Babel, M.S. and Wahid, S.M., 2009
3	Water demand vs. water availability (m^3/day)	Tien Giang Province's Clean Water and Environmental Sanitation Center; Water supply and demand ratio.
4	Percentage of households using clean water (%)	Socio-economic report of districts in Tien Giang province in 2016 2019, 2020, 2022
5	Percentage of households with clean toilets (%)	Socio-economic report of districts in Tien Giang province in 2016 2019, 2020, 2022
6	Poverty household rate (%)	Socio-economic report of districts in Tien Giang province in 2016 2019, 2020, 2022
7	Primary school completion rate (%)	Socio-economic report of districts in Tien Giang province in 2016 2019, 2020, 2022
8	Percentage of households using electricity (%)	Socio-economic report of districts in Tien Giang province in 2016 2019, 2020, 2022
	Percentage of children under one year old vaccinated (%)	Statistical Yearbook 2019, 2020 and 2022
9	Amount of water used for daily life (m^3/date)	TCXDVN 33:2006 of Ministry of Construction
10	Amount of water used for industry (m^3/day)	Project Report on Investigation and Evaluation of Restricted Groundwater Exploitation Zoning in Tien Giang Province.
11	Amount of water used vs. amount of water available (%)	OECD (2008)
12	Percentage of natural vegetation (%)	Land use planning report of districts in year 2019, 2020 and 2022

2.3. DPSIR groundwater resource pressure analysis model

To identify the productions those impact or have a large demand for regional groundwater resources as well as the regional groundwater problems, the study applies the DPSIR assessment model "Driving force – Pressure – Status – Impact – Response".

The DPSIR was developed by the European Environment Agency (EEA) in 1999. It is a cognitive model used to identify, analyze and evaluate the cause-effect relationships as the causes of environmental problems, their consequences and necessary response measures. The DPSIR is widely applied in supporting

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manager's decision-making related to the sustainable development of water resources (Sun et al., 2016) and analyzing the interaction processes between humans and the environment. In addition, the DPSIR helps managers and policy makers grasp the actual situation and manage resources more effectively and sustainably (Timmerman et al., 2011).

The purpose of the DPSIR in the study is to identify the driving factors that create pressures and impacts on regional groundwater resources. At the same time, the framework also indicates the current responses of local communities to the current environmental situation (increased demand leads to the decline of groundwater resources).

3.4. Assessing groundwater resource pressure using the Water Poverty Index (WPI)

The Water Poverty Index (WPI) has five main components (resources - R, access - A, capacity - C, use - U and environment - E) (Lawrence et al., 2002 and Sullivan, 2003). The scores for each subcomponent, major component and WPI range from 0 to 100. The level of water poverty or water resource stress is classified into five levels of water resource stress as follows (Lawrence et al., 2002):

- Severe pressure level (WPI < 48),
- High pressure level (WPI =48 – 56),
- Medium pressure level (WPI = 56 – 62),
- Low-medium pressure level (WPI = 62 – 68) and
- Low pressure level (WPI > 68)

The formula for calculating the WPI water poverty index is as follows (Sullivan, 2003):

$$WPI = (R.\ wr + A.\ wa + C.\ wc + U.\ wu + E.\ we) \quad (1)$$

There are:

wr, wa, wc, wu and we are the weights of the main components of the water poverty index.

The main components are calculated as follows:

- Resources component (*Resources - R*): *R* is calculated through three indicators: readiness (R_1), variation (R_2) and response level (R_3).

$$R = (w_1 x R_1 + w_2 x R_2 + w_3 x R_3)\ (\%) \quad (2)$$

There are:

R_1 – Readiness index is calculated with $R_1 = (Wr-500)/(1700-500) \times 100\ (\%)$ (3)

Wr – Average groundwater volume per capita per year (m^3/person/year)

1700 and 500 – are the water scarcity threshold (Falkenmark et al., 1989).

R_2 – The calculated variation index $R_2 = (1-CV/0.3) \times 100\ (\%)$ (4)

CV is the coefficient of variation between rainfall and evaporation (Lawrence et al., 2002).

