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Research Article

Risk of groundwater pollution and proposals for sustainable development in Binh Thuan province, Vietnam

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Abstract: Groundwater serves as one of the important sources of water supply for Binh Thuan province, Vietnam during dry seasons. This water source is concentrated in Quaternary sediments with two aquifers qh and qp. Geophysical methods have been applied, performing geological drilling, observing and monitoring boreholes. Determine the characteristics of the qh and qp aquifers, located along the coast of Binh Thuan province. Our research has shown that these reservoirs are contaminated. Water sources are at high risk of being contaminated with mineral oil, radioactive, organic, bacterial and saline contamination. The article warned about water resource risks in Binh Thuan province and proposed remedial measures to ensure water resources for Binh Thuan province.

Key words: Aquifers; Binh Thuan Province; Ground Water; Salinization.

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1. Introduction

Binh Thuan is a coastal province in the South-Central region, with a sea length of 192 km extending from Ca Na to Binh Chau (Figure 1). Binh Thuan has to "face to face" the phenomenon of eawater infiltrating into the land up to nearly 20 km in some places. Solving the problem of water shortage has been difficult. Currently, Binh Thuan province still has to cope with salinization. The study results identified the salinization boundaries of the aquifers in Binh Thuan province. Since then, the authors have made offers to minimize the negative impacts on water resources, serving sustainable development.

Since 1992, the United Nations has chosen March 22 every year as World Water Day. The theme of World Water Day 2022 is "Groundwater" to draw attention to the hidden and always valued water resource but has not been fully recognized for its value in sustainable development policy planning. Geophysical methods used in exploration include: i) Seismic methods are a group of methods that use seismic waves or sound waves to study the environment. The results of the exploration are the location of reflection/refraction boundaries, the speed of wave propagation in rock (or water) masses, and possibly the physical and mechanical structural characteristics of the rock and soil [1]; ii) Gravity method measures the Earth's gravity, thereby determining the density distribution (or density) of rock masses [2]; iii) Magnetic method to measure the Earth's magnetic field [3]; iv) Electrical methods are a system of methods that use voltage or constant current (DC) to study the environment through electrodes inserted into the ground, to determine the distribution of electrical conductivity characteristics of blocks or rock layer [4]; v) Electromagnetic methods are a system of methods that use electromagnetic fields to study the environment, and usually do not use electrodes. The survey results are the conductivity distribution in soil and rock, but are often expressed in resistivity [5]; vi) Radioactive exploration includes methods for characterizing and distributing natural or forced radiation in rocks and soil [6]; vii) Geothermal exploration: Measure temperature distribution in soil and rock to determine the heat source and rock state properties [7]; viii) Seismoelectrical: Research and application of electromagnetic fields generated in soil and rock under the impact of compressive elastic waves (longitudinal P waves) to predict nearby earthquakes, search and explore underground water or potentially valuable minerals. related to quartz. However, it is still rarely used [8].

Binh Thuan province's underground water resources are divided into 2 porous aquifers, 4 aquifers and fissure aquifer zones, geological formations that are extremely poor in water and contain no water. The results of assessing the exploitable reserves of underground water in Binh Thuan province show that the distribution area of freshwater layers is about 4,080.7 km^2, the exploitable reserve is 652,290 m^3/day and night [9]. Currently, the underground water reserves of Binh Thuan province are distributed in different aquifers, coastal sand dune areas with an exploitation depth of 30-40 m, in some places it is 80-100 m. Groundwater in the coastal area of the entire province is the most volatile. Mining titanium-zircon minerals requires a large amount of water, and water sources here are very scarce, and at the same time discharges a large amount of wastewater that contains radioactive substances that may be higher than allowed levels. Titanium-zircon mining technology is being applied here with the mining pit always being flooded [10]. In Binh Thuan, underground water is very important. Only 40% of domestic water demand in the province comes from surface water, the rest most people and water plants exploit underground water sources, especially hotels serving coastal tourists in the province [11].

Figure 1. Location of the study area.

The purpose of this study is to evaluate the current status of groundwater quality of the qh and qn aquifers of Binh Thuan province, Vietnam; Consider the water quality of these aquifers. Based on the results obtained, the study determined the risk of groundwater pollution and proposed solutions for sustainable development of the province.

2. Data collection and methods

2.1. Data collection

In this study, materials were utilized: (1) Groundwater research topics and projects are addressed in these documents; (2) Geological and hydrogeological research results from Binh Thuan province; (3) Documentation of field investigations in Binh Thuan province for 2016, 2018, 2020, and 2021; (4) Binh Thuan province's seaside vision for zoning distribution and groundwater resource protection by 2030; (5) Boreholes that exploit underground water in Binh Thuan province have parameters; (6) Monitoring, sampling, and analysis of water samples are the results of the author's work.

2.2. Methods

2.2.1. Data collection and analysis

The formation of porous aquifers occurs in unconsolidated sediments from the Quaternary era. The hydraulic properties of laminar water are present in them, and they are mostly found in unpressured aquifers. The Quaternary unconsolidated sediments are an underground hydraulic system that runs continuously throughout the region in essence. Water-permeable and water-repellent materials are alternately present in this heterogeneous entity. The water table in these sediments is typically less than 2 meters deep. Contamination of porous water is a common occurrence. Also, coastal water is slightly salty, while underground water is saline due to seawater intrusion. The dynamics of open water fall under both seasonal changes and coastal dynamics. Ground water levels fluctuate significantly with the seasons and extremes of water levels are reached more slowly than rainwater and surface water.

The study has sampled water in aquifers qh and qp, located along the coast of Binh Thuan province. Water samples were analyzed by 24 parametrs (pH, $CaCO_3$, TDS, NH^{4+}, Cl^-, SO_4^{2-}, ΣFe, NO_2, NO_3, COD ($KMnO_4$), Florua (F^-), Xianua (CN^-), Phenol, Asen (As), Cadimi (Cd), Pb, Cr^{6+}, Cu, Zn, Mn, Hg, Se, E. Coli, Coliform. The analysis results for water samples are compared with National Technical Regulation on Drinking Water Quality of Viet Nam.

2.2.2. Geophysical methods

Geophysical methods are amazingly effective for the in-depth study of structures. Geophysical methods allow determining the geological structures, aquifer boundary, water storage zone, saltwater/ freshwater boundary based on the difference in resistivity of the studied objects [12]. In saline water the resistivity values change suddenly (low resistance, Figure 2 shows from blue to yellow). From this, we have determined the salinization boundary. In addition, we also determined the thickness of the Quaternary sediments. That is the basis for us to determine the thickness of the aquifers. The geophysical lines are designed by us in the direction perpendicular to the coastline (Figure 3).

