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Assessment of Current Situation and Orientations for Exploitation, Utilization, and Protection of Groundwater Resources in Water–Scarce Areas of South–central Vietnam

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Groundwater resources are an extremely urgent topic for human life in the 21st century. The growing global population followed increasing water exigency for people' s activities, during water reduction and pollution in most countries around the world. Vietnam is one of the countries affected by climate change and water resource decreasing phenomena. Currently, the shortage of freshwater is still prevalent in water–scarce regions throughout Vietnam, notably the South Central region with 7 provinces: Khanh Hoa, Phu Yen, Binh Dinh, Quang Nam, Quang Ngai, Ninh Thuan, and Binh Thuan. In the South Central region, the total exploitable reserves are 50,691 m^3/day, of which Khanh Hoa province has the largest exploitable reserves with 12,758 m^3/day; Ninh Thuan province has the smallest exploitable reserves, 1,834 m^3/day. In this report, the authors will focus on assessing the current status and orientation of exploitation, use, and protection of groundwater resources in water–scarce areas in the South Central region. The results of the study show that the area has 8 layers/reservoir zone including Pleistocene sedimentary hole aquifers, fissure aquifers, fissures – sediment holes aged from Arkeozoic to Mezozoic and reservoirs along tectonic faults in intrusive rocks, The eruption is forecast to be 12,816 m^3/day and can supply a total of 128,160 people with a water usage standard of 100 l/person/day. The report has identified sanitary protection zones for residential water supply and recharge zones (replenishment areas) for particular projects, with a minimum radius of 20 meters for each project and a protection area of 3.0 to 12.0 km^2 for the recharge zones, to reasonably and sustainably exploitation, utilization, and protection of groundwater resources.

Key words: Current situation, degradation, depletion, groundwater protection, South Central Vietnam

INTRODUCTION

Groundwater resources are a special critical subject for human life. The increasing water demand for people's activities such as agricultural, industrial, and domestic uses for the growing global population, which will reach over 9 billion mark by 2050 from the current about 8 billion, during water resources have decreased since the 1970s (Alley *et al.* 1999; Arnell 1999; Alley *et al.* 2002, Hiscock *et al.* 2002, Gleeson *et al.* 2012; Singh & Panda, 2012). However, the management of groundwater is not reasonable to ensure its sustainability (Qureshi *et al.* 2010; Sophocleous 2010; Madramootoo 2012; Howard 2015). Groundwater reduction and pollution are common in most countries and have serious socio–economic impacts on locals (Lu *et al.* 2021; Naghdi *et al.* 2021; Rafipour–Ropero *et al.* 2022; Siddik *et al.* 2022; Ma*et al.* 2022; Abascal *et al.* 2022; Bruen *et al.* 2022; Norouzi Khatiri *et al.* 2023). Therefore, implementing appropriate measures to exploit, use, and manage groundwater resources is important for every country in the world.

Vietnam has abundant water resources with 16 main river basins, 3,450 rivers, and streams with a length of 10 km or more, including 405 inter–provincial rivers and streams; and 3,045 intra–provincial rivers and streams (MONRE of Vietnam, 2012). Besides, with an average heavy rainfall of 2,000 mm/year, it is capable of providing a large amount of water for surface and underground flows. The total potential amount of underground water is about 91.5 billion m^3/year (fresh water is about 69.1 billion m^3/year, and salt water is about 22.4 billion m^3/year). Groundwater reserves are mainly concentrated in the Red River Delta, Mekong Delta, and Central Highlands areas. The remaining areas have low underground water reserves and are classified as water–scarce areas of Vietnam (Vietnam Department of Water Resources Management, 2021). Vietnam's per capita water volume is 9,434 m^3, a high level compared to ASEAN and global standards (World Bank, 2019). However, Vietnam is still classified as a country at high risk of water shortage due to the following reasons: Low internal water volume (accounting for only 40% of total surface flow), uneven rainfall distribution throughout the year (About 70% in 3 summer months) and pollution of surface and groundwater sources is increasing (Son *et al.*, 2021). To ensure national water security, Vietnam needs to have a plan to evaluate, exploit, and effectively use water resources, especially underground water reserves.

