

Groundwater quality analysis in dry seasons in Panggang Cay, Kepulauan Seribu, Jakarta, Indonesia

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Abstract. Panggang Cay is a very small island (smaller than 100 km²) with the highest population density in Kepulauan Seribu, Jakarta. Like other very small islands in the world, it has insufficient water resources, which worsen during dry seasons. This study aimed to analyze the groundwater quality in Panggang Cay in dry seasons. The groundwater quality was determined based on the physical, chemical and biological characteristics and their positions against the thresholds set in the drinking water quality standards in Indonesia. The results showed that in dry seasons the groundwater salinity, as represented by the electrical conductivity, ranged from slightly brackish to saline. Some of the parameters exceeded the drinking water quality standards, namely Calcium, Magnesium, Potassium, Sodium, Chloride, BOD, COD, and Total Coliform. This finding indicates that seawater intrusion and domestic waste have contaminated the groundwater in Panggang Cay.

1. Introduction

Very small islands are not larger than 100 km² in size [1,2]. They have one common problem of limited water resources [3,4,5]. The reasons behind it are because they have (1) small catchment areas, (2) generally lower rainfall than large islands, (3) the influence of seawater intrusion as they are surrounded by the sea, and (4) the absence of groundwater recharge or flow from other regions [1,2,6,7,8,9].

Panggang Cay, located in Kepulauan Seribu Regency, Jakarta (Figure 1), is one of many very small islands in Indonesia. Geologically, it is a patch reef composed of limestone as bedrock and bioclastic materials on the surface [10]. Being the first inhabited cay in Kepulauan Seribu, it becomes the most densely populated one among the other 100 islands in this regency. It only covers an area of 9 hectares, but the population size is up to 4,000 people [11]. The high population density is also evident from the presence of settlement as the dominant land use, which extends over 74% of its total area [12].