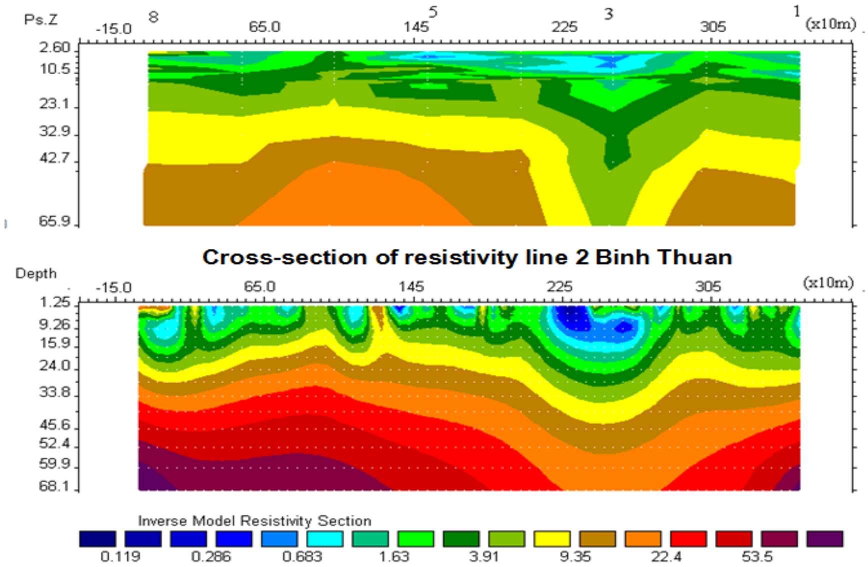

Figure 2. Resistivity section of line 2 Binh Thuan.

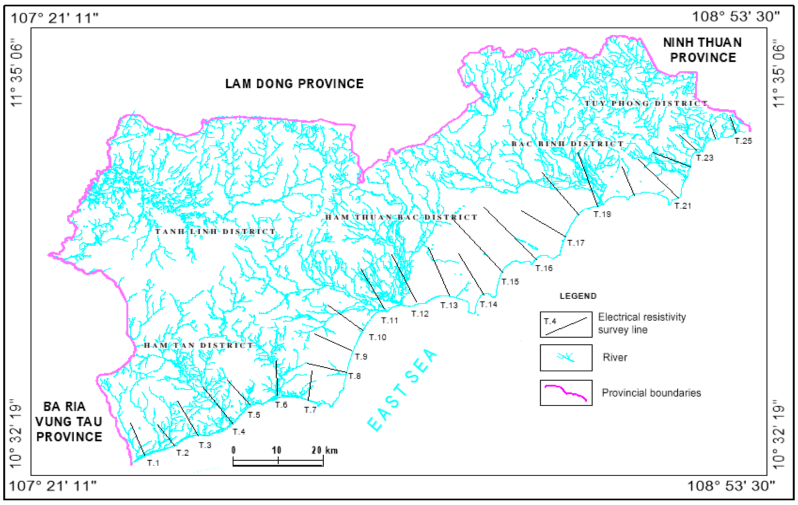

Figure 3. The diagram of the resistivity survey.

We used Schlumberger equipment with device distance ABmax = 350m, MNmax = 25m (study depth from 50÷90 m). The resistivity survey method determines the change of geological structure with depth.

The resistivity values were identified by:

$$\rho = K\frac{\Delta U}{I} \quad (1)$$

where I is an amperage; ΔU is the voltage; K is determined.

$$K = \pi\frac{AM \times AN}{MN} \quad (2)$$

Symmetrical depth method according to the diagram of figure 4.

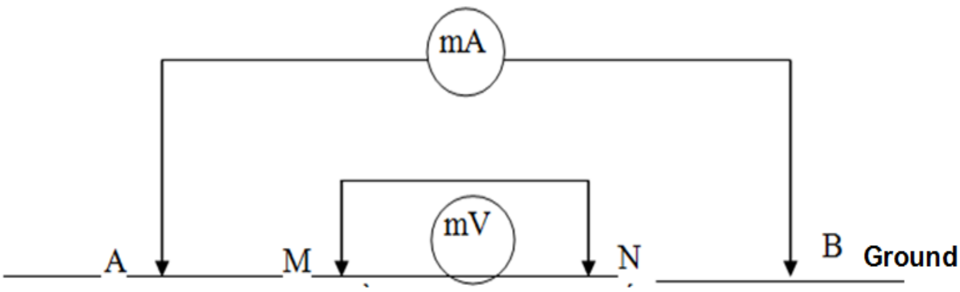

Figure 4. Diagram of method Schlumberger.

Network of measuring points: The distance between the lines is from 5km to 8km and the average distance between the measuring points is 500m. Measurement points were identified by GPS Montana 680.

2.2.3. Field observation

Field observation is a very important method, it has helped the authors to directly observe geological phenomena, geomorphological processes. Field observations have helped us to research, determine the resistivity survey, location of borehole.

2.2.4. Geological drilling method

With hundreds of wells collected from geological projects, hydrogeology helped the authors determine the thickness of aquifers. The documentation of the wells helped the authors to divide the sedimentary layers.

Coarse sediments are the distribution of groundwater, fine-grained sediments are not suitable for storing water. We did additional drilling to verify geophysical measurement results, and also took sample types (see section 2.2.5). From there, identifying the thickness of the sedimentary layers associated with the aquifers will be determined more accurately.

2.2.5. Methods of monitoring and sampling boreholes

We took water samples from drilled wells in Binh Thuan province. The results of the analysis have been compared with the National Technical Regulation on Groundwater Quality of Ministry of Natural Resources and Environment in Vietnam: 09/2023/ MONRE (Table 1).

Table 1. Table of water quality standards for groundwater (Vietnamese Standards: 09/2023/MONRE).