R_3 – response index calculated $R_3 = (1-W_D/W_A) \times 100\ (\%)$ (5)

W_D – is the total groundwater demand (domestic, industrial)

W_A – is the total amount of available and exploitable groundwater

- Access component (Access – A): A is calculated through two social indicators (A_1) (the ratio of households using clean water compared to the total population of the area), and environmental sanitation index (A_2) (the ratio of households with toilets that meet new rural standards or meet the standards of the Ministry of Health compared to the total population of the study area).

$$A = (A1 + A2)/2\ (\%) \quad (6)$$

There are:

$A_1 = Pn / P \times 100\ (\%)$ and $A_2 = Pvs / P\ (\%)$ (7)

Pn and *Pvs* are households using hygienic water and hygienic toilets respectively; *P* is the total population of the study area

- Capacity component (Capacity – C): *C* is calculated through two financial factors (C_1), an education factor (C_2) and an infrastructure factor (C_3). In which, financial factor C_1 is calculated through the poverty rate and education factor C_2 is calculated according to the rate of students completing the universal education program (primary school). Infrastructure factor C_3 is calculated through the average of the rate of households using electricity for daily life (C_{3a}) and the rate of households with access to medical facilities - the number of children in the study area who are fully vaccinated according to regulations of the Ministry of Health (C_{3b}).

$$C = (C_1+C_2 + (C_{3a}+C_{3b})/2)/3 \quad (8)$$

There are:

$$C_1 = (1 – Pngh/P) \times 100 (\%); \quad C_2 = Pgd/P \times 100 (\%); \quad (9)$$

$$C_{3a} = Ps/P \times 100 (\%); \quad C_{3b}=Tvx/T \times 100 (\%) \quad (10)$$

Pngh and *Pgd* are the rate of poor households and students completing primary school respectively.

Ps is a household with electricity; *Tvx* is the number of infants fully vaccinated; *T* is the total number of newborns born in a year (Tien Giang Province Statistical Yearbook, 2019, 2020, 2021 and 2022).

- Use component (Use – U): U is calculated through two indicators of water use efficiency in domestic use (U_1) and in production (U_2). The maximum water demand limit is 20 liters/person/day (UNICEF, 2000) and the normal is 100 liters/person/day (Howard and Bartram. 2003) are used for calculating U_1.

$$U = (U_1 + U_2)/2 (\%) \quad (11)$$

There are:

$$U_1 = 1- (1-SH)/(100-20) \times 100 (\%) \text{ và}$$

$$U_2 = (GDPcn / GDP) / (Wcn/WD) \times 100 (\%) \quad (12)$$

SH is the amount of water used for domestic purposes (liters/person/day)

GDPcn/*GDP* is the economic structure of the industry; *Wcn* is the groundwater demand for industry in the study area.

- Environmental component (Environment – E): E is calculated through three indexes including stress index (E_1) (OECD. 2008), cover index (E_2) (WHO, 2003) and quality index (E_3).

$$E = (E_1 + E_2 + E_3)/3 (\%) \quad (13)$$

There are:

$$E_1 = (1-(WD/WA)/0.4) \times 100 (\%) \text{ and } E_2 = Atv / Atn \times 100 (\%) \quad (14)$$

E3 is calculated by a water quality index for groundwater (Trinh thi Tham, 2022).

Atv is the area of natural vegetation (km^2); *Atn* is the total basin area (km^2)

3. Results and discussions

3.1. Identifying areas that put pressure on groundwater resources in Tien Giang Province

In the study, the factors/indicators reflecting the components of the DPSIR are identified through an analysis of the economic development status, the environmental issues of Tien Giang Province in the period of 2019-2022 such as saline intrusion, groundwater level decline, water shortage for daily life, production, etc. All indicators and factors of each component of the DPSIR are summarized as shown in Figure 2 below.

As Figure 2 describes, the study focuses on assessing issues related to groundwater demand in the region with the following areas: (1) people's livelihoods; (2) agricultural and industrial production. However, according to the annual agricultural production report of the Department of Agriculture and Rural Development of Tien Giang, the agricultural area using groundwater for irrigation has decreased significantly when the districts of the province have adjusted the crop calendar to match the increased use of surface water and rainwater. Thus, in the study, only the production water demand for the industrial sector is calculated.