STUDY AREAS AND RESEARCH METHODS

Study area

The study was conducted in the South Central region of Vietnam consisting of 7 provinces: Quang Nam,

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Quang Ngai, Binh Dinh, Phu Yen, Khanh Hoa, Ninh Thuan, and Binh Thuan. The Water scarce areas of the provinces were selected based on the principles: mountainous regions satisfy 2 conditions, have an area coefficient ≥ 0.5, and have not yet been investigated and evaluated for groundwater resources; The midland and delta regions meet the conditions of having an area coefficient of 0.2 and have not yet had their groundwater resources investigated and evaluated for domestic water supply. Based on the principles, there were, 28 areas in the South Central region have been identified in 7 provinces: Khanh Hoa (06 areas in communes: Son Binh, Son Lam, Khanh Nam, Khanh Binh, Khanh Dong, Khanh Phu); Phu Yen (04 areas in communes: Xuan Hoa, Krong Pa, An Hiep, An Dan); Binh Dinh (03 areas in communes: Canh Vinh, An Tan, Hoai Son); Quang Nam (06 areas in communes: Tien Cam, Tien Phong, Tien Tho, Tien My, Que Loc, Tien Hiep); Quang Ngai (04 areas in communes: Ba Dinh, Ba Bich, Ba To, Ba Xa); Ninh Thuan (01 area in Phuoc Chien commune) and Binh Thuan (04 areas in communes: Son My, Thang Hai, Thuan Quy, Tan Thang) are water scarce areas (Fig. 1).

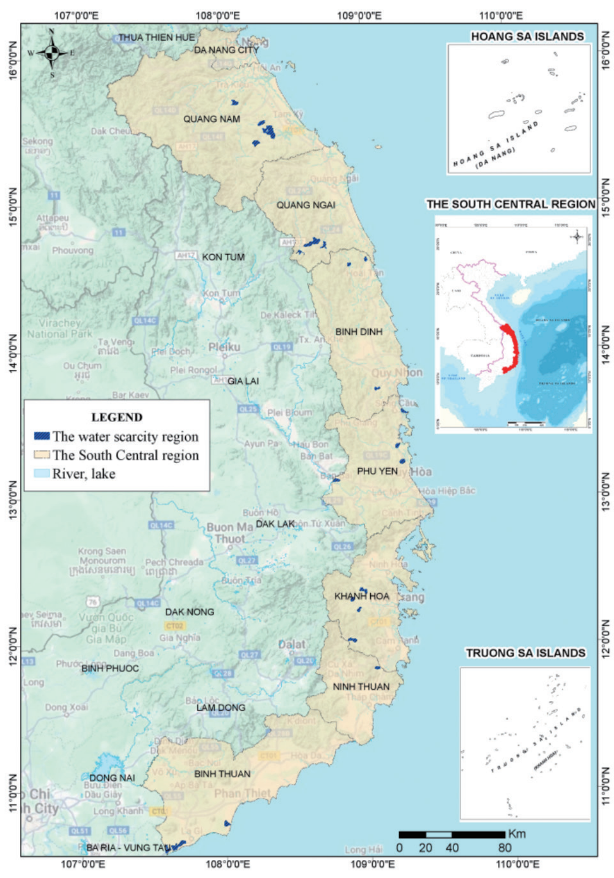


Fig. 1. Diagram of water scarce areas in the South Central region.

Data source

The data used in the study was based on experimental pumping results at exploratory boreholes expected to be exploited based on the water demand of each water–scarce region in the South Central region. As follows:

In the Pleistocene (qp) aquifer made by marine and river sediments (mQ_1^3, amQ_1^3) in An Dan area, the average discharge of boreholes by area from 2.25 l/s (Xuan Hoa area) to 3.05 l/s (An Dan area). Calculation results of hydrogeological parameters in the aquifer showed that the permeability coefficient from 0.52 m/day (borehole VCPY.1 in Xuan Hoa area) to 2.57 m/day (borehole VCPY.12 An Dan area), average 1.26 m/day; The water conductivity coefficient from 24.7 m^2/day (borehole VCPY.11 in An Dan area) to 132.35 m^2/day (borehole VCPY.12 in An Dan area), the average is 54.00 m^2/day.

In the crack–hole aquifer of eruptive basalt (βn) in the An Hiep area showed that capacity varied from 1.5 l/s to 2.0 l/s, total flow volume was 3.5 l/s. Calculation results of hydrogeological parameters show that the average permeability coefficient is 0.52 m^2/day, water conductivity coefficient is 34.45 m^2/day.