TT	Parameters	Units	Vietnamese standards: 09/2015/ Monre
1	pH		5.8 - 8.5
2	$CaCO_3$	mg/l	500
3	TDS	mg/l	1500
4	Amonium (NH^{4+})	mg/l	1
5	Cloride (Cl^-)	mg/l	250
6	Sulpate (SO_4^{2-})	mg/l	400
7	Total Fe	mg/l	5
8	Nitrite (NO_2)	mg/l	1
9	Nitrate (NO_3)	mg/l	15
10	COD ($KMnO_4$)	mg/l	4
11	Fluoride (F^-)	mg/l	1
12	Cyanide (CN^-)	mg/l	0.01
13	Phenol	mg/l	0.001
14	As	mg/l	0.05
15	Cd	mg/l	0.005
16	Pb	mg/l	0.01
17	Cr^{6+}	mg/l	0.05
18	Cu	mg/l	1.0
19	Zn	mg/l	3.0
20	Mn	mg/l	0.5
21	Hg	mg/l	0.001
22	Se	mg/l	0.01
23	E. Coli	MNP/	0
24	Coliform	100ml	3

2.2.6. Sample analysis method

Water samples were analyzed for 24 parameters. Samples analyzed at Nation Lab Nation Lab. VLAT 1-1.0517; ISO/IEC 17025.2017 and Institute of Environmental & Circular Economy Sothern_ IECES (Table 1).

3. Results and discussion

3.1. Characteristics of aquifers

Research results showed that Binh Thuan province has 7 aquifers, including porous aquifer and fractured aquifer [13–15]. In this article, we only refer to the porous aquifer, because the fault aquifer belongs to the low-productivity aquifer type, which is not the subject of this study.

In porous aquifers, water exists and circulates ceaselessly in the gaps between particles of non-cohesive matter. As for bulk materials, they are often described in terms of the grain size of individual particles such as sand, pebbles, gravel, etc., widely distributed porous aquifers, forming coastal plains and valleys of rivers and streams.

a) Porous aquifers in unclassified Quaternary sediments (q)

Porous aquifers in unclassified Quaternary sediments (q) are formed by the deluvial sediments (dQ), deluvial - proluvial (dpQ), eluvial - deluvial (edQ) and aluvial - deluvial (adQ). The aquifer thickness varies from 0.5m to 7.0m, in some places up to 17.0m. (LK1016 - Ham Tan). The common thickness is 3m - 5m. The total distributed area of the porous aquifers in unclassified Quaternary sediments is about 128 km^2. The compositions of the sediments include debris, sand, gravel, silt, clay, pebble, rock, etc, discrete texture. Deep of water level of the wells is from 2.83m - 5.98m deep, with average of 4.18m. Porous aquifer in unclassified Quaternary sediments belong to the low yield aquifer category. The test results of the water pump are shown in Table 2.

Table 2. Results of experimental water pump of pits and wells of the porous aquifer in unclassified Quaternary sediments (q).

Value	Static Water Level (m)	Discharge (l/s)	TDS (g/l)	permeability coefficient (m/ng)
Maximum	5.98	0.85	0.18	2.80
Minimum	2.83	0.03	0.04	0.14
Medium	4.18	0.28	0.15	1.10

The source of supply for this aquifer is mainly rainwater, surface water and from aquifers located above. The drainage area is the hydrological network in the area. Research results have shown that the water level often rises in the rainy season and wells dry up in the dry season. The water level changes between 2 seasons from 2m to 4m. Porous aquifers in unclassified Quaternary sediments have had discontinuous distribution, forming narrow bands, thin thickness, low productivity aquifers.

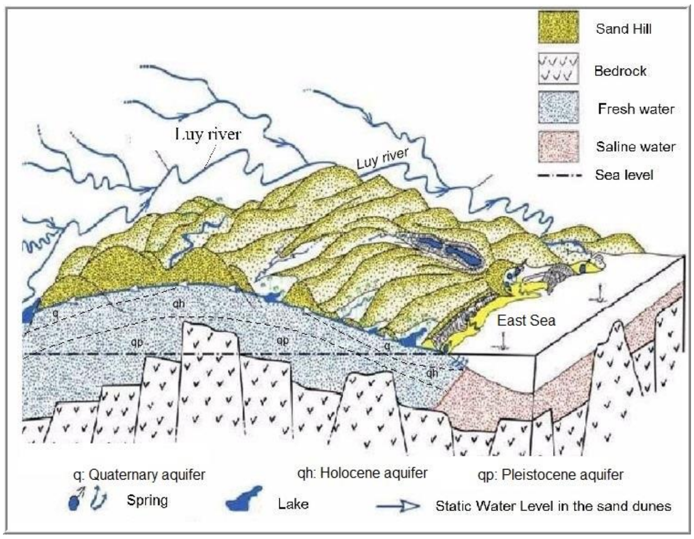

Figure 5. Map of Binh Thuan province Hydrogeology.

b) Porous aquifer in Holocene sediments (qh)

Porous aquifer in Holocene sediments is made up of marine sediments (mQ_2^2, mQ_2^{2-3}, mQ_2^3), marine sediments - marshy (mbQ_2^2, mbQ_2^{2-3}, mbQ_2^3), wind origin sediments (vQ_2^2, vQ_2^{2-3}, vQ_2^3), alluvial sediments - marine (amQ_2^{2-3}), alluvial sediments (aQ_2^{2-3}, aQ_2^3). They are distributed in the Vinh Hao deltas, Tuy Phong delta, Bac Binh delta, Ham Thuan Bac delta, along with the valley of Phan river, valley of Dinh river, valley of

Long Song river the valley of Phan river, Bau Sen area, Ham Tan area, Thuan Quy area, Tan Thanh area, etc. Total distributed area is 983 km^2. The compositions of the sediments include debris, sand, gravel, silt, clay, pebble, rock, etc, discrete texture. Holocene aquifer thickness ranges from 1m - 2m to 20m - 40m, with an average of about 10m. The water capacity of Holocene sediments is very erratic and depends on the composition of sediment, distributed location, and thickness of the rock.

Experimental results of pumping water in pits and wells in Holocene aquifers showed that: The water had no pressure, the water depth was from 0.5m to 5.0m. The water flow at these outcrops ranged from 0.01 liters to 0.3 liters per second. The main source of supply for the Holocene aquifer was rainwater; Water level in rainy and dry seasons was from 0.3m to 0.4m. The experimental water pumping results showed that the flow of the well ranged from 0.06 liters - 0.91 liters per second, an average of 0.45 liters per second; seepage coefficient ranged from 2.0 meters - 3.0 meters per day, well flow ranged from 0.2 liters - 0.4 liters per second.

Table 3. Experimental pumping results of pits and wells in low-yield areas of Holocene aquifers.

