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Research Paper

Evaluating Groundwater Quality in Bac Lieu Province Using Multivariate Statistical Method and Groundwater Quality Index

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Abstract
This study aimed to evaluate groundwater quality in Bac Lieu province, Vietnam using multivariate statistical methods and groundwater quality indices (GWQI). Eleven groundwater quality parameters including pH, chloride (Cl^-), total dissolved solids (TDS), nitrate ($N\text{-}NO_3^-$), ammonium ($N\text{-}NH_4^+$), sulfate (SO_4^{2-}), iron (Fe), manganese (Mn), Arsenic (As), hardness and coliforms were collected at seven monitoring sites in May 2020. These parameters were compared with the national technical regulation on groundwater quality (QCVN 09-MT:2015/BTNMT). Cluster analysis (CA) and principal component analysis (PCA) were used to elaborate on the groundwater quality variation and pollution sources. The results indicated that groundwater in the study area was polluted by $N\text{-}NH_4^+$ while other parameters were within the national regulatory limits. The high concentration of $N\text{-}NH_4^+$ could be attributed to intensive agricultural practices, especially fertilizer usage. CA results divided the monitoring sites into three clusters by the parameters of pH, $N\text{-}NO_3^-$, Cl^-, TDS, SO_4^{2-}, Fe, Mn, and hardness. The results of PCA revealed that the groundwater quality variation could be caused by four potential sources. The main parameters that influenced groundwater quality were pH, Cl^-, TDS, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, Fe, and Mn. The GWQI values were in the range of 2.0-12.6, which means that groundwater quality at all studied sites is of excellent quality. Preventive measures should be strictly implemented to avoid groundwater pollution since this water source is more pivotal under the effects of surface water pollution and climate change.

Keywords
Ammonium, Cluster Analysis, Groundwater, Principal Component Analysis

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1. INTRODUCTION

Bac Lieu province, a coastal province of the Mekong Delta, is located in the east of the Ca Mau peninsula, Vietnam. The province has a natural area of 266,900.08 ha. While the terrain is relatively flat and mainly situated at an altitude of about 1.2 m above sea level, the rest are dunes and some low-lying areas flooded all year round (Bac Lieu's People Committees, 2020). The terrain tended to slope from the coast to the inland, from the Northeast to the Southwest. This area has a tropical monsoon climate with two distinct seasons: the rainy season from May to November and the dry season from December to April. The hydrographic regime is directly influenced by the East Sea tides that are irregular semi-diurnal tides, and part of the West Sea tidal regime and the Mekong River flood. The regional economic growth rate continuously increases with the average rate of 8.35%/year from 2016 to 2020. Advanced technologies have been applied to local agricultural practices to improve productivity. Moreover, industry and construction are also promoting their potentials and strengths to develop the regional economy, especially in renewable energy and clean energy (Bac Lieu's People Committees, 2020). Urbanization has led to considerable population growth in urban areas, namely Bac Lieu city. As a result, this socio-economic growth has put great pressure on environmental quality by increasing waste generation from domestics, industries and other activities (Bac Lieu's People Committees, 2020).

Groundwater is the primary source of freshwater supply for domestic activities and industrial production in Bac Lieu province (Bac Lieu's People Committees, 2020). The province has about 104,601 drilled wells with an exploitation flow of about 257,918 m^3/day. The socio-economic development will put great pressure on groundwater resources. This water source plays an even more critical role in the current context of surface water pollution and climate change impacts such as saltwater intrusion and drought (Bac Lieu's People Committees, 2020). Therefore, groundwater quality assessment is of great concern to scientists. For example, groundwater quality in Dong Thap province was evaluated, and it was found that this water source was slightly polluted in the shallow layers due to domestic activities (Chan and Hoa, 2005). Groundwater quality in Can Tho city was contaminated by COD and coliform (Vinh, 2018). Ammonium and arsenic contamination of groundwater has been reported in An Giang province (Stanger et al., 2005; Thu et al, 2011; Phan and Nguyen, 2018). Nitrate was found the groundwater pollutants in China (Zhang et al., 2019), India (Raju and Singh, 2017). Previous studies have employed the national groundwater quality standards to evaluate groundwater quality. However, only a few studies have applied multivariate statistical approaches for the assessment of groundwater quality. This study assesses groundwater quality in Bac Lieu using multivariate statistics, including cluster analysis and principal component analysis, to determine groundwater quality characteristics and key criteria affecting groundwater quality. The current results could provide scientific information on the status of groundwater quality for management.