The crack aquifer of the Early–Middle Jurassic sediments (j_{1-2}) showed that the average discharge of boreholes ranged from 1.25 l/s (Krong Pa area) to 2.5 l/s (Son Lam area). Calculation results of hydrogeological parameters show that the permeability coefficient ranges from 0.15 to 0.36 m/day; average of 0.23 m/day. The water conductivity coefficient ranges from 9.53 m^2/day to 34.10 m^2/day; average of 20.53 m^2/day.

In the crack aquifer of the Proterozoic sediments (pr) showed that the average capacity of boreholes ranged from 2.0 l/s (Tien Phong, Tien Tho areas) to 2.55 l/s (Tien Hiep area). Calculation results of hydrogeological parameters show that the permeability coefficient ranges from 0.04 to 0.23 m/day; average of 0.11 m/day. The water conductivity coefficient ranges from 5.3 m^2/day to 21.8 m^2/day; average 12.55 m^2/day

The crack aquifer of the Arkeiozoic (ar) sediments showed that the average capacity of boreholes ranged from 1.25 l/s (Ba Bich, Ba To area) to 1.9 l/s (Ba Bich area). Calculation results of hydrogeological parameters showed that the permeability coefficient ranges from 0.07 to 0.09 m/day; average of 0.08 m/day. The water conductivity coefficient ranges from 2.72 m^2/day to 21.0 m^2/day; average of 12.91 m^2/day.

In the Aquifer Zone in intrusive–eruptive formations aged from Late Jurassic to Cretaceous (J_3–K_2), the average capacity of boreholes ranged from 1.09 l/s (Thang Hai area) to 2.25 l/s (Xuan Hoa area). Calculation results of hydrogeological parameters show that the permeability coefficient ranged from 0.1 to 1.46 m/day; average of 0.48 m/day. The water conductivity coefficient ranges from 7.16 m^2/day to 62.46 m^2/day; average of 26.08 m^2/day.

In the Aquifer Zone in Triassic intrusive formations (γT_2vc) in the Canh Vinh area, the capacity of boreholes ranged from 1.2 l/s (VCBD.2) to 2.4 l/s (VCBD.1), an average of 1.8 l/s. Calculation results of hydrogeological parameters showed that the average permeability coefficient of this aquifer zone is 0.16 m/day; The average water conductivity coefficient is 14.8 m^2/day.

In the Aquifer Zone in Late Paleozoic intrusive formations (γPZ_3bg–qs) in An Tan area, the average capacity of boreholes ranged from 1.05 l/s (Que Loc area) to 1.43 l/s (An Tan area). Calculation results of hydrogeological parameters showed that the average permeability coefficient of this aquifer zone is 0.51 m/day; The average water conductivity coefficient is 9.62 m^2/day.

The parameters of the researched aquifers are summarized according to Table 1, in which the values are recorded according to the structure: minimum value – maximum value (average value) or only the average value is recorded.

Methodologies

Based on that data, calculate the potential reserves of underground water and exploitable reserves, the exploitation flow of forecast works, thereby orienting the exploitation and water resources using underground water. There are water–scarce areas in the South Central provinces.

Potential underground water reserves are calculated according to the following formula:

$$Q_{kt} = Q_d + Q_t \qquad (1)$$

In there:

Q_d – Dynamic reserves of the aquifer;

Q_t – Static resources of the aquifer.

In the researched area, static resources consist of two components:

$$Q_t = Q_{tl} + Q_{dh} \qquad (2)$$

In there:

Q_{tl} – Gravity static resources of aquifers;

Q_{dh} – Elastic static resources of the aquifer.

Within the scope of research, the studied aquifers are usually nonpressured aquifers that exist in cracks of fractured rock or holes in terrigenous sediments. Therefore, the static resource of the aquifer is usually a static gravity resource (Q_{tl}).

Exploitable reserves of groundwater are determined in high mountainous and water–scarce areas nonpressured aquifers be allowed intrusion from 50% of static gravity resources for less than 50 m aquifer thickness, with thicker aquifers allowed exploitation is up to 50 m water depth from the ground surface (according to Decree 167/2018/ND–CP regulating the groundwater exploitation restriction).

Based on the capacity of exploitation works in water–scarce areas be established a sanitary protection zone for the domestic water intake area and a water supply zone (recharge zone) for the works. The delineation of the sanitary protection zone of exploitation works and the protection area of the water supply zone is carried out as follows:

Vietnam Water Resources Law No. 17/2012/QH13 stipulates: "The sanitary protection zone for domestic water intake areas in the vicinity of water intake areas from regulated water sources that must be protected to prevent and combat water source pollution". The scope of the sanitary protection zone of the domestic water intake area of the underground water exploitation works is specified in Article 6, Circular No. 24/2016/TT–BTNMT as follows:

– For groundwater exploitation works for domestic use with a scale of over 10 m^3/day to less than 3,000 m^3/day, the scope of the sanitary protection zone of the domestic water supply area is not less than 20 m calculated from the well.

