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Groundwater Exploitation Zoning Aiming at Management of Sustainable Groundwater Exploitation and Use in Ca Mau Peninsula, Vietnam

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Abstract
Groundwater system in Camau Peninsula has 6 main aquifers (not including very poorly productive qh aquifer), of which 4 aquifers are predominantly exploited, namely qp_{2-3}, qp_1, n_2^2 and n_2^1; 2 minor aquifers are qp_3 and n_1^3. Although the aquifers are located over the area, due to complicated fresh/saline interfaces in sections, exploitation and protection of groundwater sources is dealing with many problems. In the paper, information of aquifers is systematized into a map of groundwater exploitation zoning on scale 1:200,000 for the purpose of supplying essential information of water sources management in each socio-economical zone.
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1. Introduction

In traditional hydrogeological study, special information is synthesized and displayed with hydrogeological maps. Hydrogeological maps are composed in accordance with Vietnam technical regulations, so they are sophisticatedly and exploitation of information from them (reading and understanding) faces certain difficulties. Actually, managers and people with no sound special background have troubles in adequate perceiving of information displayed on hydrogeological maps. In previous projects of Department of Geology and Minerals of Vietnam, people have tried to simplify presentation of special information with maps of potential groundwater exploitation (*Chan, 2010; Linh, 1992; Tuan &Chan, 1992*). In these maps, contents of information have been simplified, but some other contents of sophisticated specialty were added. Therefore, their popularity is not so high.

In studying distribution of groundwater reserve of an area, people rely on maps that contain synthesized information of reserve. This paper assesses potential of groundwater use based on map of groundwater exploitation zoning. On this map, the area in question will be divided into regions having similarity of distribution laws of aquifers and its exploitation potential. Besides, for the purpose of management and reasonable use of water sources, ecological regions will be attached, aiming at supplying information for development planning of fields which have water demand.

Studies in this paper inherit ideas of map of groundwater exploitation potential and study of criteria of exploitation zoning in Hien (2009). Intermediate processing will be combined for presenting necessary information in simple way so people can approach easily.

2. Overall of groundwater system of camau peninsula

Results of the scientific research of state level KC08.08/16-20 (*Study of measures for mitigating and adapting to drought and salinity intrusion as natural hazards in Camau peninsula)* show that in Camau peninsula exist 7 granular aquifers, being: Holocene (qh), Upper Pleistocene (qp_3), Middle-Upper Pleistocene (qp_{2-3}), Lower Pleistocene (qp_1), Middle Pliocene (n_2^2), Lower Pliocene (n_2^1) and Upper Miocene (n_1^3). Distribution features of aquifers are presented in Tables 1 and 2.

Table 1. Areal distribution features of aquifers

#	Aquifers	Distribution area (km^2)	Distribution area of regions (km^2)							
			A	B1	B2	B3	C1	C2	D	E
1	qh	8,052	3,826	1,482	1,558	181	183	18	602	201
2	qp_3	14,545	4,332	1,482	1,923	968	2,177	1,025	1,086	1,553
3	qp_{2-3}	16,564	4,332	1,482	2,083	1,132	2,177	1,053	1,254	3,051
4	qp_1	16,600	4,332	1,482	2,082	1,132	2,177	1,052	1,359	3,052
5	n_2^2	16,092	4,332	1,482	2,082	1,132	1,639	1,015	1,358	3,051
6	n_2^1	15,580	4,332	1,482	2,082	1,132	1,448	688	1,365	3,051
7	n_1^3	14,111	4,149	1,482	2,082	1,132	572	286	1,357	3,051

Table 2. Depth distribution features of aquifers

#	Aquifers	Top depth (m)			Bottom depth (m)			Thickness (m)		
		From	To	Avg.	From	To	Avg.	From	To	Avg.
1	qh	0.0	61.0	19.6	8.0	75.0	30.8	0.6	65.0	11.3
2	qp_3	20.0	94.5	46.3	29.0	162.0	71.7	1.9	122.4	25.6
3	qp_{2-3}	44.0	162.0	85.1	62.2	207.0	127.2	2.0	109.5	42.1
4	qp_1	85.5	226.0	147.0	108.0	287.2	186.9	3.0	110.2	39.9
5	n_2^2	130.0	310.6	210.6	144.0	334.0	256.9	3.0	133.0	46.3
6	n_2^1	149.0	363.3	283.4	180.0	408.7	328.6	10.0	139.0	45.3
7	n_1^3	285.4	508.0	378.0	313.5	602.0	442.3	6.5	129.0	64.2