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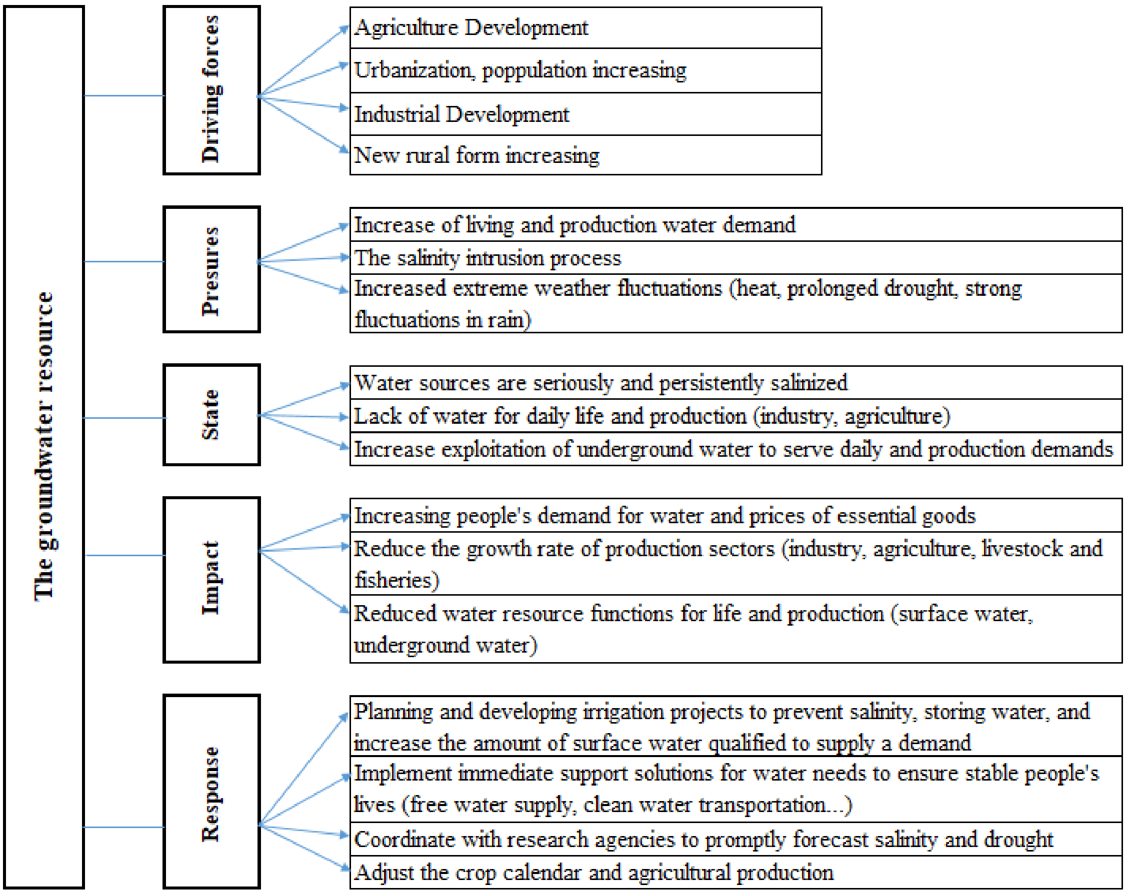

Fig. 2. Diagram of groundwater resource pressure assessment in Tien Giang Province

In addition, the problem of groundwater pollution due to economic activities and saline intrusion is also ignored because it does not fluctuate much between years and the water quality of the layers (n_2^1, n_2^2, n_2^3) is still quite good and meets the needs of daily life (Department of Natural Resources and Environment, 2020).

In summary, the indicators and factors used to calculate the main components (resources, accessibility, capacity, use and environment) of the water poverty index assess the level of groundwater resource pressure in Tien Giang Province. For example: (1) Total available and exploitable groundwater volume; (2) Total groundwater demand for industry in the study area; (3) Total groundwater demand (domestic, industrial); (4) Average groundwater volume per person in year (m^3/person/year); (5) Annual rainfall and evaporation data series; (6) Area of natural vegetation (km^2) identified as mangrove forests, flooded mangrove forests in each district, city, town, and township of Tien Giang Province; (7) Total area of districts, cities, towns and townships of Tien Giang Province (km^2);…

The above indicators and factors are determined and collected from documents collected in the research area summarized in Table 1 above.