Value	Static Water Level (m)	Discharge (l/s)	Draw- down (m)	TDS (g/l)	permeability coefficient (m/ng)
pits					
Maximum	4.5	0.91	4.33	5.91	4.53
Minimum	0.3	0.06	1.03	0.07	0.72
Medium	1.86	0.45	1.85	1.23	2.55
wells					
Maximum	11.55	0.99	25.8	1.987	4.76
Minimum	0.05	0.054	0.29	0.05	0.02
Medium	2.64	0.33	6.61	0.84	1.34

Table 4. Experimental pumping results of pits and wells in high-yield areas of Holocene aquifers.

Value	Static Water Level (m)	Discharge (l/s)	Draw- down (m)	TDS (g/l)	permeability coefficient (m/ng)
Pits					
Maximum	4.1	4.44	3.56	1.11	46.93
Minimum	0.0	1.00	1.16	0.11	3.13
Medium	1.90	1.75	2.08	0.57	12.92
wells					
Maximum	6.17	2.00	9.33	0.165	11.63
Minimum	0.88	1.10	0.74	0.045	0.77
Medium	2.92	1.33	4.51	0.11	2.80

In general, water in the Holocene was super freshwater to saline water, TDS ranged from 0.045 grams - 1.987 grams per liter, the frequent values ranged from 0.5 grams - 0.7 grams per liter. The low-yield sediments, distributed in the coastal area, have high TDS due to salinization from seawater. Checking 38 constructions, up to 7 waterworks were salinization (M = 1.6 grams - 5.91 grams per liter). The groundwater changed seasonally, closely related to surface water and rainwater. The groundwater level monitoring results of well BBM11 showed the highest water level in October (water level depth: 1.0 m) and the water level was lowest in May (water level depth: 1.58 m), the water level difference of the season rainy and dry season was 0.58 m [16].

Most of Holocene aquifers distributed in Phan Thiet area have been affected by salinity. Freshwater was only available at a depth of < 5.0 m, from 5.0 m or more, the water has been contaminated with salt (resistivity survey results by Geophysical methods, gave small resistivity values, corresponded to high salinity values of water).

In summary, the Holocene aquifer had a discontinuous distribution. Level of water storage was from low- yield to medium - yield. Porous aquifer in Holocene sediments could be water supply small scale, in the estuary areas of the Cai river, Phan river. Porous aquifers in Holocene sediments were salinization.

c) Pleistocen aquifer (qp)

Porous aquifers in Pleistocene sediments (qp) are made up of alluvial sediments (aQ23, aQ22-3), alluvial marine sediments (amQ12-3, amQ13.2), marine sediments (mQ12-3, mQ13.2, mQ12.1)); marine - marsh sediments (mbQ12-3, mbQ13.2), wind source sediments (vQ13), deluvial - proluvial (dpQ) and eluvial - deluvial (edQ). They are distributed mainly in low-lying plains from Tuy Phong to Ham Tan, along Highway 1A, Ham Hiep, Ham Phu, Ham Liem, along Ca Tot river, Ca Ty river, etc. Total surface area is about 1,414 km^2.

The compositions of the sediment include: the upper part is quartz sand, sand, clayey sand, siltstone, the lower part is pebbles, gravel, dark gray, yellowish gray, discrete texture. The thickness of the Pleistocene aquifer varies by region: in Ham Tan - Phan Thiet area, it is from 10m - 15m; in Bac Binh: from 8m - 12m; in Tuy Phong: from 5m - 14m.

The low-yield area is distributed in Vinh Hao, Lien Huong, Hong Thai, Phan Thiet, Tan Thang, Ham Tan, etc. The ingredient of sediments includes quartz sand, mixed sand, sand, and clay, which covers an area of about 1,634 square kilometers. The Pleistocene aquifer has a level of water from 1.5 m to 3.0 m. Experimental pumping results of wells in the Pleistocene aquifer showed that: discharge the wells varied from 0.07 liters to 0.91 liters per second, with an average of 0.31 liters per second; Permeability coefficient was from 1.0m to 2.0m per day.

Table 5. Experimental pumping results of pits and wells in water-poor regions of the Pleistocene aquifer (qp).

Value	Static Water Level (m)	Discharge (l/s)	Draw-down (m)	TDS (g/l)	permeability coefficient (m/ng)
pits					
Maximum	5.50	0.91	4.20	0.77	4.00
Minimum	0.90	0.07	1.11	0.067	0.84
Medium	2.64	0.31	1.73	0.29	1.68
wells					
Maximum	104.0	0.9	33.3	2.05	3.18
Minimum	0.2	0.04	0.09	0.02	0.01
Medium	4.89	0.32	8.00	0.52	0.63

- The test results of the water-pump showed: Average-yield water storage area has water level depth from 0.4m - 66.96m, the value from 3.0m to 6.0m.

Table 6. Experimental pumping results of pits and wells in high yield area of the Pleistocene aquifer (qp).

Value	Static Water Level (m)	Discharge (l/s)	Draw- down (m)	TDS (g/l)	permeability coefficient (m/ng)
Pits					
Maximum	4.10	2.56	2.31	1.69	9.60
Minimum	1.10	1.00	1.04	0.05	0.84
Medium	2.53	1.81	1.69	0.46	3.91
wells					
High	66.96	3.50	18.30	2.16	7.18
Low	0.40	1.00	1.10	0.044	0.167
Moderate	13.88	1.89	8.29	0.32	2.36

The Pleistocene aquifer was mainly super freshwater to freshwater, in some places, it is salt-water (M = 1.69 grams - 2.16 grams per liter). TDS was from 0.044 grams - 2.16 grams per liter, frequent values were from 0.2 grams - 0.5 grams per liter. Water in the Pleistocene aquifer changeed with the seasons, closely related to surface water and rainwater. The results of monitoring at wells HTM4 showed that the water level was highest in September (water depth: 0.23m) and lowest water level in April (water depth: 2.1m). Supply for Pleistocene aquifer was mainly surface water and rainwater. Most of the distributed area of the Pleistocene aquifers of Phan Thiet area was in the salinization. This was an important aquifer to provide domestic water, and social-economic development [16].

3.2. Water quality in Binh Thuan

The analysis results of 1949 water samples of the Holocene aquifer showed that there were 162 Samples beyond the limit. In which the COD indicator has the highest % samples beyond the limit (73.8%), there are 12 indicators % samples beyond the limit (Table 7).

Table 7. Underground analysis results of Holocene aquifer.