Potential exploitable groundwater reserves were evaluated for 6 perspective aquifers, being: qp_3, qp_{2-3}, qp_1, n_2^2, n_2^1 and n_1^3. Aquifer qh has narrow distribution area, small thickness and poor productivity, so it was neglected. Potential exploitable fresh groundwater reserve for entire Camau peninsula was calculated after balance method as 11,340,102 m^3/day, rounded as: 11,340,100m^3/day. In details: Static gravitational reserve: 8,972,925m^3/day, rounded as 8,972,900m^3/day; static elastic reserve: 870,231m^3/day, rounded as: 870,200m^3/day and dynamic reserve: 1,496,947m^3/day, rounded as 1,497,900m^3/day. Potential exploitable groundwater reserves of each ecological region are presented in Table 3. Dynamic reserves are presented in Table 4.

Table 3. Potential fresh groundwater exploitable reserve

Aquifers	Potential fresh groundwater exploitable reserve (m^3/day)								Total (m^3/day)
	A	**B1**	**B2**	**B3**	**C1**	**C2**	**D**	**E**	
qp_3	433,679	170,785	36,575	0	0	0	14,571	0	655,611
qp_{2-3}	887,558	387,348	532,591	322,987	544,772	242,478	329,285	529,664	3,776,684
qp_1	439,591	279,629	394,524	313,125	311,600	248,521	403,621	627,469	3,018,079
n_2^2	198,225	115,277	202,120	321,117	237,426	154,507	209,349	394,273	1,832,295
n_2^1	568,309	703	155,106	201,224	124,264	0	150,957	143,250	1,343,814
n_1^3	146,056	127,137	334,778	93,914	702	0	11,033	0	713,620
Total	2,673,420	1,080,879	1,655,694	1,252,367	1,218,764	645,506	1,118,816	1,694,656	11,340,102

Table 4. Dynamic reserves in ecological regions

Aquifers	Dynamic reserves in ecological regions (m^3/day)								Total (m^3/day)
	A	B1	B2	B3	C1	C2	D	E	
qp_3	97,711	67,940	8,273	0	0	0	2,588	0	176,512
qp_{2-3}	146,178	84,347	95,811	22,118	67,486	41,624	79,316	44,916	581,796
qp_1	19,834	25,243	36,245	20,715	17,899	26,553	78,148	106,712	331,350
n_2^2	11,715	8,239	19,966	38,022	15,100	19,825	31,293	96,062	240,221
n_2^1	30,433	0	17,706	16,602	8,084	0	29,266	22,263	124,355
n_1^3	14,393	14,374	8,528	2,116	702	0	2,600	0	42,713
Total	320,265	200,142	186,529	99,573	109,270	88,002	223,212	269,952	1,496,947

Remark: Ecological regions A, B1, B2, B3, C1, C2, D and E were taken, referred to documents of Southern Institute of Water Resources Planning (2007) as displayed in Figure 1a.

3. Method of groundwater exploitation zoning in camau peninsula

3.1 Method of zoning

Map of groundwater exploitation zoning was composed in accordance with the principle: *water demand for development* and *perspective of groundwater exploitation*. After this principle, the study area is divided based on the following criteria:

- Water demand for development (demand of water use in ecological regions).

- Perspective of fresh groundwater exploitation (is there perspective of good quality groundwater exploitation?).
- Satisfaction level of water demand for domestic and production purposes (potential of groundwater source and satisfaction level).

3.2- Basis of groundwater exploitation zoning mapping

a- Topographical base map: Topographical base map used for mapping is topographical map of system VN-2000 on scale 1:200,000. Information shown are: Locations and names of cities, provinces, districts, communes, hamlets, rivers, coordinate grid, provincial boundaries, elevation marks, transportation system (ground, asphalt routes), water network, lakes, ponds….

b- Hydrogeological base map: Hydrogeological base map of the same scale 1:200,000. Boundaries and special information were extracted from this base map.