3.2. Calculation of main components of the water poverty index

The results of calculating the main components and the groundwater poverty index (WPI) for districts, towns and cities in Tien Giang Province are based on socio-economic development documents of the Departments, offices and People's Committees in the period 2019-2022.

The results of calculating the groundwater resource index (R) of districts and cities in Tien Giang Province for the period 2019-2022 are summarized in Figure 3 below.

From the results of the resource composition of the water poverty index (Figure 3), (if classified according to the level of water poverty above), groundwater resources are being exploited very heavily (seriously) in most districts, towns and cities of Tien Giang Province. The level of fluctuation in groundwater exploitation is not much in the period 2019-2022. In particular, Go Cong Tay district has a large increase in groundwater exploitation because this district is located in an area bordering the sea but is still in an area with a system of irrigation works to prevent salinity. Therefore, the number of wells to exploit groundwater in this district increased after the system of works was completed.

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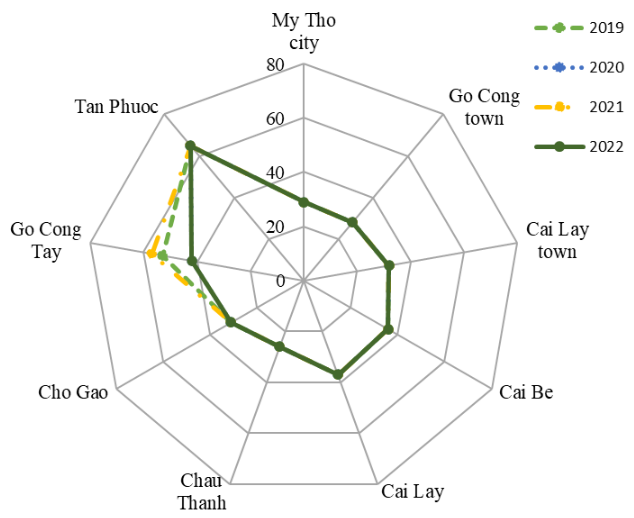

Fig. 3. Resource composition chart (R) of districts and cities in Tien Giang province

The results of calculating the accessibility of groundwater resources (A) of districts and cities in Tien Giang Province in the period of 2019-2022 are summarized in Figure 4 below.

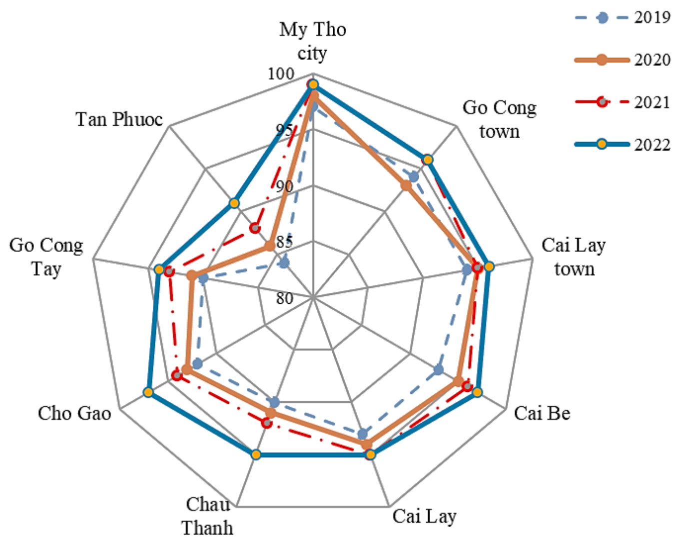

Fig. 4. Accessibility chart (A) of districts and cities in Tien Giang Province

The results of calculating the components of accessibility of groundwater resources in districts, towns and cities in Tien Giang Province show a very good level. This reflects the reality that groundwater exploitation for domestic and industrial purposes in Tien Giang Province is very popular and groundwater is a widely used water source. According to data from the Department of Natural Resources and Environment in 2022, there are up to 1,450 licensed wells in the Province with a flow rate of over 211,000 m^3/day and night.