2. EXPERIMENTAL SECTION

Groundwater samples were collected at nine locations in Bac Lieu province in May 2020. These sampling locations were water supply stations in Bac Lieu city, Chau Hung town - Vinh Loi district, Hoa Binh town - Hoa Binh district, Phuoc Long town- Phuoc Long district, Ngan Dua town - Hong Dan district, Ward 1 - Gia Rai town, and Ganh Hao town - Dong Hai district. The physio-chemical parameter of groundwater including pH, chloride (Cl^-), total dissolved solids (TDS), arsenic (As), Nitrate ($N\text{-}NO_3^-$), ammonium ($N\text{-}NH_4^+$), sulfate (SO_4^{2-}), iron (Fe), manganese (Mn), hardness and coliforms were analyzed. Symbols and brief descriptions of sampling locations are shown in Table 1.

The methods of collecting and analyzing groundwater quality samples are presented in Table 2. The analysis results of groundwater quality parameters were compared with the national technical regulation on groundwater quality (QCVN 09-MT:2015/BTNMT). Limit values of water quality parameters are presented in Table 2. The data after measurement and analysis were synthesized and processed using Primer 5.2 software (PRIMER-E Ltd, Plymouth, UK). Based on the results of eleven groundwater parameters, monitoring sites shared with groundwater quality criteria are grouped using cluster analysis (CA) method. The principal component analysis (PCA) technique identified important groundwater quality parameters by reducing the contribution of less important variables without loss of information (Hajigholizadeh and Melesse, 2017; Varol, 2020). The groundwater quality index (GWQI) is an assessment technique that provides the aggregate influence of each quality parameter on the entire water quality. GWQI is a quantitative description of water quality and usability, expressed through a scale, which is an important parameter for zoning groundwater quality. The study calculated the GWQI values using the following Equation (1):

$$\mathrm{GWQI} = \frac{\sum_{n=1}^{10} (\mathrm{q}_n \mathrm{W}_n)}{\sum_{n=1}^{10} W_n} \tag{1}$$

where q_n is the sub-assessment quality index corresponding to the nth parameter; V_n is the test result of the nth parameter of a particular sample. W_n is the weight of the nth parameter which is presented in Table 3. S_n is the limit values of groundwater quality specified in QCVN 09-MT:2015/BTNMT. GWQI classifies groundwater into five levels. GWQI from 0-20 indicates excellent (level A); from 26-50 indicates good (level B); from 51-75 indicates poor (level C); from 76-100 indicates very poor (level D) and >100 indicates inappropriate for drinking (level E).

3. RESULTS AND DISCUSSION

As indicated in Table 4, the pH in groundwater at the survey sites ranged from 7.16 to 8.20, which was within the allowable limits of QCVN 09-MT:2015/BTNMT (pH 5.5-8.5). Previous studies showed that the pH in groundwater in An Giang ranged from 6.6-7.1 (Phan and Nguyen, 2018), pH in groundwater in Vinh Chau (Soc Trang Province, 2010) ranged from 6.9-7.7 (Giao et al, 2021). This fluctuation of pH value in the study area has not adversely affected human activities and the reactions with other toxic substances. In the aquatic environment, pH affects the solubility, dilution, and activity of toxic substances (Manahan, 2017). High pH is a necessary condition for arsenic to seep into groundwater (An Giang People's Committees, 2015). In natural water, the pH is usually in the range of 6.0-8.5 (Unicef, 2008).