4. Contents and presentation method

4.1 Contents

In the study area there are combinations of one or multiple aquifers that have potential to meet water demand for domestic and production purposes. May be a case that in this locality a definite aquifer plays utmost important role, but in other locality it has a minor role or does not exist. In the entire area there are 6 aquifers (aquifer qh is neglected), of which potential of fresh groundwater exploitation is focused on 4 main aquifers, being: qp_{2-3}, qp_1, n_2^2 and n_2^1. Aquifers qp_3 and n_1^3, although can be exploited for fresh water of good quality, but considered as minor due to:

- Aquifer qp_3: small thickness, can be exploited on household scale.
- Aquifer n_1^3: Large thickness and productive, but because of deep distribution and large exploitation investment, they are considered as minor.

Based on this principle the Camau peninsula is divided into 3 main units downwards as follows:

Exploitation region: is divided usually after criterion of purpose of exploitation of water sources for social economical development. In 2007, Southern Institute of Water Resources Planning divided Camau peninsula into 8 ecological regions based on water resources and production pattern (symbolized as: A, B1, B2, B3, C1, C2, D and E), and this paper inherits this result (Figure 1a).

Exploitation area: is divided after perspective of fresh groundwater exploitation (fresh groundwater can be exploited or fresh groundwater is not available), see details in Figure 1b.

- Area of perspective fresh groundwater exploitation (at least 1 fresh aquifer), refered to as (I), symbol: I.
- Area of no perspective for fresh groundwater exploitation (all aquifers are saline), refered to as (II), symbol: II.

Exploitation plot: is divided after level of satisfaction for water demand for domestic and production purposes. Criteria are number of main aquifers and potential groundwater exploitable reserve.

- Plot I-1 - Scarce: one fresh aquifer (qp_{2-3}).
- Plot I-2 - medium: two fresh aquifers (qp_{2-3} and qp_1).
- Plot I-3 - Rich: three fresh aquifers (qp_{2-3}, qp_1 and n_2^2).
- Plot I-4 - abundant: four fresh aquifers (qp_{2-3}, qp_1, n_2^2 and n_2^1).

Area II was not divided into plot.

4.2 Implementation method Contents

On the basis of the mentioned principle and study results of the research, we composed map of groundwater exploitation zoning after following procedure:

Step 1: Determination of groundwater exploitation regions

- Compilation of groundwater exploitation regions, determination of distribution range, boundaries, areas
- Calculation of groundwater exploitable reserve for each region (potential groundwater exploitable reserve and secure exploitable groundwater reserve).

Step 2: Determination of groundwater exploitation areas and plots

- Superimposition fresh-saline boundaries (TDS = 1g/l) of 4 main aquifers qp_{2-3}, qp_1, n_2^2 and n_2^1. Determination of areas and plots: range and area, see details in Figure 2
- Calculation of groundwater reserve for each plot (potential groundwater exploitable reserve and secure exploitable groundwater reserve),

Step 3: Determination of range of possible fresh water exploitation of minor aquifers

- Determination of fresh water distribution based on fresh-saline boundaries (TDS = 1g/l) of aquifers,
- In each exploitation plot, calculation of groundwater reserve for each aquifer (potential groundwater exploitable reserve and secure exploitable groundwater reserve).

Step 4: Composition of map of groundwater exploitation zoning

- Draft of map legend,
- Superimposition of maps as implemented in previous steps,
- To bring special information into the map.

Implementation results are displayed in Figure 3.