The results of calculating the capacity component in the water poverty index (C) of districts and cities in Tien Giang Province in the period of 2019-2022 are summarized in Figure 5 below.

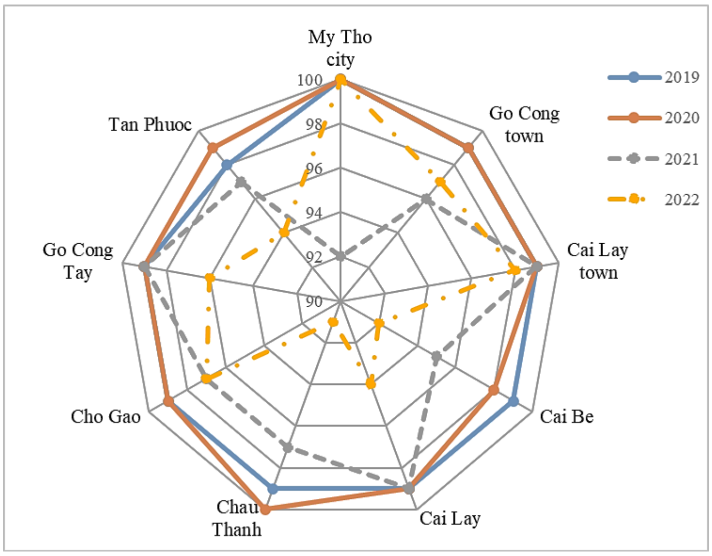

Fig. 5. Capacity component chart (C) of districts and cities in Tien Giang Province

The capacity component is calculated from the poverty rate, the number of vaccinated children, the number of students completing primary education... However, in the period of 2021-2022, the whole country experienced a major epidemic with isolation measures. This led to a sudden decrease in the rate of people accessing medical services and the number of fully vaccinated newborns, leading to a decrease in the capacity level of districts, towns, cities and cities in Tien Giang Province compared to the years 2019-2020.

The results of calculating the use component in the water poverty index (U) of districts and cities in Tien Giang Province in the period of 2019-2022 are summarized as Figure 6 below.

The use component of groundwater resources focuses on the efficiency of water use in daily life and industrial production. As Figure 6 shows, the administrative units of cities, towns, and townships of Tien Giang Province are where the province's large production facilities and industrial parks are concentrated, so the efficiency of groundwater use is higher than that of other districts.

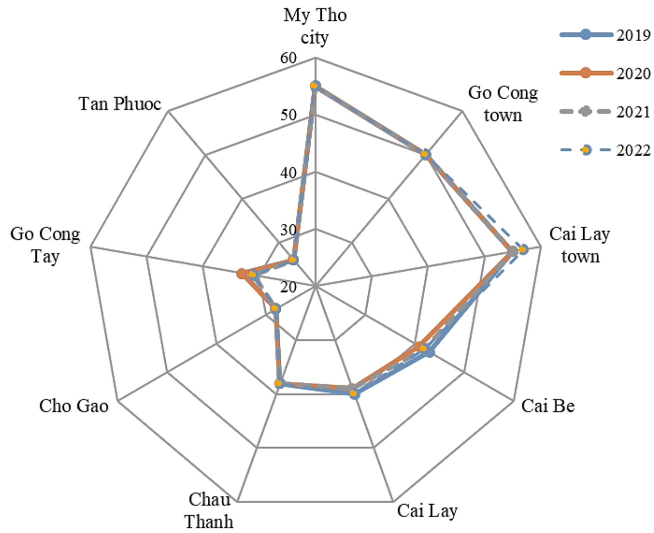

Fig. 6. Graph of groundwater use components (U) of districts and cities in Tien Giang Province

The environmental component in the water poverty index (E) of districts and cities in Tien Giang Province in the period of 2019-2022.