Ammonium in groundwater at the study sites in Bac Lieu province was in the range of 0.4-2.7 mg/L (Table 4). Ammonium at all locations exceeded the allowable limit of QCVN 09-MT:2015/BTNMT (1 mg/L) from 1.8 to 2.7 times, with the exception of GW5 and GW6. Ammonium concentration in groundwater in An Giang ranged from 0.07-2.55 mg/L (Giao, 2021); in Vinh Chau, Soc Trang was 0.76-5.3 mg/L (Giao et al, 2021). At monitoring wells in Tra Vinh, ammonium concentrations ranged from 0-7 mg/L (Van Be, 2007). In An Giang, ammonium concentration in groundwater was detected up to 4 mg/L in some certain places where pig carcasses were buried due to African swine fever (Giao, 2021). Furthermore, ammonium concentration in groundwater is high due to influence from poultry, livestock, domestic waste, septic tank, and aquaculture activities (Danh, 2008). Mainly, in agricultural activities, fertilizer application for soil improvement and nutrient supply for plants also contributes to an increase in ammonium in groundwater.

Nitrate in groundwater at Bac Lieu ranged from 0.41-1.91 mg/L (Table 4). Nitrate at observation wells GW5, GW6, GW7 was significantly higher than that of other wells. It can be seen that most of the nitrogen present in groundwater in the study area is in the form of ammonium which may be

Table 1. Groundwater Sampling Locations

Code	Sampling Sites
GW1	Water Plant No. 1 - Ward 1, Bac Lieu City
GW2	Concentrated water supply station in Chau Hung town - Vinh Loi district
GW3	Centralized water supply station in Hoa Binh town - Hoa Binh district
GW4	Centralized water supply station Phuoc Long town - Phuoc Long district
GW5	Concentrated water supply station in Ngan Dua town - Hong Dan district
GW6	Centralized water supply station in Ward 1 - Gia Rai town
GW7	Centralized water supply station in Ganh Hao town - Dong Hai district

Table 2. Sample Analysis Methods and Limit Values of Groundwater

Parameter	Unit	Analytical Methods	Limit Value*
pH	-	TCVN 6492:2011	5.5-8.5
Cl^-	mg/L	TCVN 6194:1996	250
TDS	mg/L	SMEWW 2540B:2017	1500
As	mg/L	Spectrophotometer	0.05
N-NO_3^-	mg/L	SMEWW 4500-NO_3^-.E:2017	15
N-NH_4^+	mg/L	SMEWW 4500NH_3B&F:2017	1
SO_4^{2-}	mg/L	SMEWW 4500-SO_4^{2-}.E:2017	400
Fe	mg/L	TCVN 6177:1996	5
Mn	mg/L	Hach Method 8149	0.5
Hardness	mg/L	SMEWW 2340C:2017	500
Coliforms	MPN/100 mL	TCVN 6187-2:1996	3

Table 3. The Weight Factor of Groundwater Parameters

Parameter	S_n	$1/S_n$	W_n
pH	5.5-8.5	0.12	0.0051
Hardness	500	0.002	0.00008
TDS	1500	0.0007	0.00003
N-NO_3^-	15	0.067	0.03
N-NO_2^-	1	1	0.04
Fe	5	0.2	0.008
Mn	0.5	2	0.08
As	0.05	20	0.8
SO_4^{2-}	400	0.0025	0.0001
Coliform	3	0.33	0.01

due to the lack of dissolved oxygen to convert ammonium to nitrate. The allowable limit of nitrate in groundwater is 15 mg/L according to QCVN 09-MT:2015/BTNMT. The nitrate concentration in groundwater in Vinh Chau district, Soc Trang province ranges from 0.008-0.047 mg/L (Giao et al, 2021). In groundwater wells in An Giang, nitrate nitrogen ranged from 0.51 ± 0.42 to 1.55 ± 2.15 mg/L (Giao, 2021). In monitoring wells in Tra Vinh province, nitrate was up to 30 mg/L (Van Be, 2007). Nitrate in groundwater at the burial site of sick death pigs ranged from 0.011 to 2.96 mg/L (Giao, 2021). The nitrate concentration in groundwater in Pleiku city, Gia Lai is very high, in the range of 0.09-95.96 mg/L (Vinh, 2018). The results indicate that groundwater in many places in Vietnam has been polluted due to nutrient compounds.

Total dissolved solids (TDS) concentrations ranged from 286 to 715 mg/L (Table 4). TDS at all survey sites is within the allowable limit of QCVN 09-MT:2015/BTNMT (1500 mg/L). TDS in groundwater in An Giang fluctuated greatly, especially some wells up to 4516 mg/L (Phan and Nguyen, 2018), which is much higher than that found in the study area in Bac Lieu. The high level of TDS in groundwater are mainly due to the presence of sulfate ions, iron and sometimes dissolved arsenic.