– For groundwater exploitation works for domestic use with a capacity of 3,000 m^3/day or more, the sanitary protection zone of the domestic water supply area is not less than 30 m from the well.

Within the sanitary protection zone of the domestic water intake works, to ensure the prevention of pollution and degradation of water sources and water intake works, the following activities are prohibited: Prohibition of vehicles and pedestrians; Prohibition of farming and animal husbandry; Prohibition use of fertilizers, pesticides and plant protection drugs; Prohibition of activities related to radioactive waste; Prohibition of storing gasoline and oil, discharging and burying liquid and solid waste; Prohibition of the construction of wastewater drainage works through protected areas; Prohibition of building cemeteries, bury waste, and bury explosives; Prohibition of surface and underground mining activities; Prohibition of military exercises and explosions (Fig. 2).

Outside the sanitary protection zone of domestic waterworks, protecting and maintaining the quantity and quality of groundwater sources is necessary for each exploitation work. The scope of this protection zone is determined according to the recharge area of the exploitation work, specifically the basin/sub–basin for water

Table 1. The parameters of the researched aquifers

No.	Aquifer	Capacity (l/s)	Water conductivity coefficient (m^2/day)	Permeability coefficient (m^2/day)	Static water depth (m)
1	Pleistocen (qp)	2.25 – 3.05	24.7 – 132.35 (54.0)	0.52 – 2.57 (1.26)	2.4 – 9.5
2	Basalt (βn)	1.5 – 2.0	34.45	0.52	13.25 – 26
3	Early – Middle Jurassic (j_{1-2})	1.25 – 2.5	9.53 – 34.1 (20.53)	0.15 – 0.36 (0.23)	0.2 – 7.33
4	Proterozoic (pr)	2.0 – 2.55	5.3 – 21.8 (12.55)	0.04 – 0.23 (0.11)	0.2 – 12.78
5	Arkeiozoic (ar)	1.25 – 1.9	2.72 – 21.0 (12.91)	0.07 – 0.09 (0.08)	0.4 – 9.9
6	Late Jurassic to Cretaceous (J_3-K_2)	1.09 – 2.25	7.16 – 62.46 (26.08)	0.1 – 1.46 (0.48)	2.46 – 24.54
7	Triassic (γT_2vc)	1.2 – 2.4	14.8	0.16	5.3 – 8.5
8	Late Paleozoic (γPZ_3bg–qs)	1.05 – 1.43	9.62	0.51	0.5 – 6.0

sources in fractured rock, for water sources in porous soil and rock, and the influenced scope of the works (radius of influence).

Within the water supply area protection zone of underground water exploitation works, to ensure the maintenance of quantity and quality of water sources, the following activities are prohibited: Prohibition of building cemeteries, burying waste, and burying filling explosives; Prohibition of surface and underground mining activities; Prohibition of military exercises and explosions; Prohibition of large–scale grazing of livestock and poultry.

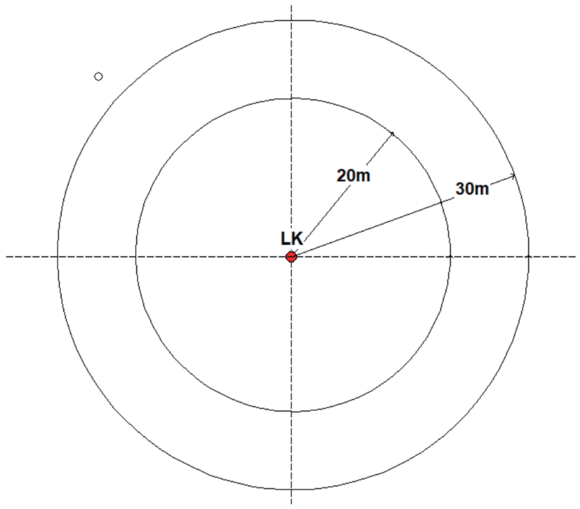


Fig. 2. Sanitary protection zone for groundwater exploitation works.