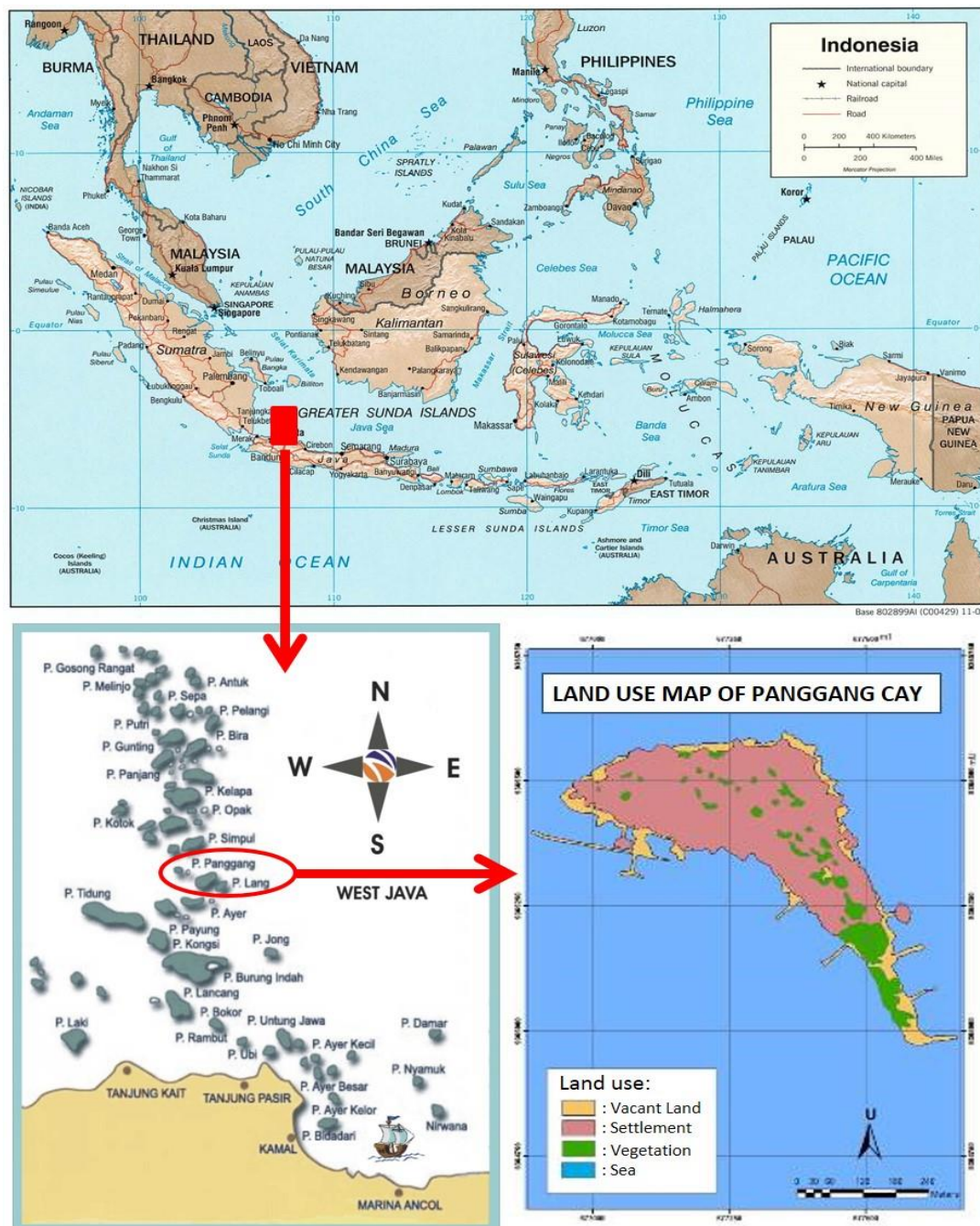


Figure 1. Research area.

Despite its limited area, the population of Panggang Cay continues to grow from year to year [11]. This growth will undoubtedly lead to increased resource utilization. Groundwater is one of the resources that must receive particular attention [13,14,15]. Population growth affects the amount of water demand for domestic use and other purposes that support various human activities and, therefore, increases the threats to groundwater resources [16,17], for instance, anthropogenic contamination and seawater intrusion due to excessive pumping. This situation deteriorates in dry seasons when groundwater recharge, i.e., rainwater, is not available [18]. This study aimed to analyze the condition of groundwater quality in Panggang Cay in dry seasons. The results are expected to

provide an insight into water resources management planning and mitigation efforts hydrological drought in very small cay like Panggang Cay.

Methods

The water quality in Panggang Cay was determined from the chemical, biological and physical analysis of the groundwater samples. This study drew eight (8) samples from shallow wells that were assumed to represent the edge and the middle of the cay. It examined several water quality parameters, namely pH, major elements (i.e., calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride), BOD, COD, total coliform, and electrical conductivity to reflect groundwater salinity levels. It also referred to the water quality standards issued in the Regulation of the Minister of Health No. 90/2002 and Government Regulation No. 20/1990, as well as the water quality requirements for drinking water used by experts [19] mainly for parameters excluded in the first two directives. This study also used the triangular and rectangular Piper diagrams to thoroughly analyze the process taking place in the groundwater using [13,16,20,21,22].

Results and Discussion

The groundwater quality analysis revealed that some of the parameters exceeded the thresholds for drinking water, indicating damages to the groundwater resources in Panggang Cay. These parameters, the red-highlighted cells in Table 1, were calcium, magnesium, sodium, potassium, BOD, COD, and Total Coliform. In addition to signifying the occurrence of groundwater pollution by seawater intrusion, these findings imply that human (domestic) activities have contaminated the groundwater. This condition is evident from the exceeded BOD and COD thresholds and the high total coliform.

Table 1. The results of groundwater quality analysis in Panggang Cay.