Table 4. Groundwater Quality in Bac Lieu Province

Parameter	GW1	GW2	GW3	GW4	GW5	GW6	GW7
pH	7.99	7.16	8.11	7.25	7.35	8.03	8.2
Cl^-	130.5	73.7	98	175.8	221.2	22.7	65.2
TDS	608	599	655	508	715	286	773
As	0	0	0	0	0	0	0
$N\text{-}NO_3^-$	0.48	0.53	0.52	0.41	1.91	1.06	1.86
$N\text{-}NH_4^+$	2.7	1.9	2.2	2.2	0.7	0.4	1.8
SO_4^{2-}	122.42	137.6	97.95	54.13	99.08	36.9	111.18
Fe	0.094	0.062	0.041	0.109	0.084	0.063	0.119
Mn	0.063	0.041	0.028	0.052	0.035	0.01	0.03
Hardness	125	134	98	172	166	105	117
Coliforms	0	0	0	0	0	0	0
GWQI	12.6	8.5	9.9	10.1	3.5	2	8.7

The Cl^- concentration in groundwater in the study area varied from 22.7 mg/L (GW6) to 221.2 mg/L (GW5) (Table 4). At all locations, Cl^- concentration was within the allowable limit of QCVN 09-MT:2015/BTNMT (250 mg/L). In Vinh Chau, Soc Trang, this concentration in groundwater ranged from 115.7 to 171.5 mg/L (Giao et al, 2021). Besides, Cl^- concentration in groundwater between 35-135 mg/L can be considered normal, when the concentration of 250-400 mg/L water will have a salty taste (Unicef, 2008). Therefore, the water quality in the study area is almost unaffected by salinity. However, in the GW4 and GW5 wells, the chloride concentration has exceeded the standard threshold, making it difficult to use.

The sulfate concentration in groundwater ranged from 36.9 (GW6) to 137.6 mg/L (GW2) (Table 4). Sulfate concentration has a large variation between the study sites but is still within the allowable limit of QCVN 09-MT:2015/BTNMT (400 mg/L). Groundwater in locations with high chloride and sulfate concentration often leads to high TDS and high hardness. The hardness in groundwater at the study area ranged from 98 mg/L (GW3) to 172 mg/L (GW4) (Table 4). The hardness in groundwater wells of An Giang province ranged from 220.15 ± 128.20 to 1262.5 ± 1.13 mg/L (Giao, 2021). In general, the hardness in groundwater in this study is still within the allowable limit of QCVN 09-MT:2015/BTNMT (500 mg/L). The hardness of water is determined by the mineral concentration in the water, mainly Ca^{2+} and Mg^{2+}. High hardness in groundwater would degrade water quality, hence unsuitable water source for domestic purposes and costly to treat before use.

The results showed that the Fe concentration in groundwater ranges from 0.041 mg/L (GW3) to 0.119 mg/L (GW7) (Table 4) and had considerable variation among monitoring wells. Fe concentration in monitoring wells at Vinh Chau, Soc Trang ranged from 0.81 to 2.19 mg/L (Giao et al, 2021); Fe at wells in An Giang was 0.07-2.16 mg/L (Phan and Nguyen, 2018). In some groundwater wells in An Phu district, An Giang province, Fe concentration was up to 4.62 ± 6.48 mg/L (Giao, 2021). Fe concentration in groundwater at Tra Vinh ranged from 1.5 to 10 mg/L (Van Be, 2007). The results present that Fe concentration in groundwater in Bac Lieu province is much lower than previous studies and still within the allowable limit of QCVN 09-MT:2015/BTNMT with the permissible value of 5 mg/L. However, regular use of iron-contaminated water will cause accumulation, gradually causing significant impacts on health. Fe element is often present in groundwater as soluble or complex salts due to dissolution from mineral deposits in rocks or contamination of the water surface by wastewater (Manahan, 2017). The Mn concentration in groundwater in the study area ranged from 0.01 mg/L (GW6) to 0.063 mg/L (GW1) (Table 4). Mn at all locations has a very significant difference, however, it is within the allowable limit of QCVN 09-MT:2015/BTNMT (0.5 mg/L).