In general, the current quality of groundwater is assessed to be still guaranteed and can be supplied directly for domestic use (DONRE, 2022). Therefore, the value of E3 = 0 and the formula for calculating the water content is shortened as formula (15) below.

$$E = (E_1 + E_2)/2 \ (\%) \quad (15)$$

The results of calculating the environmental component in the water poverty index (E) of districts and cities in Tien Giang Province in the period of 2019-2022 are summarized as Figure 7 below. The

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environmental component in the groundwater poverty index mainly focuses on the level of stress in water use and vegetation cover. This shows that densely populated areas such as cities and towns have lower coverage levels than districts in Tien Giang province. With lower coverage, the corresponding groundwater recharge (water seeping into the ground) in urban areas will also be lower. In the period 2019-2022, the level of change in coverage area in the province did not change much.

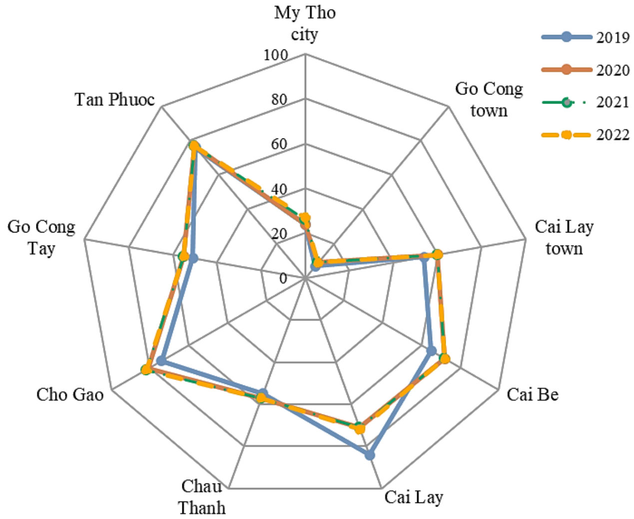

Fig. 7. Environmental component chart (E) of districts and cities in Tien Giang Province

From the analysis results for each main component of the WPI groundwater poverty index of districts and cities... in Tien Giang province, it shows that the level of fluctuation of the components (R, A, U, E) in the period 2019-2022 is quite small when the lines of the years in the chart are close or overlap (only in the case of capacity C, there is a strong fluctuation due to serious epidemics during this period). See Table 2 below.

Tab. 2. Results of main components of water poverty index each year

Location	R				A				C				U				E			
	2019	2020	2021	2022	2019	2020	2021	2022	2019	2020	2021	2022	2019	2020	2021	2022	2019	2020	2021	2022
My Tho	29	29	29	29	97	98	99	99	100	100	92	100	55	55	55	55	24	24	26	27
Go Cong Town	28	28	28	28	94	93	96	96	99	99	96	97	50	50	50	50	7	9	9	9
Cai Lay Town	32	32	32	32	94	95	95	96	99	99	99	98	55	55	55	57	54	60	60	60
Cai Be	36	36	36	36	93	95	96	97	99	98	95	92	43	41	42	42	65	72	72	72
Cai Lay	37	37	37	37	93	94	95	95	99	99	99	94	40	39	39	40	84	71	71	72
Chau Thanh	26	26	26	26	90	91	92	95	99	100	97	91	38	38	38	38	55	57	57	57
Cho Gao	31	31	31	31	92	93	94	97	99	99	97	97	28	28	28	28	74	81	82	82
Go Cong	53	42	57	42	90	91	93	94	99	99	99	96	33	33	31	31	51	55	55	55
Tan Phuoc	65	65	65	65	84	86	88	91	98	99	97	94	26	26	26	26	76	77	77	77

However, when comparing administrative units of Tien Giang Province with each other, the level of fluctuation of the main components (R, A, C, U, E) of the WPI groundwater poverty index is very large, especially with the resource component (R) and the usage component (U), which reflects the pressure in exploiting to meet the demand for groundwater use in densely populated areas with many industrial parks such as My Tho City, Go Cong Town. See Table 3 below. The Table 3 shows that values of (R) are lower than other components. There are some reasons as the rainfall amount decreased and the high demand for groundwater while exploitation capacity does not increase.