No.	pH	Ca ²⁺ (mg/l)	Mg ²⁺ (mg/l)	Na ⁺ (mg/l)	K ⁺ (mg/l)	HCO ₃ ²⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	Cl ⁻ (mg/l)	BOD (mg/l)	COD (mg/l)	Total Coliform
1	8.13	370	399	495.8	59.5	380	62.1	2,680	3.32	997.00	39
2	8.39	300	832	581.3	60.7	192	78.8	4,180	4.70	14.10	11
3	7.87	280	750	543.0	58.7	332	61.9	3,890	10.78	32.33	22
4	7.93	350	796	422.8	60.0	324	68.5	3,910	5.43	16.29	Absent
5	8.35	400	881	267.4	60.0	268	65.9	3,540	11.18	33.54	11
6	8.19	320	700	467.2	60.7	236	70.9	3,130	5.51	16.59	4
7	8.44	230	587	537.2	58.2	228	25.8	3,200	2.27	6.81	13
8	8.43	280	556	424.0	58.2	228	6.7	3,200	1.70	5.10	52
Standards	6.5-8.5 ^a	100 ^c	50 ^c	200.00 ^a	50.00 ^c	500 ^c	250 ^a	250 ^a	6.0 ^b	10 ^b	Absent ^b

Notes: ^aThe Regulation of Indonesian Minister of Health No. 90/2002, ^bGovernment Regulation No. 20/1990, ^cTodd & Mays (2004)

The high calcium level in the groundwater may be caused by its natural occurrence on Earth. The same case is found in Pramuka and Pari Cays that geologically resemble the genesis and the constituent materials of the aquifer in Panggang Cay [23,24]. The aquifer is primarily composed of CaCO₃-rich bioclastic materials [25,26], which are the primary source of calcium abundance in the groundwater.

The high level of magnesium, sodium, potassium, and chloride reflects the influence of seawater intrusion on groundwater [21,27,28,29]. In Panggang Cay, these ions were found way above the water quality standards. For instance, the concentration of chloride was 12 times higher than its allowed presence in drinking water. The high electrical conductivity (EC) affirmed this condition (Figure 2).

The map of EC-based groundwater salinity shows that the EC values vary between 4,500 µS/cm and 35,000 µS/cm (Figure 2.). The low EC values are distributed in the middle of the cay. This part of the cay is likely the least affected area by the seawater; therefore, its electrical conductivity is the smallest. The same pattern is found in Pramuka and Pari Cays [24,30]. On the contrary, the high EC values along the edge of the cay represent the effects of excessive groundwater withdrawal particularly for domestic purposes, except for drinking water, which relies on bottled water sent from outside the

cay. The growing population considerably increases the water demand and potentially leads to seawater intrusion due to groundwater extraction.