RESULTS AND DISCUSSIONS

Potential reserves of groundwater

The results of calculating the water resource potential of the South Central region showed that the total potential of water resources in 28 areas in 7 provinces is 168,960 m^3/day, of which Khanh Hoa province has a result of 42,531 m^3/day in 6 regions, that is the largest potential province; Ninh Thuan province has the smallest potential of 6,112 m^3/day in one investigation area (Table 2).

Reserves of underground water can be exploited

Calculation results showed that the total exploitable reserve in the South Central region is 50,691 m^3/day, Khanh Hoa province has the largest exploitable reserve with 12,758 m^3/day; Ninh Thuan province has the smallest exploitable reserves, 1,834 m^3/day. (Table 3).

Forecasted exploitation capacity

Forecasted exploitation capacity is the capacity calculated based on experimental pumping results at exploratory boreholes expected to be exploited based on the water demand of each area. Work reserves are calculated with an exploitation period of 27 years. Calculation and assessment results showed that the forecasted exploitation capacity in the South Central region is 12,816 m^3/day, capable of supplying a total of 128,160 people with a water usage standard of 100 l/person/day. Among the 7 provinces in the South Central

Table 2. Potential of underground water resources in the South Central region

No.	Province	Aquifer	No. of areas	Potential reserves of underground water (m^3/day)
1	Quang Nam	pr, gPZ3bg–qs	6	27.489
2	Quang Ngai	ar	4	17.834
3	Binh Dinh	gPZ3bg–qs, gT2vc	3	17.564
4	Phu Yen	qp, βn, n1, J1, gK2đc	4	36.422
5	Khanh Hoa	j2	6	42.531
6	Ninh Thuan	gdJ3đq	1	6.112
7	Binh Thuan	qp, gK2đc, Knt	4	21.008
	Total		**28**	**168.960**

Table 3. Exploitable reserves of groundwater in the South Central region

No.	Province	Aquifer	No. of areas	Exploitable reserves (m^3/day)
1	Quang Nam	pr, gPZ3bg–qs	6	8.249
2	Quang Ngai	ar	4	5.351
3	Binh Dinh	gPZ3bg–qs, gT2vc	3	5.270
4	Phu Yen	qp, βn, n1, J1, gK2đc	4	10.927
5	Khanh Hoa	j2	6	12.758
6	Ninh Thuan	gdJ3đq	1	1.834
7	Binh Thuan	qp, gK2đc, Knt	4	6.302
	Total		**28**	**50.691**

region, Khanh Hoa province has the largest forecasted exploitation capacity, 2,902.0 m^3/day; followed by Quang Nam and Binh Thuan provinces; Ninh Thuan province has the smallest forecasted exploitation capacity of 550.0 m^3/day in one investigation area (Table 4).

Orientation for exploiting underground water resources

In the entire region, there are 28 scarce areas within 7 provinces with the presence of 14 aquifers, a total number of exploitation works of 84 boreholes, ground-

Table 4. Forecasted exploitation capacity of the South Central region

No.	Province	No. of areas	Experimental pumping capacity (m^3/day)	Forecasted exploitation capacity (m^3/day)	Number of beneficiaries (100 l/person/day)
1	Quang Nam	6	2,501.0	2,425.0	24.250
2	Quang Ngai	4	1,685.0	1,667.0	16.670
3	Binh Dinh	3	1,408.0	1,373.0	13.730
4	Phu Yen	4	2,170.0	1,850.0	18.500
5	Khanh Hoa	6	2,929.0	2,902.0	29.020
6	Ninh Thuan	1	562.0	550.0	5.500
7	Binh Thuan	4	2,108.0	2,049.0	20.490
	Total	**28**	**13,363.0**	**12,816,0**	**128.160**

Table 5. Orientation for exploiting underground water resources of the South Central region