Table 3. Results of the main components of WPI in the period 2019-2022

No	Location	R	A	C	U	E	No	Location	R	A	C	U	E
1	My Tho City	29	98	98	55	25	6	Chau Thanh	26	92	97	38	57
2	Go Cong Town	28	95	98	50	9	7	Cho Gao	31	94	98	28	80
3	Cai Lay Town	32	95	99	56	59	8	Go Cong Tay	49	92	98	32	54
4	Cai Be	36	95	96	42	70	9	Tan Phuoc	65	87	97	26	77
5	Cai Lay Distr.	37	94	98	40	75	fluctuation		138	8	1	108	528

3.3. Calculating the WPI water poverty index for Tien Giang Province in the period of 2019-2022

The calculation of the WPI value determines the level of groundwater pressure in the administrative units of Tien Giang Province according to formula (1). The weighted values of each main component of the WPI water poverty index are determined through a survey of expert opinions, including management staff of the Department of Natural Resources and Environment of the province, the Department of Agriculture and Rural Development of the province, and leaders of the natural resources departments of districts, towns, and cities in Tien Giang Province.

The WPI water poverty index value and the level of groundwater pressure of the administrative units and Tien Giang Province are shown in Table 4 below.

Tab. 4. WPI value and groundwater pressure level in Tien Giang Province

No	Name	WPI				2019-2022	Pressure level
		2019	2020	2021	2022		
1	My Tho City	68.4	68.7	67.7	68.5	68.5	Low
2	Go Cong Town	54.8	55.4	54.9	55.0	55.0	High
3	Cai Lay Town	57.5	58.6	58.4	58.4	58.4	Median
4	Cai Be	56.0	57.3	57.3	57.1	57.2	Median
5	Cai Lay Distr.	53.5	51.9	51.7	50.8	51.8	High
6	Chau Thanh	45.0	45.8	45.1	44.5	45.0	Serious
7	Cho Gao	55.8	57.0	56.8	57.1	56.9	Median
8	Go Cong Tay	60.0	62.1	62.3	56.5	61.0	Median
9	Tan Phuoc	54.3	55.0	54.4	53.8	54.4	High
10	Tien Giang	55.8	57.0	56.8	56.5	56.9	Median

Thus, the level of pressure on groundwater resources in Tien Giang Province is average in the period of 2019-2022. The administrative units of the province with high population density and concentration of industrial parks and craft villages will have high pressure on groundwater resources such as Tan Phuoc district, Go Cong town, Cai Lay district. Chau Thanh district alone has a serious groundwater level. The main reason is that the groundwater level in Chau Thanh district is low (according to DonRe's survey in 2022), the economic development of Chau Thanh district is also at the lowest level of Tien Giang province, so the efficiency in using groundwater resources is the lowest. Distribution of pressure on groundwater resources in administrative units of Tien Giang Province in the period of 2019-2022, see Figure 8 below.

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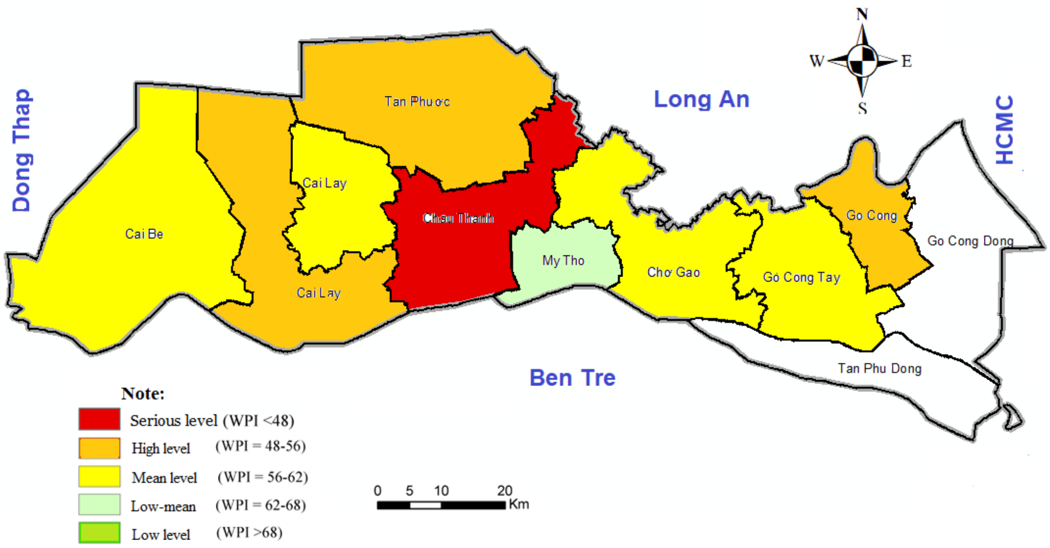

Fig. 8. Map of groundwater pressure distribution in Tien Giang Province in the period of 2019-2022

To recognize the importance or contribution of the main components of the water poverty index in determining the level of pressure on groundwater resources in Tien Giang Province, the study determined the correlation coefficient between the main components and the water poverty index in the period of 2019-2022. The calculation results are summarized in Table 5 below.