Nº	Parameter	Samples	Units	content			Vietnamese Standards: 09/2015/ MONRE	Samples beyond the limit	Samples beyond the limit
				Min	Max	medium			
1	pH	217		5.91	8.39	7.41	5.5 - 8.5	0	0
2	$CaCO_3$	191	mg/l	6.00	1944	110	500	3	1.6
3	TDS	217	mg/l	31.5	49436.0	1110.3	1500	20	9.2
4	Amonium (NH^{4+})	191	mg/l	0.007	0.21	0.06	0.1	40	20.9
5	Cl^-	217	mg/l	2.8	27882.4	542.4	250	36	16.6
6	SO_4^{2-}	191	mg/l	0.12	465.84	18.70	400	1	0.5
7	Total Fe	195	mg/l	0	11.13	0.84	5	3	1.5
8	NO_2	191	mg/l	0.01	1.14	0.06	1.0	1	0.5
9	NO_3	191	mg/l	0.08	68.20	4.61	15	16	8.4
10	COD	46	mg/l	0.00	192.40	31.01	4	36	78.3
11	F^-	8	mg/l	0.049	5.244	1.380	1.0	2	25
12	CN^-	8	mg/l	0.002	0.006	0.003	0.01	0	0
13	Phenol	8	mg/l	<0.001	<0.001	<0.001	0.001	0	0
14	As	8	mg/l	<0.001	0.023	0.001	0.05	0	0
15	Cd	8	mg/l	<0.001	0.002	<0.001	0.005	0	0
16	Pb	8	mg/l	<0.001	0.003	0.001	0.01	0	0
17	Cr^{6+}	8	mg/l	<0.001	<0.001	<0.001	0.05	0	0
18	Cu	8	mg/l	<0.001	0.002	0.001	1.0	0	0
19	Zn	8	mg/l	0.004	0.022	0.013	3.0	0	0
20	Mn	8	mg/l	0.028	0.617	0.173	0.5	1	12.5
21	Hg	8	mg/l	<0.001	<0.001	<0.001	0.001	0	0
22	Se	8	mg/l	<0.001	0.003	<0.001	0.01	0	0
23	E. Coli	3	MNP /100 ml	0	0	0	KPH	0	0
24	Coliform	3		4	1100	735	3	3	100
	Total	**1949**						**162**	

Analysis results of 1459 water samples of Pleistocene aquifer showed that 104 samples exceeded the limit. In which the COD parameter had the highest % of samples exceeding the limit (58.3%), there were 11 parameters that exceed the limit (Table 8). Therefore, the pollution level of the Holocene aquifer was higher than that of the Pleistocene aquifer. Compared with Vietnam standards 09/2015 of the Ministry of Natural Resources and Environment, coastal water quality tends to be salty polluted; The content of SO_4^{2-} and total Iron is higher than the standard.

Table 8. Results of underground analysis of Pleistocene aquifers.

No	Parameter	Samples	Units	Content			Vietnamese Standards: September 2015/Monre	Samples beyond the limit	Samples beyond the limit
				Min	Max	medium			
1	pH	151		5.33	9.77	7.31	5.5 - 8.5	1	0.7
2	$CaCO_3$	146	mg/l	5.00	1616	155	500	5	3.4
3	TDS	151	mg/l	35	6872	507	1500	12	7.9
4	Amonium (NH^{4+})	146	mg/l	0.004	0.21	0.05	0.1	18	12.3
5	Cl^-	151	mg/l	1.8	3483.6	155.2	250	21	13.9
6	SO_4^{2-}	146	mg/l	0.14	325.52	13.27	400	0	0
7	ΣFe	150	mg/l	0	12.68	0.62	5	3	2
8	NO_2	146	mg/l	0.01	1.13	0.06	1.0	1	0.7
9	NO_3	146	mg/l	0.08	290.40	13.07	15	23	15.8
10	COD	24	mg/l	0.06	51.30	10.85	4	14	58.3
11	F^-	8	mg/l	0.049	0.451	0.154	1.0	0	0
12	CN^-	8	mg/l	0.001	0.003	0.001	0.01	0	0
13	Phenol	8	mg/l	<0.001	<0.001	<0.001	0.001	0	0
14	As	8	mg/l	<0.001	0.003	<0.001	0.05	0	0
15	Cd	8	mg/l	<0.001	0.001	<0.001	0.005	0	0
16	Pb	8	mg/l	<0.001	0.001	<0.001	0.01	0	0
17	Cr^{6+}	8	mg/l	<0.001	0.001	<0.001	0.05	0	0
18	Cu	8	mg/l	<0.001	0.001	0.001	1.0	0	0
19	Zn	8	mg/l	0.005	0.055	0.024	3.0	0	0
20	Mn	8	mg/l	0.009	0.885	0.168	0.5	0	0
21	Hg	8	mg/l	<0.001	0.001	<0.001	0.001	0	0
22	Se	8	mg/l	<0.001	<0.001	<0.001	0.01	0	0
23	E. Coli	3	MNP	4	1100	521	KPH	3	100
24	Coliform	3	/100ml	93	1100	764	3	3	100
	Total	**1459**						**104**	

3.3. Saline Boundary

The analysis results of 24 parameters in Table 10 and Table 11, it shows that salinization of Holocene and Pleistocene aquifers has occurred. The Holocene aquifer has 20 saline samples, accounting for 9.2% of the total samples analyzed (Table 7). The Pleistocene aquifer has 12 samples that have exceeded the limit, accounting for 7.9% of the total samples analyzed. Thus, the saline level of the Holocene aquifer is higher than that of the Pleistocene aquifer.

One cause of salinization of aquifers in Binh Thuan province is that titanium mining enterprises have used sea water to select ore, seawater has infiltrated aquifers qh, qp. In addition, it is also contaminated with mineral oil and radiation (α, β), organic and bacteria [16]. From the resistivity survey results and sample analysis results (Table 7, Table 8), we have determined the saline intrusion boundary of Binh Thuan province. The saline boundary has $M \geq 1g/l$. In addition, at the saline sites, there were saline concentrations higher than 1g/l, which were outside this saline boundary (Figure 6).