Arsenic in groundwater at monitoring wells of Bac Lieu province was below the detection limit. Previous studies have shown that toxic metal As often occurs in groundwater. Some groundwater wells in Tra Vinh province had As concentrations up to 60 μg/L (Van Be, 2007). The mean arsenic concentration in groundwater in An Giang province was up to 0.55 ± 1.21 mg/L (Phan and Nguyen, 2018). Groundwater contaminated by As has been becoming a major health risk in the Mekong Delta, Vietnam (Berg et al, 2007; Winkel et al., 2011). According to Berg et al (2007), arsenic concentrations in groundwater in the Mekong Delta ranged from 1 to 845 μg/L and averaged at 39 μg/L. This concentration was higher than the safety level for arsenic concentration in drinking water as recommended by World Health Organization (2008) and the Vietnamese government. The occurrence of As in groundwater study in An Giang province could cause carcinogenic risk for the human in which the cancer risks ranged from medium (8.66 x 10^{-4}) to high (8.26 x 10^{-2}) for both children and adults (Phan and Nguyen, 2018). As regulated by QCVN 09-MT:2015/BTNMT, As is still permitted in groundwater for drinking level at 50 μg/L. Due to its being highly toxic, this level is reduced to 10 μg/L for drinking water according to regulations of the EU and WHO. In this study, arsenic is still within the permissible limit of QCVN 09-MT:2015/BTNMT.

Coliform was not detected in groundwater in the study area (Table 4). The average coliform density in wells in An Giang during the period 2006-2016 was about 693.9 MPN/100 mL (Phan and Nguyen, 2018). The density of coliforms at the monitoring wells of Vinh Chau town in 2016 and 2018 was less than 3 MPN/100 mL, but in 2017 the observed concentration of coliforms was 5 MPN/100 mL, higher than the permitted limit of QCVN 09-MT:2015/BTNMT. The density of coliform in well water samples in the area affected by burying death pigs due to the epidemic (African swine fever) fluctuated considerably from 9 to 9,300 MPN/100 mL (Giao, 2021). Coliform in groundwater samples in 07 districts of Hanoi in 2018 ranged from 0-1,100 MPN/100 mL (Binh et al, 2019). According to research by Sánh et al. (2010), coliforms in well water in Tra Vinh province were contaminated with coliform with high density from 4 to 2,400 MPN/100 mL. Microbial contamination in groundwater is quite common in the Mekong Delta (Unicef, 2008; World Health Organization, 2008; Hoa, 2016) mainly because wells are improperly preserved (Unicef, 2008; An Giang People's Committees, 2015). Microbiological contamination in groundwater is one of the significant risks to human health during domestic uses.

The calculated GWQI in Table 4 showed that groundwater quality at all sampling locations is in excellent quality, with values ranging from 2.0 to 12.6. The groundwater quality in GW1, GW2, GW3, GW4, and GW7 was worse than in GW5 and GW6. The sources of groundwater pollution in Bac Lieu province include over-exploitation, which contributes to the saltwater intrusion into aquifers; activities of illegally converting forest agricultural land to aquaculture land, causing salinization of land resources, pulling the saline boundary deep into the underground water exploitation zone; surface water pollution due to domestic and industrial wastewater, and aquaculture wastewater; residues of pesticides and antibiotics in agricultural and aquaculture activities accumulate for a long time in the soil according to water sources, causing impacts on underground water resources; leachate from domestic waste, outdoor areas containing waste, industrial and handicraft production waste, livestock waste that have not been thoroughly treated (Bac Lieu's People Committees, 2020).