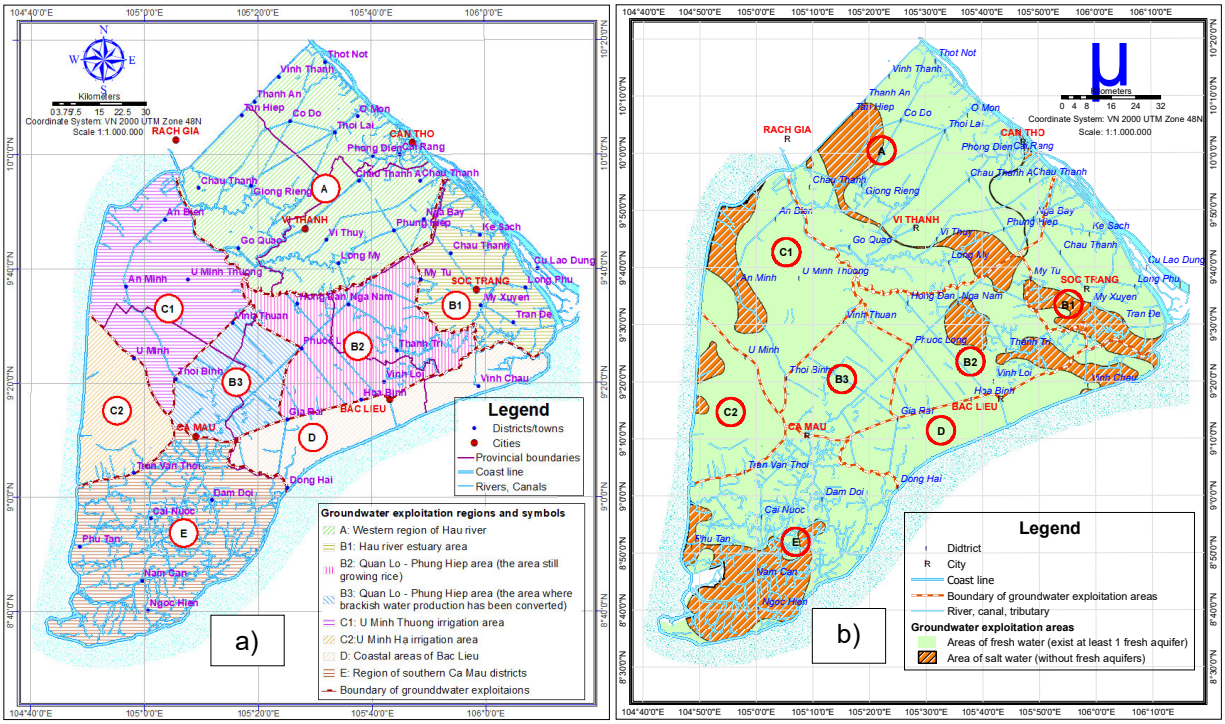

Figure 1. Map of Groundwater Exploitation Regions (a) and map of Perspective Groundwater Exploitation Areas (b)

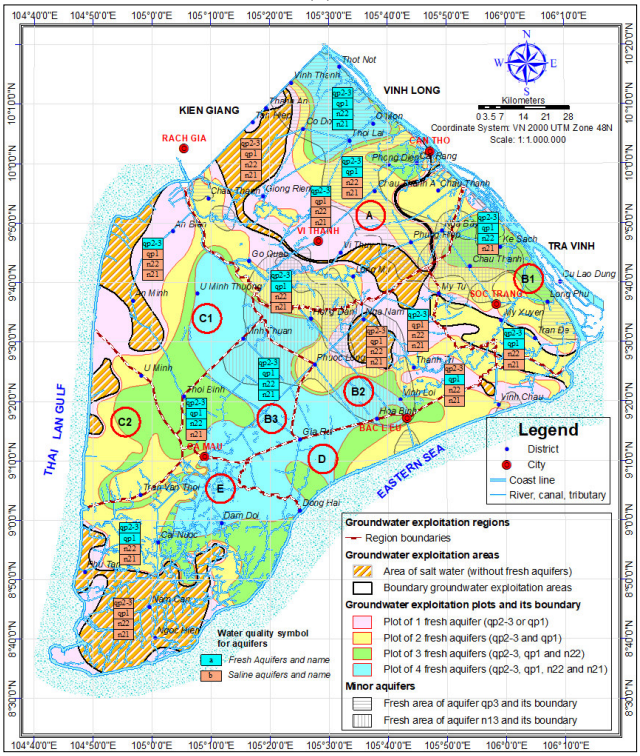

Figure 2. Map of Groundwater Exploitation Plots

5. Results and discussion

From the entire Camau peninsula, area from which fresh groundwater can be exploited is 13,871.9km^2 (83.6%). Area of saline groundwater is 2,728.1km^2 (16.4%). Potential fresh groundwater exploitable reserve is 11,340,102m^3/day (of which, fresh groundwater secure exploitable reserve is 741,534m^3/day, approximately 6.5% of potential fresh groundwater exploitable reserve). Potential saline groundwater exploitable reserve is

4,865,900m^3/day. In area range of fresh water (area I), potential exploitable groundwater reserve of each plot is different:
- Scarce plot: Fresh groundwater can be exploited only from aquifer $qp2_{-3}$ in total range of 2,844.8 km^2.
- Medium plot: Fresh groundwater can be exploited from aquifers qp_{2-3} and qp_1 in total range of 4,832.6 km^2.
- Rich plot: Fresh groundwater can be exploited from aquifers qp_{2-3}, qp_1, n_2^2 and n_2^1 in total range of 2,847.1km^2.
- Abundant plot: Fresh groundwater can be exploited from aquifers qp_{2-3}, qp_1, n_2^2 and n_2^1 in total range of 3,377.5km^2.