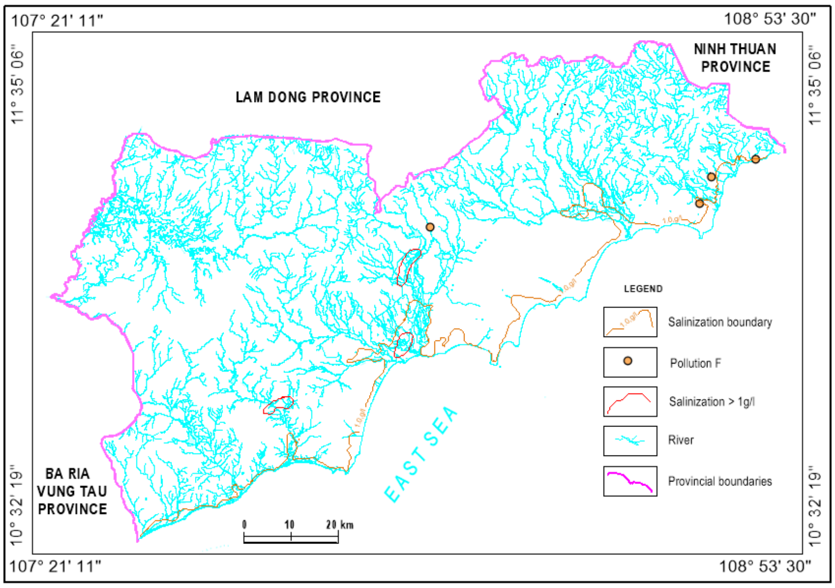

Figure 6. Map of groundwater pollution in Binh Thuan province.

3.4. Sustainable development of water resources solutions for Binh Thuan province

Domestic water shortage in Binh Thuan province often occurs in the dry season, in some areas people have to buy freshwater. Currently, Binh Thuan province also has no solution. Based on the Study of the characteristics of aquifers in Binh Thuan province, the authors have identified areas with water storage capacity (qp aquifer). These aquifers are distributed in Tuy Phong, Phan Thiet, Ham Tan.

Refer to the experience of some countries around the world [17–20]. The study has proposed solutions for sustainable development of water resources for Binh Thuan province as follows:

3.4.1. Planting forests to increase cover, prevent soil erosion, increase water storage capacity

- Planting forests to keep the land and prevent erosion

Experiments have proven that the force of rainwater falling on the forested area is much weaker than in the non-forested area due to the barrier of the forest canopy. Research results have also shown that the level of erosion in non-forested areas is 30 to 35 times higher than in forested areas.

- Forest canopy contributes to reducing floods and droughts

In places where there is no forest, when it rains heavily, the soil is eroded by rainwater, filling upriver beds and stream beds. When water does not drain in time, it overflows into low-lying areas causing flooding. Where there is no forest, the soil cannot hold water causing drought. In the dry season, the streams in Binh Thuan no longer have water, people dig holes in the stream bed but there is no water.

- Forests contribute to the protection of groundwater resources.

Rainwater falling into the forest will be partially retained and gradually wetted down to the soil and rock layers, forming underground flows, then flowing down to the low places to form rivers and streams. It is an important source of water for domestic and agricultural uses. Thus, forests not only reduce drought, but also protect groundwater.

3.4.2. Saving water in agricultural production such as drip irrigation, sprinkler irrigation

This is a highly effective method of Saving water. This method has been successfully applied in many countries around the world, such as Israel. Binh Thuan province is applying this method to agricultural production (Figures 7a-7b).

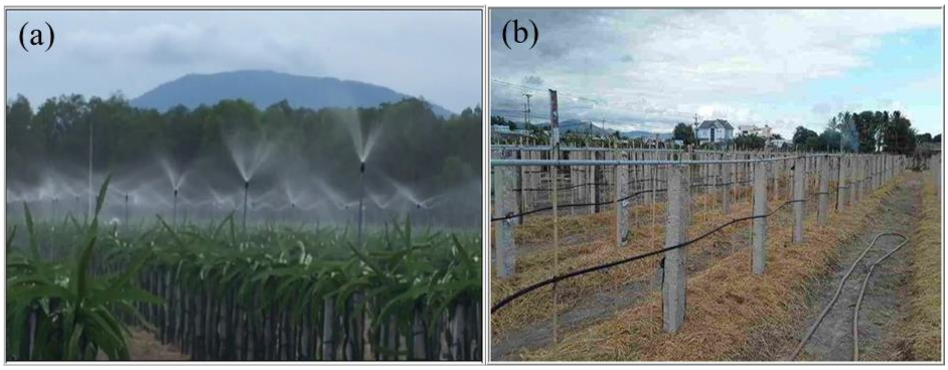

Figure 7. Save water in agricultural production: a) Sprinkler irrigation; b) Drip irrigation.

3.4.3. Not licensed to mine Titan in the coastal area

Binh Thuan is a province located in the drought areas of Vietnam. In the dry season, people often suffer from water shortages. Titan ore is distributed mainly along the 192 km coastline, located in the sand layers, with a total area of about 782 km^2. Distribution depth titanium ore from 30-50 m [21]. Mining titan consumes a lot of water. According to calculations, taking titanium ore in $1m^3$ of sand requires 2 m^3 of water. If mining titan huge impact on people's lives and economic sectors (agriculture, tourism, Commerce, wind electricity, forestry). Therefore, not licensed to mine Titan is necessary work.

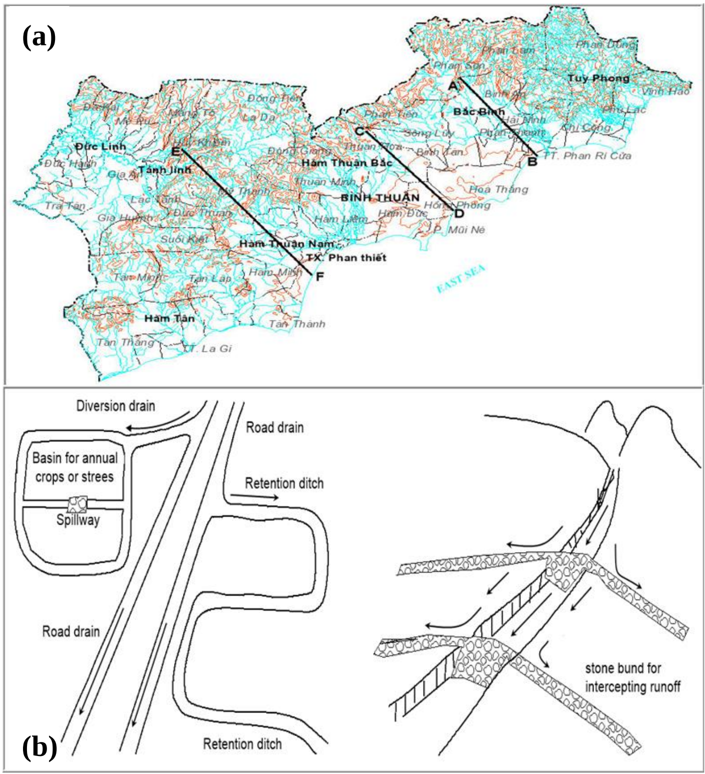

Figure 8. Lead rainwater along with the lines AB, CD, EF and store into the rainwater reservoir, do not allow water flows into the East Sea.