Seven monitoring sites were divided into three clusters at the Euclid distance of 4, as illustrated in Figure 1. Cluster 1 comprised only GW6, central water supply at Ward 1, Gia Rai town, Bac Lieu province. In this cluster, pH and nitrate were found to be higher compared to the other clusters (Table 5). However, the water quality in the cluster 1 was within the limit values of QCVN 09-MT:2015/BTNMT. Cluster 2 only included the sampling site GW4 where is

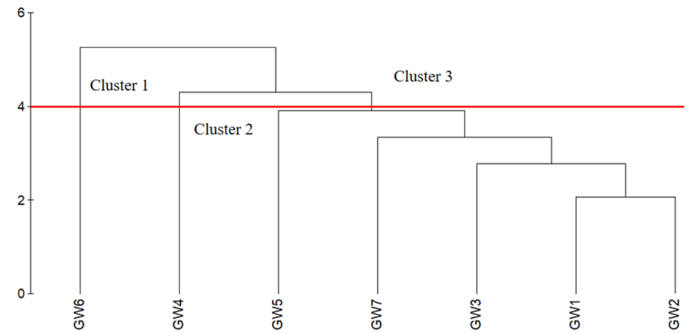

Figure 1. Clustering Groundwater Quality in The Study Area

in the central water supply at Phuoc Long town, Phuoc Long district, Bac Lieu province. This cluster was polluted by N-NH_4^+ and the groundwater quality parameters of Cl^-, TDS, SO_4^{2-}, Fe, Mn, hardness were much higher than the cluster 1 (Table 5). Cluster 3 included the monitoring sites GW1, GW2, GW3, GW5, GW7. This cluster was polluted by N-NH_4^+, and the groundwater quality parameters of Cl^-, TDS, N-NO_3^-, SO_4^{2-}, hardness were higher than those in cluster 1 and 2 (Table 5).

The PCA revealed that 6 PCs could explain 100% of the variation of groundwater quality in the study area (Table 6). PC1, PC2, PC3, PC4 significantly caused changes in groundwater quality by 37.8%, 24.1%, 19.9% and 11.4%, respectively. PC5 and PC6 only contributed to the change in groundwater quality in the study area by 5% and 1.8%, respectively. Four potential groundwater polluting sources were identified as PC1-PC4 since their Eigenvalues were greater than 1 (Kale et al., 2020). The weighted correlation coefficient of each PCs is used to provides information regarding the correlation between the groundwater quality variables and the potential polluting sources, hence becoming the main factors influencing groundwater quality in the study area. The weighted correlation coefficient is considered strong, moderate, and weak if the absolute value is > 0.75, 0.75-0.50 and 0.50-0.30, respectively (Chounlamany et al., 2017). PC1 was weakly correlated with Cl^-, TDS, Mn and hardness (Table 6). PC2 was also weakly correlated with pH, N-NO_3^-, SO_4^{2-}, hardness and moderately correlated with N-NH_4^+ (Table 6). PC3 was weakly correlated with pH and moderately related to TDS and N-NO_3^-. PC4 was weakly impacted by pH and SO_4^{2-} while it was moderately controlled by Fe. PC5 was moderately correlated with Cl^- while weakly correlated to pH, SO_4^{2-} and Fe. PC6 was weakly influenced by TDS, N-NH_4^+, SO_4^{2-} while it was moderately modified by Mn (Table 6). Moreover, pH was influenced by PC1-PC5. Cl^- was weakly and moderately impacted by PC1 and PC5, respectively. TDS was weakly correlated with PC1 and PC6 while moderately correlated with PC3. N-NH_4^+ was moderately influenced by PC2 and weaky influenced by PC6. SO_4^{2-} was weakly modified by

Table 5. Groundwater Quality in The Clusters

Parameters	Cluster 1	Cluster 2	Cluster 3	Limit Values
pH	8.03	7.25	7.76	5.5-8.5
Cl^-	22.7	175.8	117.7	250
TDS	286	508	670	1500
As	0	0	0	0.05
$N\text{-}NO_3^-$	1.06	0.41	1.06	15
$N\text{-}NH_4^+$	0.35	2.15	1.82	1
SO_4^{2-}	36.9	54.13	113.6	400
Fe	0.06	0.11	0.08	5
Mn	0.01	0.052	0.04	0.5
Hardness	105	172	128	500
Coliforms	0	0	0	3