Specifications of exploitation regions are shown in details in Table 5 and Figure 3.

Table 5. Specifications of exploitation regions

Region		Area				Plot		Perspective
Symbol	Area (km^2)	Symbol	Area (km^2)	Reserve (m^3/day) Potential	Reserve (m^3/day) Secure	Symbol	Area (km^2)	
A	4,200.0	A-I	3,697.3	2,673,420	151,141	A-I-1	1.192,1	Scarce
						A-I-2	1.701,0	Medium
						A-I-3	279,6	Rich
						A-I-4	524,6	Abundant
		A-II	502.7	4,309,363				No fresh GW
B1	1,560.0	B1-I	1,219.0	1,080,879	112,263	B1-I-1	148,8	Scarce
						B1-I-2	612,0	Medium
						B1-I-3	458,2	Rich
		B1-II	341.0	1,593,786				No fresh GW
B2	1,950.0	B2-I	1,646.7	1,655,694	115,208	B2-I-1	417,5	Scarce
						B2-I-2	518,1	Medium
						B2-I-3	148,8	Rich
						B2-I-4	562,3	Abundant
		B2-II	303.3	1,730,405				No fresh GW
B3	1,200.0	B3-I	1,200.0	1,252,367	78,518	B3-I-2	35,6	Medium
						B3-I-3	337,9	Rich
						B3-I-4	826,5	Abundant
		B3-II	0.0	514,495				No fresh GW
C1	2,200.0	C1-I	1,815.0	1,218,764	41,254	C1-I-1	661,2	Scarce
						C1-I-2	271,0	Medium
						C1-I-3	377,3	Rich
						C1-I-4	505,5	Abundant
		C1-II	385.0	1,460,362				No fresh GW
C2	1,100.0	C2-I	1.000.2	645,506	30,095	C2-I-1	100,8	Scarce
						C2-I-2	557,0	Medium
						C2-I-3	342,4	Rich
		C2-II	99.8	780,035				No fresh GW
D	1.500.0	D-I	1,289.5	1,118,816	80,884	D-I-1	35,2	Scarce
						D-I-2	492,7	Medium
						D-I-3	319,0	Rich
						D-I-4	442,6	Abundant
		D-II	210.6	1,167,337				No fresh GW
E	2,950.0	E-I	2,034.3	1,694,656	132,172	E-I-1	289,2	Scarce
						E-I-2	645,2	Medium
						E-I-3	583,9	Rich
						E-I-4	516,0	Abundant
		E-2	915.7	3,310,117				No fresh GW
Overall	**16,600.0**	**I**	**13,871.9**	**11,340,102**	**741,534**	**I-1**	**2.844,8**	**Scarce**
						I-2	**4.832,6**	**Medium**
						I-3	**2.847,1**	**Rich**
						I-4	**3.377,5**	**Abundant**
		II	**2,728.1**	**14,865,900**				**No fresh GW**

Besides, in each region fresh groundwater in also can be exploited from minor aquifers as follows:
- Aquifer qp_3 has fresh groundwater area 2,756.5km^2 and potential exploitable reserve 655,611m^3/day.
- Aquifer n_1^3 has fresh groundwater area 2,350.8km^2 and potential exploitable reserve 713,620m^3/day.

Specifications of minor aquifers in exploitation regions are listed in Table 6 and its distribution ranges are displayed in Figure 2.