3.4.4. Build water storage, do not allow water flows into the sea

This is a model that has been successfully applied in the world [17–18, 21]. When the rainy season comes, many areas of Binh Thuan province are flooded (Ham Thuan Bac district, Tanh Linh district). We have studied geology, geomorphology, hydrogeology, structure of aquifers to come up with a plan to build water storage (on the face and under the ground).

Build concrete dam rainwater collection, prevents rainwater flow into the sea, preventing the salinization of seawater into the continent. We have designed for rainwater to flow along lines AB, CD, EF (Figure 8a). The water storage (Figure 8b) is arranged in appropriate positions on both sides of the axes AB, CD, and EF. That is the systems of rainwater retaining wall, reservoir rainwater, do not allow water flows into the East Sea.

3.4.5. Water replenishment for aquifers

The water replenishment for aquifers has been developed in several countries around the world [19–20]. The reference to the literature and the combination of our research results are the basis for us to choose the appropriate positions. Water replenishment was rainwater. Areas were selected based on the following conditions:

- Determine the permeability coefficient of the soil cover on the topographic surface in the selected areas for water storage.

- Check the wetting ability of the unsaturated zone and check for the existence of tarnished areas in the unsaturated zone that may adversely affect the water quality.

- Check the water transmission capacity of aquifers.

- Field investigation of geology, hydrogeology, geochemistry to select the distribution areas of surface sediments with high permeability coefficient in Binh Thuan. The results of Field investigation geology, hydrogeology determined that the sand strip at the seaside distributed from Phan Ri to Ham Tan - Binh Thuan, has satisfied the above conditions. These are suitable areas for the arrangement of construction systems that add rainwater to the qp aquifer. Rainwater is added to underground aquifers in the following manner:

- Create a rainwater reservoir at a location with a permeability coefficient of 2-7 m/day, rainwater will seep through the sand layers to the qh underground aquifer.

- Collect rainwater in the drainage ditch and put it in a suitable location to add rainwater for the underground aquifer (Figure 9).

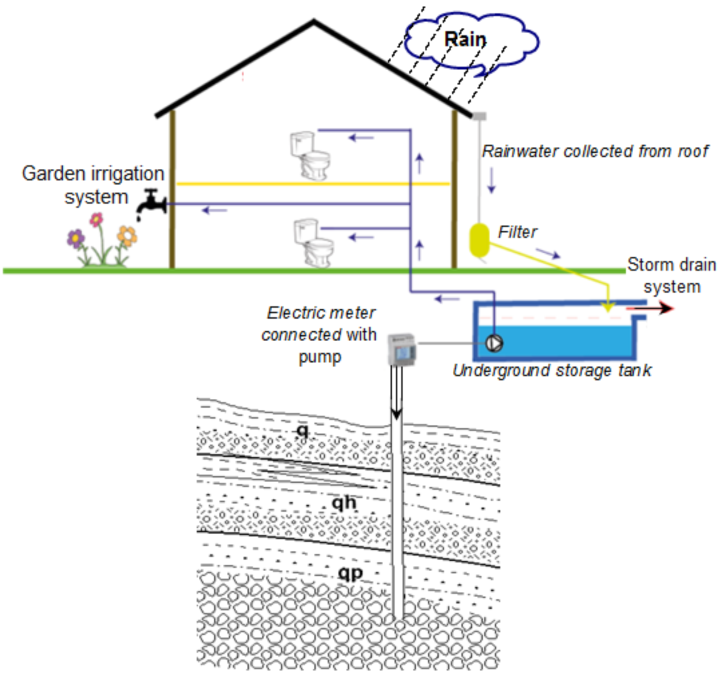

Figure 9. Rainwater collection for domestic water use and addition to aquifer qp.

- Build underground storage tanks under buildings for rainwater collection and add rainwater to the aquifer with wells (Figure 10).

According to [18], rainwater is collected into underground storage tanks, which then provides for the needs of use water in buildings. We recommend that it is necessary to design boreholes and an additional water pump to the qp aquifer (Figure 8 and Figure 9).

3.4.6. The subsurface dam method.

This method has been applied in some countries around the world such as India, Japan. In Vietnam, the model of an underground dam on sand, preventing water loss has been successfully built in My Thanh (Binh Thuan). The underground dam was made of bentonite soil cement with a length of 370m, a depth of 5m to 9.5m, forming a cobblestone tank with a capacity of nearly 200,000 m^3, ensuring the operation of My Thanh water plant for 3 months in the dry season [19, 21].

From this model, it can be extended to similar areas in the territory of Vietnam. In addition, it is possible to build a sand barrier dam at the foot of the coastal dunes of Binh Thuan province. This sand barrage traps rainwater contained in the sand layer and prevents seawater infiltration (Figure 10).

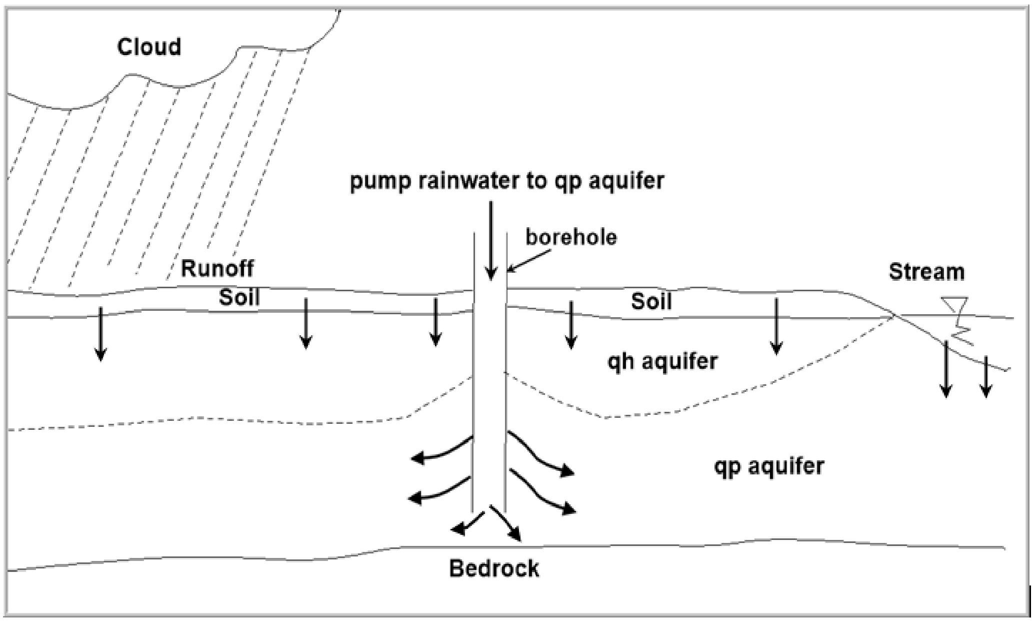

Figure 10. Rainwater addition to aquifer qp.