Table 6. Key Parameters Influencing Groundwater Quality in Bac Lieu Province

Parameters	PC1	PC2	PC3	PC4	PC5	PC6
pH	0.31	0.324	0.305	0.409	0.455	-0.29
Cl^-	-0.424	-0.273	0.003	-0.109	0.679	-0.179
TDS	-0.309	0.203	0.52	-0.218	0.188	0.482
$N\text{-}NO_3^-$	0.046	-0.319	0.654	-0.004	-0.059	-0.16
$N\text{-}NH_4^+$	-0.29	0.521	-0.145	0.232	0.094	0.417
SO_4^{2-}	-0.255	0.408	0.268	-0.445	-0.374	-0.379
Fe	-0.286	-0.134	0.257	0.7	-0.37	0.049
Mn	-0.472	0.206	-0.195	0.178	0	-0.542
Hardness	-0.415	-0.423	-0.108	0.004	-0.083	0.113
Eigenvalues	3.41	2.17	1.79	1.02	0.45	0.16
%Variation	37.8	24.1	19.9	11.4	5	1.8
Cum.%Variation	37.8	62	81.8	93.2	98.2	100

PC2, and PC4 to PC6. Fe was weakly controlled by PC5, moderately correlated with PC4. Mn was weakly influenced by PC1 while moderately impacted by PC6. Hardness was weakly affected by PC1 and PC3. In this study, the parameters of pH, Cl^-, TDS, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, Fe, and Mn were the main parameters influencing groundwater quality in the study area.

4. CONCLUSIONS

The results of this study revealed that groundwater in all sampling sites was polluted by $N\text{-}NH_4^+$. High $N\text{-}NH_4^+$ concentration was found in Water Plant No. 1, Bac Lieu City (GW1), Chau Hung Town Water Supply Center, Vinh Loi District (GW2), Hoa Binh Town Water Supply Center, Hoa Binh district (GW3), concentrated water supply station in Phuoc Long town, Phuoc Long district (GW4) and concentrated water supply station in Ganh Hao town, Dong Hai district (GW7). It is the result of agricultural activities, namely the overuse of fertilizers to improve the soil and provide nutrients for plants. However, the values of GWQI (2.0-12.6) showed that groundwater quality at all sampling locations is of excellent quality. CA results divided the monitoring sites into three clusters. In cluster 1, pH and nitrate were higher than those in other clusters. Cluster 2 was polluted by $N\text{-}NH_4^+$, and the parameters of Cl^-, TDS, SO_4^{2-}, Fe, Mn, and hardness were much higher than cluster 1. Cluster 3 was also polluted by $N\text{-}NH_4^+$, and the groundwater quality parameters of Cl^-, TDS, $N\text{-}NO_3^-$, SO_4^{2-}, and hardness were higher than those in clusters 1 and 2. PCA revealed that 6 PCs explained 100% of the variation of groundwater quality in the study area in which PC1, PC2, PC3, PC4 significantly caused changes in groundwater quality. The main parameters influencing groundwater quality in the study area were pH, Cl^-, TDS, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, Fe, and Mn.

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REFERENCES

Berg, M., C. Stengel, P. T. K. Trang, P. H. Viet, M. L. Sampson, M. Leng, S. Samreth, and D. Fredericks (2007). Magnitude of Arsenic Pollution in the Mekong and Red River Deltas-Cambodia and Vietnam. *Science of The Total Environment*, **372**(3); 413–425

Binh, P.T.X, Quynh, L.T.P., Huong, P.T.M (2019). Initial Survey of Microbial Density in Domestic Water in Some Districts in Hanoi City. *Science and Technology Magazine*, **55**; 99–102

Chan, N.D and Hoa, D.T.T (2005). Evaluation of Groundwater Quality in Dong Thap Province, Southern Vietnam. *Federation of Hydrogeology-Engineering Geology*

Stanley, M(2017). *Environmental Chemistry*. Boca Raton: Scientific and Technical

Chounlamany, V., M. A. Tanchuling, and T. Inoue (2017). Spatial and Temporal Variation of Water Quality of A Segment of Marikina River Using Multivariate Statistical Methods. *Water Science and Technology*, **76**(6); 1510–1522

An Giang People's Committees (2015). *Report on The State of Environment in Five Years (2011 - 2015) of An Giang Province*. Technical report

Bac Lieu's People Committees (2020). *Five Year (2015-2022) Environmental State Report*. Technical report

Danh, V.T (2008). *Household Switching Behavior in The Use of Ground Water in The Mekong Delta, Vietnam*. EEPSEA, IDRC Regional Office for Southeast and East Asia, Singapore