No.	Province	Areas	Aquifer	Potential reserve (m^3/day)	Exploitable reserves (m^3/day)	Forecasted exploitation capacity (m^3/day)
1	Quang Nam	Tien Cam	NP–e$_1$*mv*	2,515	755	350.0
2		Tien Phong	NP–e$_1$*mv*	3,364	1,009	345.0
3		Tien Tho	MP–NP*kd*	3,932	1,180	709.0
4		Tien My	MP–NP*kd*	2,337	701	363.0
5		Que Loc	GDiPZ$_3$*bg–qs*	6,644	1,996	217.0
6		Tien Hiep	MP–NP*kd*	8,697	2,609	441.0
7	Quang Ngai	Ba Xa	A–PP*kn*	5,192	1,558	545.0
8		Ba To	A–PP*kn*	4,417	1,325	419.0
9		Ba Dinh	A–PP*kn*	5,858	1,758	493.0
10		Ba Bich	A–PP*kn*	2,367	710	210.0
11	Binh Dinh	Canh Vinh	T$_2$*vc*	6,345	1,904	380.0
12		An Tan	PZ$_3$*bg–qs*	5,424	1,628	372.0
13		Hoai Son	PZ$_3$*bg–qs*	5,795	1,739	621.0
14	Phu Yen	Xuan Hoa	qh/K$_2$đc	9,398	2,819	570.0
15		Krong Pa	N$_1$*sb*/J$_1$*cl*	7,882	2,365	220.0
16		An Hiep	/N$_2$*đn*	11,173	3,352	303.0
17		An Dan	qh	7,969	2,391	757.0
18	Khanh Hoa	Son Binh	J$_2$*ln*	9,317	2,795	590.0
19		Son Lam	J$_2$*ln*	6,560	1,968	650.0
20		Khanh Binh	J$_2$*ln*	8,558	2,567	495.0
21		Khanh Dong	J$_2$*ln*	7,958	2,387	460.0
22		Khanh Nam	J$_2$*ln*	4,430	1,329	180.0
23		Khanh Phu	J$_2$*ln*	5,708	1,712	527.0
24	Binh Thuan	Phuoc Chien	F/(J$_3$*đq$_3$*)	6,112	1,834	550.0
25	Binh Thuan	Thuan Quy	qp/F/(K$_2$*đc*)	6,690	2,007	398.0
26		Thang Hai	Knt	4,857	1,457	330.0
27		Tan Thang	Knt	5,139	1,542	665.0
28		Son My	qp/F/(K$_2$*đc*)	4,322	1,296	656.0

Table 6. Scale of groundwater exploitation flow in the South Central region

No.	Province	Type 1		Type 2		Type 3	
		No. of area	Forecasted exploitation capacity (m^3/day)	No. of area	Forecasted exploitation capacity (m^3/day)	No. of area	Forecasted exploitation capacity (m^3/day)
1	Quang Nam	1	217	4	1,499	1	709
2	Quang Ngai	1	210	3	1,457		
3	Binh Dinh			2	752	1	621
4	Phu Yen	2	523			2	1,327
5	Khanh Hoa	1	180	3	1,482	2	1,240
6	Ninh Thuan			1	550		
7	Binh Thuan	1	330	1	398	2	1,321
	Total	**6**	**1,460**	**14**	**6,138**	**8**	**5,218**

Table 7. Sanitary protection zone of domestic water intake area and water supply area protection zone (recharge zone) for exploitation works of South Central region

No.	Province	Commune	Area	Exploitation works	Sanitary protection zone (m)	Recharge protection zone (km^2)
1	Quang Nam	Tien Phuoc	Tien Cam	VCQNa.1	33.2	5.7
2				VCQNa.2	28.8	5.7
3			Tien Phong	VCQNa.3	27.6	5.9
4				VCQNa.4	22.6	5.9
5			Tien Tho	VCQNa.5	26.5	9.6
6				VCQNa.6	28.1	9.6
7				VCQNa.16	34.1	9.6
8				VCQNa.17	34.1	9.6
9			Tien My	VCQNa.7	28.2	5.7
10				VCQNa.8	23.3	5.7
11		Nong Son	Que Loc	VCQNa.9	20	14
12				VCQNa.10	20	14
13				VCQNa.11	20	14
14		Tien Phuoc	Tien Hiep	VCQNa.12	29.1	13.6
15				VCQNa.13	28.5	13.6
16	Quang Ngai	Ba To	Ba Xa	VCQNg.10	27.4	6.7
17				VCQNg.11	26.8	6.7
18				VCQNg.12	24.3	6.7
19			Ba To	VCQNg.6	20.1	8
20				VCQNg.7	20.1	8
21				VCQNg.8	21.7	8
22				VCQNg.9	20	8
23			Ba Dinh	VCQNg.1	26.6	9
24				VCQNg.2	23.4	9
25				VCQNg.3	31.3	9
26			Ba Bich	VCQNg.4	23.4	3.7
27				VCQNg.5	22.3	3.7
28	Binh Dinh	Van Canh	Canh Vinh	VCBĐ.1	32.9	6.4
29				VCBĐ.2	23.2	6.4
30				VCBĐ.3	23.2	6.4
31		An Lao	An Tan	VCBĐ.4	29.6	5.7
32				VCBĐ.5	29.6	5.7
33				VCBĐ.6	27.5	5.7
34		Hoai Nhon	Hoai Son	VCBĐ.10	35.3	5.5
35				VCBĐ.11	37.7	5.5
36				VCBĐ.12	40	5.5