3.4.7. Sand dam

Binh Thuan province has many rivers. In the dry season, they have no water. The sand dam can be built for water storage. This model has been present in many countries around the world such as India, South Africa, Kenya (Figure 11).

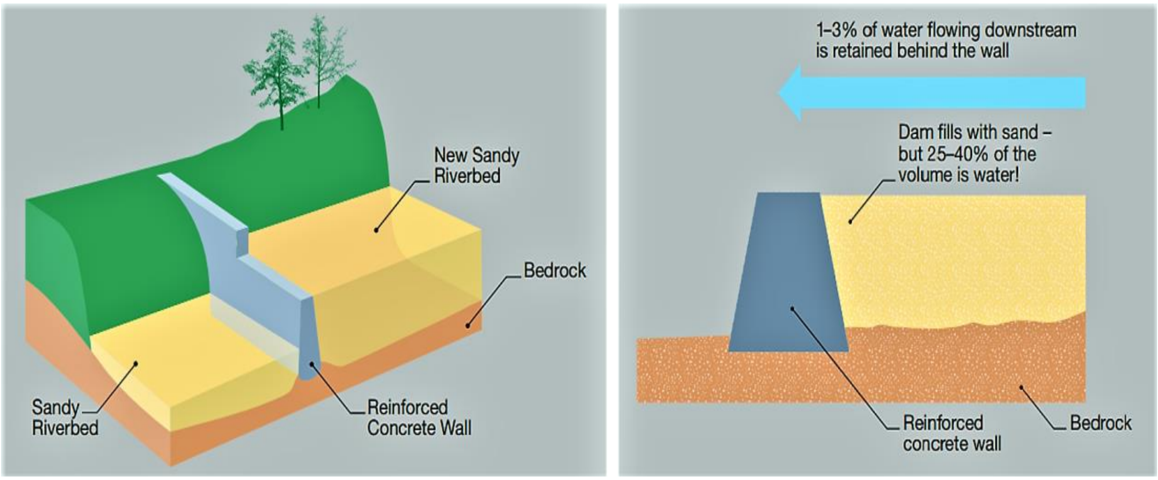

Figure 11. Left: Schematic cross-section of a sand dam. Right: Sand accumulates until the dam is completely full of sand up to the spillway. Water is stored within the sand, protected and filtered, making up to 40% of the total volume [19].

3.4.8. Manufacturing seawater purifier

Vietnam has successfully made seawater purifier into freshwater, power reached 91 million liters of fresh water per day, named "Made in Vietnam". Vietnam has exported seawater purifiers to Saudi Arabic. We also made this device, power from 400 m^3 to 600m^3 per day [20] (Figure 12). Seawater purifier has been installed in Binh Thuan, Ben Tre, and Can Tho provinces. The defect of this device is the high price.

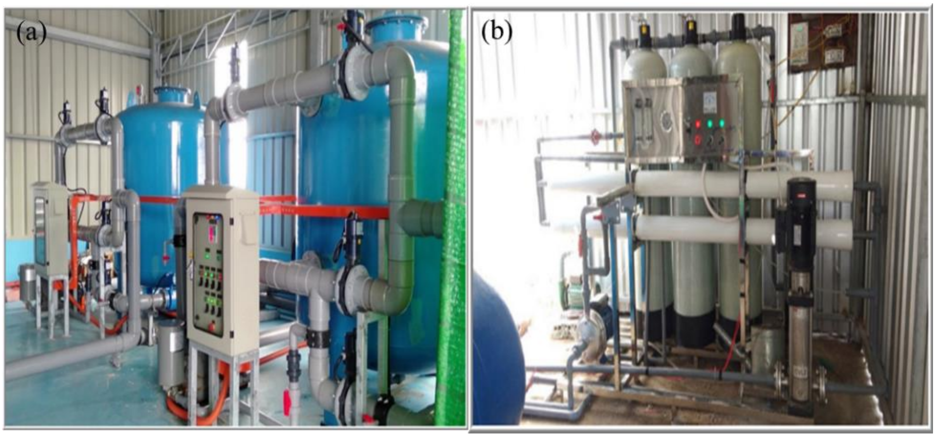

Figure 12. Seawater purifier [20].

4. Conclusions

Binh Thuan is the place with the least distribution of rainfall compared to other regions in the territory of Vietnam. The groundwater of Binh Thuan province is taken from Quaternary sediments and these aquifers have been polluted. Currently, the process of salinization into aquifers qh and qp is taking place strongly and tends to increase. Groundwater is mainly taken from qh and qp aquifers, some places have been polluted. The reserves of these two aquifers are not large because the aquifer has a thin thickness (from 3-5m to 30-50m). Water resources of Binh Thuan province are at high risk of being contaminated with mineral oil, radioactive (α, β), organic, bacterial, and salinity. Binh Thuan province often suffers from water shortage in the dry season and is at high risk of pollution. The authors' recommendations on mitigating water shortages were applied in Binh Thuan province. The collection of rainwater has been used, and at the same time, pumping rainwater into the qp aquifer, underground dam method, sand dam construction, construction of a rainwater drainage system in the Northwest - Southeast direction, increasing the mobility of water. Solutions for sustainable development of water resources not only help Binh Thuan province but also can be applied well to other provinces in the territory of Vietnam. The article studies the highly significant risk of groundwater pollution and provides an assessment of the possibility of groundwater pollution to have appropriate solutions to ensure sustainable development.

Authors contribution: Constructing research idea: H.P., T.T.M.H.; Select research methods: H.P; Data processing: H.P., T.T.M.H.; Sample analysis: H.P., T.T.M.H.; Take samples: H.P., T.T.M.H.; Writing original draft preparation: H.P., T.T.M.H.; Writing review and editing: H.P., T.T.M.H.

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Conflicts of interest: The authors declare that this article was the work of the authors, has not been published elsewhere, has not been copied from previous research; there was no conflict of interest within the author group.

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