Tab. 5. Correlation coefficient between the main components and the value of the water poverty index

Components	R	A	C	U	E	WPI
R	1					
A	**-0.8**	1				
C	-0.1	0.2	1			
U	**-0.6**	**0.76**	0.22	1		
E	0.43	-0.5	-0.1	**-0.7**	1	
WPI	**0.66**	-0.3	0.01	-0.2	**0.7**	1

Based on the assessment of the correlation between the main components and the WPI water poverty index values of the administrative units of Tien Giang Province (See Table 5), it can be seen that the main components such as Resources (R), accessibility (A), use (U) and environment (E) have a fairly close correlation with each other in both positive and negative directions. For example, the Environmental component will decrease when the level of groundwater use for domestic use and industrial production increases. When the accessibility to groundwater is good (exploited a lot, easy, licensed a lot), the Resources will decrease. The correlation between the WPI water poverty index and the Resources and Environment components is positive. This corresponds to the lower the pressure on groundwater resources (the higher the WPI), the quality of Environment and Resources will be guaranteed. Components A and U have a high positive relationship (0.76). This may mean that areas with good access to groundwater (with many exploitation projects) will have a high level of groundwater use. Although the correlation between WPI and the components of accessibility or Use is weak (<0.5) and negative, it also shows that if the accessibility and use of groundwater increases, the level of pressure on groundwater resources also increases (WPI has a decreasing value). This will also be the basis for considering directions for regional water resource environmental management.

Based on the analysis of the correlation between the value of the WPI water poverty index and the main components (Table 5), the study would like to propose some directions for environmental management in general and groundwater resource management in particular in Tien Giang province as follows:

- For districts and towns with low to medium groundwater resource pressure, it is necessary to maintain control over the increase in exploitation and use of groundwater for production activities (Table 5 shows that the correlation between U with E and R is negative and quite tight). Increase the vegetation cover in the area by increasing area of fruit trees, parks, urban green areas... or expand the sweetening areas with irrigation systems, etc.

- For units with high groundwater resource pressure such as My Tho City, Go Cong Town, and Cho Gao, it is necessary to increase the WPI index (reduce groundwater resource pressure) by environmental solutions (increase coverage, control water quality) and increase additional water resources such as increasing surface water and atmospheric water. Chau Thanh District should strengthen the management of groundwater exploitation to ensure rational and effective use.
- In general, in the whole Tien Giang Province, although the pressure on groundwater resources is still at an average level, it is necessary to have solutions and environmental control programs, strictly manage the exploitation of groundwater without planning and build irrigation projects to increase alternative water sources suitable for daily life and production.

4. Conclusion

Tien Giang Province has a medium level of water poverty (WPI) with a WPI value of 58. However, there is a large difference in water pressure between districts and cities of the province. The main problem leading to such a large difference is that the management of groundwater exploitation and use by the province's administrative units is not really effective. The correlation between the main components of the water poverty index and the index value is different and fluctuates greatly (from weak to strong). The above correlation between the components and the WPI index clearly reflects the current status of exploitation, use as well as the type of socio-economic activities using groundwater resources. The environmental situation in the administrative units of the province is degraded (deforestation, urbanization, industrialization) which will lead to increased pressure on groundwater resources (reduced WPI value). Within the limited scope of our research, the calculation of WPI value is as follows: (1) Water use for agriculture (specifically crop and livestock farming) has not been considered in the study; (2) The study has not yet shown the change in WPI value over time of year; and (3) The study has not considered the issue of saline intrusion, drought and intervention through the operation of irrigation works in the area to increase the possibility of having many alternative water sources such as surface water and rainwater.

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