No.	Province	Commune	Area	Exploitation works	Sanitary protection zone (m)	Recharge protection zone (km^2)
37	Phu Yen	Song Cau	Xuan Hoa	VCPY.1	100.1	8
38				VCPY.2	111.7	8
39				VCPY.3	33.2	8
40				VCPY.4	52	8
41		Son Hoa	Krong Pa	VCPY.5	28.4	9
42				VCPY.6	26.1	9
43				VCPY.7	26.1	9
44		Tuy An	An Hiep	VCPY.8	32.7	11
45				VCPY.9	37.8	11
46			An Dan	VCPY.10	211.2	7
47				VCPY.11	145.2	7
48				VCPY.12	142.1	7
49	Khanh Hoa	Khanh Son	Son Binh	VCKH.1	25.1	7.5
50				VCKH.2	40.5	7.5
51				VCKH.3	38.1	7.5
52			Son Lam	VCKH.4	30.3	5.5
53				VCKH.5	34.5	5.5
54				VCKH.6	37.5	5.5
55		Khanh Vinh	Khanh Binh	VCKH.9	35.8	7.4
56				VCKH.10	31	7.4
57				VCKH.11	20	7.4
58			Khanh Dong	VCKH.12	30.7	6.2
59				VCKH.13	23.5	6.2
60				VCKH.14	32.4	6.2
61			Khanh Nam	VCKH.7	23.3	8.2
62				VCKH.8	20.8	8.2
63			Khanh Phu	VCKH.15	26.6	7.1
64				VCKH.16	33.6	7.1
65				VCKH.17	32.2	7.1
66	Ninh Thuan	Thuan Bac	Phuoc Chien	VCNT.1	26	6.8
67				VCNT.2	32.7	6.8
68				VCNT.3	28.1	6.8
69				VCNT.4	23.7	6.8
70	Binh Thuan	Ham Thuan Nam	Thuan Quy	VCBT.11	33.3	13.5
71				VCBT.12	34.3	13.5
72				VCBT.13	33.3	13.5
73		Ham Tan	Thang Hai	VCBT.7	25.3	13.5
74				VCBT.8	24.5	13.5
75				VCBT.9	25.3	13.5
76				VCBT.10	27.5	13.5
77			Tan Thang	VCBT.14	33.4	15.5
78				VCBT.15	39.2	15.5
79				VCBT.16	28.99	15.5
80				VCBT.17	43.39	15.5
81			Son My	VCBT.3	40.86	16
82				VCBT.4	24.62	16
83				VCBT.5	39.88	16
84				VCBT.6	43.57	16

water potential, and reserves that can be exploited, and forecasted exploitation capacity as Table 5.

DISCUSSION

Orientation for using underground water resources

In each area, the number of exploitation boreholes ranges from 1 to a few works with exploitation capacity ranging from 210 m^3/day to 757 m^3/day.

According to the scale of construction of typical water supply systems in water–scarce areas, water treatment station systems are divided into 3 groups as follows: Type 1: 300 m^3/day water–supply station (applicable to areas with water supply demand by 2030 is less than 350 m^3/day); Type 2:500 m^3/day water–supply station (applicable to areas with water supply needs by 2030 from 350 m^3/day less than 550 m^3/day); Type 3: 1,000 m^3/day water–supply station (applicable to areas with water supply demand by 2030 is over than 550 m^3/day).

Based on the above classification, the capacity of underground water exploitation works is typical for each province. The South Central region has a total of 28 water–supply stations in 7 provinces, including 6 water–supply stations of type 1, 14 water–supply stations of type 2, and 8 water–supply stations of type 3. Details are in Table 6 and shown in Figure 3 as follows:

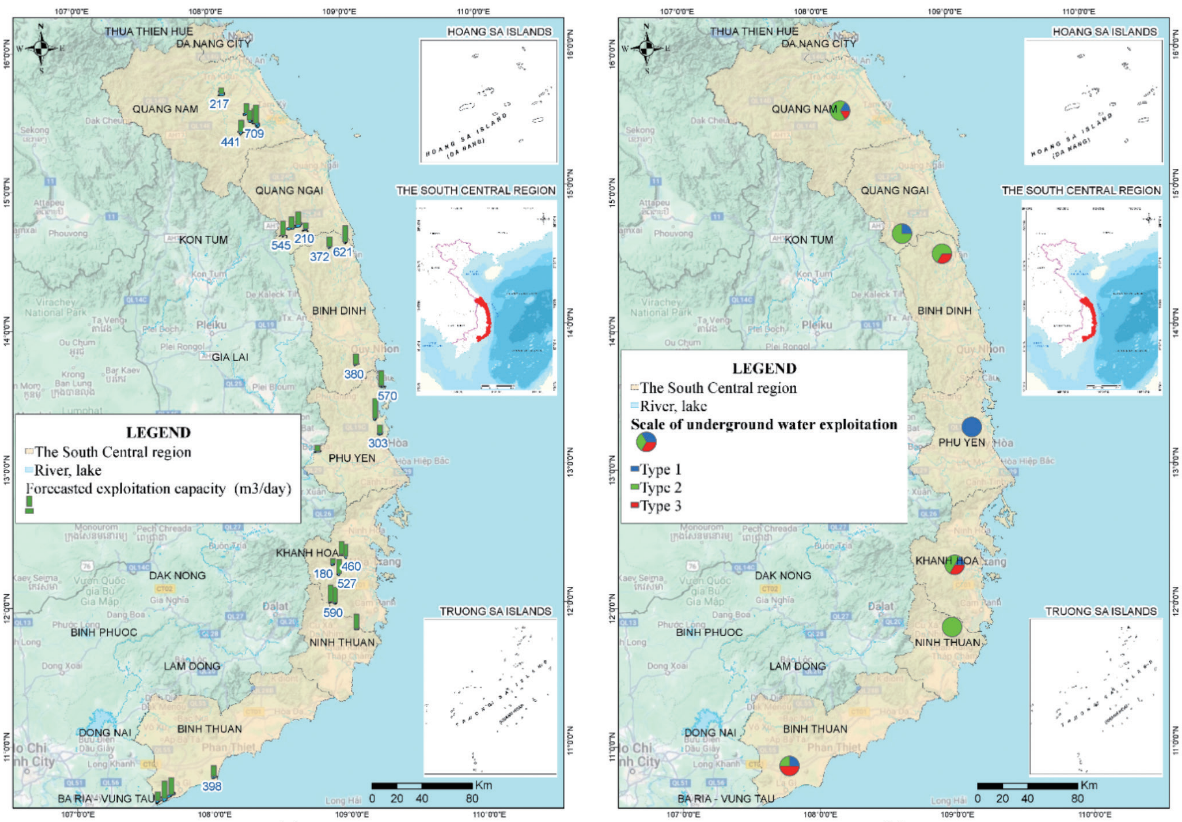
Solutions to protect underground water resources

In 28 areas of 7 provinces in the South Central region, there are 84 exploitation works from over 10 to under 3,000 m^3/day, there are no exploitation works over 3,000 m^3/day, detail of sanitary protection zone of domestic water intake area and water supply area protection zone (recharge zone) according to Table 7 is as follows:

CONCLUSIONS

Thus, the research results, show that the water–scarce region of the South Central region has 8 aquifers/zones including Pleistocene sedimentary porous aquifers, fissure aquifers, and sedimentary fissures, age from Arkeozoic to Mezozoic and water zones along tectonic faults in intrusive and eruptive rocks with a forecast exploitation capacity of 12,816 m^3/day and capable of supplying a total of 128,160 people with water usage standard of 100 liters/person/day. To exploit, use, and protect water resources reasonably and sustainably, the sanitary protection zone for domestic water intake areas and the supply area protection zone (recharge zone) with a minimum radius for each work is 20 m, the area of recharge protection zone is from 3.0 to 12.0 km^2.

The authorities need to consider building water supply systems suitable to water source characteristics and water use practices based on research results on groundwater sources to ensure sustainable domestic water supply. sustainable and safe for people in high mountainous areas and water–scarce areas in the South Central region.



(a) (b)

Fig. 3. (a) Orientation for exploiting groundwater and (b) Orientation for using groundwater in water scarce areas in the South Central region.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation and data collection were performed by Than Van DON, Hoang Van THUC, Nguyen Hai NUI. Analysis was per formed by Cao Truong SON, Nguyen Xuan Hoa, and Mitsuyasu YABE. The first draft of the manuscript was written by Cao Truong SON, Than Van DON, Mitsuyasu YABE and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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