Giao, N.T (2021). Chemical And Microbial Characteristics of Surface And Ground Water in The Areas Burying Swine Infected with African Swine Fever in An Giang Province, Vietnam. *Journal of Energy Technology and Environment*, **3**; 1–10

Giao N.T., Them, L.T.H., Ly, L.N.T (2021). Survey on Current Status of Management, Exploitation, Use and Quality of Groundwater in Vinh Chau, Soc Trang. *Journal of Agriculture and Rural Development*, **11**; 162–169

Hajigholizadeh, M. and A. M. Melesse (2017). Assortment and Spatiotemporal Analysis of Surface Water Quality Using Cluster and Discriminant Analyses. *Catena*, **151**; 247–258

Hoa, V (2016). *Evaluation of Management Activities and Quality of Rural Water Supply from Groundwater in Tien Giang Province*. Master's thesis, Can Tho University

Kale, A., N. Bandela, J. Kulkarni, and K. Raut (2020). Factor Analysis and Spatial Distribution of Water Quality Parameters of Aurangabad District, India. *Groundwater for Sustainable Development*, **10**; 100345

Soc Trang Province Department of Natural Resources and Environment (2010). *Report on the investigation of the status of Groundwater. Project: Planning for Exploitation, Use and Protection of Groundwater Resources in Soc Trang Province until 2020*. Technical report

World Health Organization (2008). *Guidelines for Drinking-Water Quality - Volume 1: Recommendations Third Edition, Incorporating First and Second Addenda. Geneva: World Health Organization*. Technical report

Phan, K. A. and T. G. Nguyen (2018). Groundwater Quality and Human Health Risk Assessment Related to Groundwater Consumption in An Giang Province, Vietnam. *Journal of Vietnamese Environment*, **10**(2); 85–91

Raju, A. and A. Singh (2017). Assessment of Groundwater Quality and Mapping Human Health Risk in Central Ganga Alluvial Plain, Northern India. *Environmental Processes*, **4**(2); 375–397

Sánh, N. V., N. Son, V. Tuan, and L. Khoi (2010). Research on Water Resources in Tra Vinh: Current Status of Exploitation, Use and Solutions for Sustainable Use Management. *Journal of Science, 15b*, **15**; 167–177

Stanger, G., T. Van Truong, K. L. T. M. Ngoc, T. Luyen, and T. T. Thanh (2005). Arsenic in Groundwaters of The Lower Mekong. *Environmental Geochemistry and Health*, **27**(4); 341–357

Thu, T.A., Tinh, T.K., Minh, V.Q (2011). Research on Sources of Arsenic Contamination in Groundwater in An Phu District, An Giang Province. *Journal of Science Can Tho University*, **17**; 118–123

Unicef (2008). *Arsenic Primer: Guidance for UNICEF Country Offices on the Investigation and Mitigation of Arsenic Contamination. Water, Environment and Sanitation Section Programme Division UNICEF New York*. Technical report

Van Be, T. and Tuyen, T.T (2007). Status of Exploitation, Management and Quality of Sand Dune Groundwater in Tra Vinh Province. *Journal of Science Can Tho University*, **8**; 95–104

Varol, M (2020). Spatio-Temporal Changes in Surface Water Quality and Sediment Phosphorus Content of A Large Reservoir In Turkey. *Environmental Pollution*, **259**; 113860

Vinh, L. T., D.C (2018). Nitrate Concentrations in Shallow Groundwater in HCMC Pleiku, Gia Lai. *Journal of Science and Technology University of Danang*, **3**; 116–118

Winkel, L. H., P. T. K. Trang, V. M. Lan, C. Stengel, M. Amini, N. T. Ha, P. H. Viet, and M. Berg (2011). Arsenic Pollution of Groundwater in Vietnam Exacerbated by Deep Aquifer Exploitation for More than a Century. *Proceedings of The National Academy of Sciences*, **108**(4); 1246–1251

Zhang, Q., P. Xu, and H. Qian (2019). Assessment of Groundwater Quality and Human Health Risk (HHR) Evaluation of Nitrate in The Central-Western Guanzhong Basin, China. *International Journal of Environmental Research and Public Health*, **16**(21); 4246