Table 6. Specifications of minor aquifers in exploitation regions

Exploitation regions	Area of fresh water (km^2)		Potential exploitable reserve (m^3/day)		Secure exploitable reserve (m^3/day)	
	qp_3	n_1^3	qp_3	n_1^3	qp_3	n_1^3
A	1,929.0	452.7	433,679	146,056	35,607	10,059
B1	590.5	387.,8	170,785	127,137	33,713	6,679
B2	162.4	1,115.0	36,575	334,778	6,202	4,799
B3		315.7		93,914		1,577
C1		50.4		702		581
C2						
D	74.6	29.2	14,571	11,033	503	
E					0	
Tổng	2,756.5	2,350.8	655,611	713,620	76,025	23,695

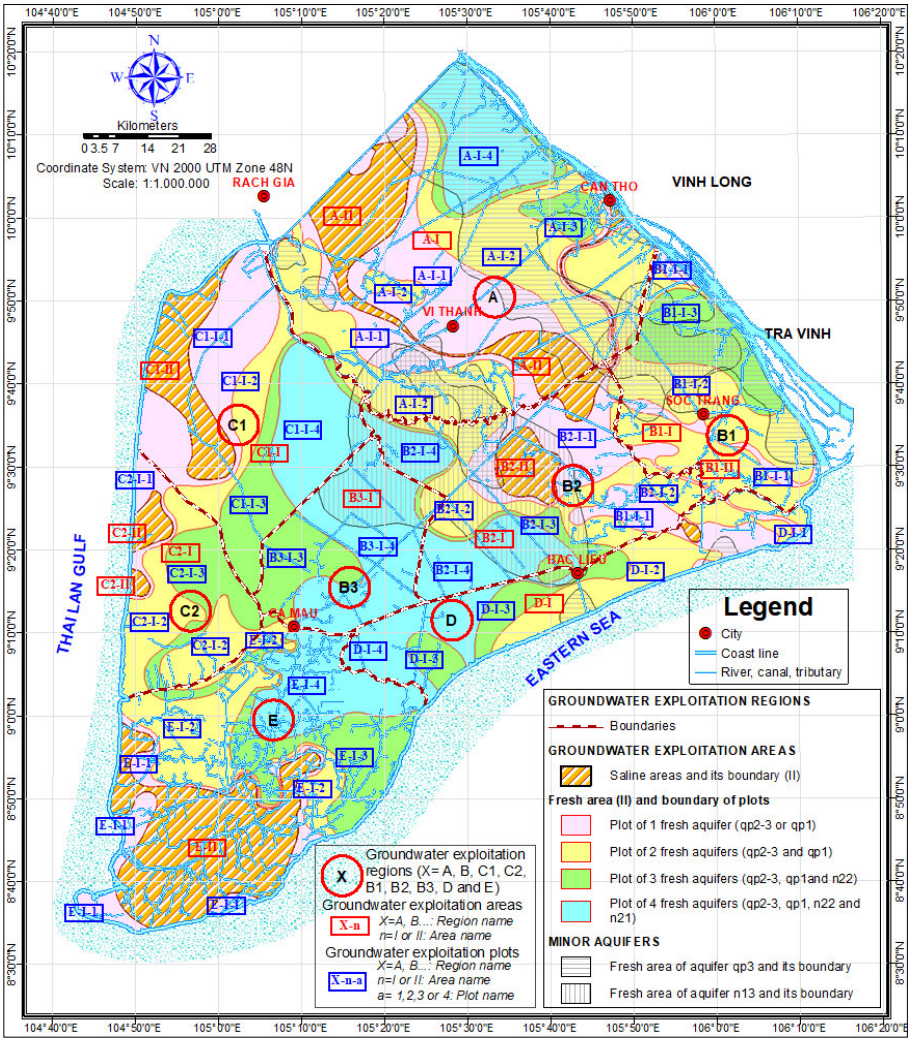

Figure 3. Map of groundwater exploitation zoning of Camau peninsula

6. Conclusion

Results of map of groundwater exploitation zoning on scale 1:200,000 of Camau peninsula help readers to easily know potential exploitable groundwater reserve in each ecological regions. Besides, concrete information regarding number of aquifers and secure exploitable reserve are presented in details. This is essential information for management of licensing groundwater exploitation, zoning prohibition and restriction of groundwater exploitation in accordance with Decree 167/2018/ND-CP; orientation of groundwater exploitation and use of

groundwater sources in socio-economical development planning or allocation of water sources in water resources planning (according to Circular 42/2015/TT-BTNMT).

In groundwater exploitation zoning in this paper just considering water as fresh when having TDS <1.0g/l (*QCVN09, 2015*). Practically, in localities of scarce water sources such as coastal area in southern part of Ca Mau province and some areas in Kien Giang, Bac Lieu and Soc Trang provinces people also exploit and use groundwater having TDS = 1.0 ÷ 1.5g/l.

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