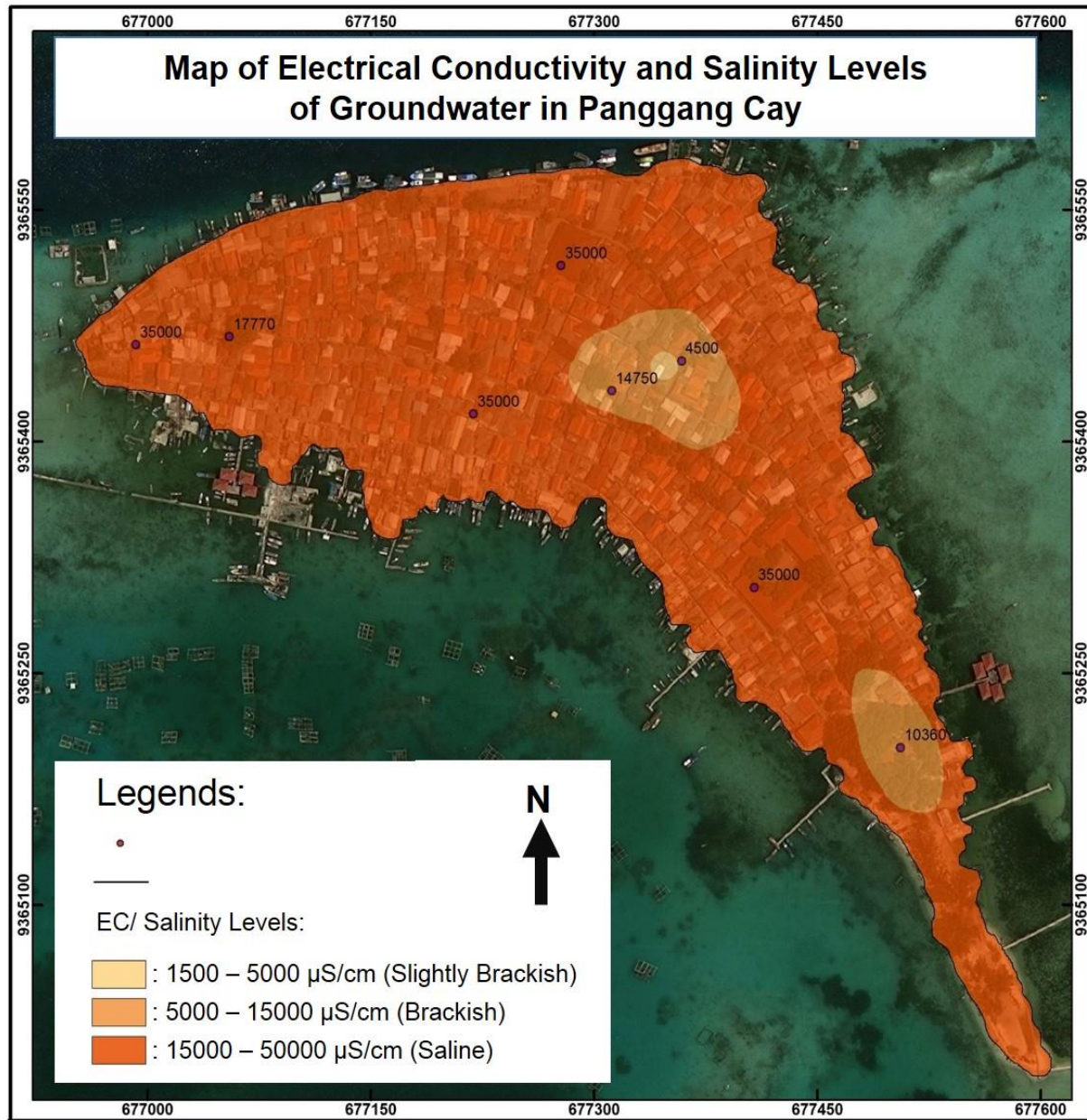


Figure 2. The spatial distribution of groundwater salinity and electrical conductivity in Panggang Cay.

The EC measurement results were analyzed by initially dividing them according to the classification of EC-based groundwater salinity, namely slightly brackish, brackish, and saline water (Table 2). The analysis confirmed that the salinity level was within the range of slightly brackish and saline (Figure 2), signifying the absence of fresh groundwater in Panggang Cay. As a conclusion, the groundwater in this cay is not safe for consumption (drinking water).

The triangular Piper diagram of the groundwater quality parameters (Figure 3) depicts a cluster of groundwater samples containing high levels of calcium and magnesium (Type H). Aside from these two cations, seawater intrusion is indicated by chloride. The diagram also presents chloride enrichment in the groundwater due to natural process (Type F).

Table 2. The classification of salinity level based on electrical conductivity.

Salinity Levels	Electrical Conductivity ($\mu\text{S/cm}$)
Fresh Water	$< 1,500$
Slightly Brackish Water	$> 1,500 - \leq 5,000$
Brackish Water	$> 5,000 - \leq 15,000$
Saline Water	$> 15,000 - \leq 50,000$

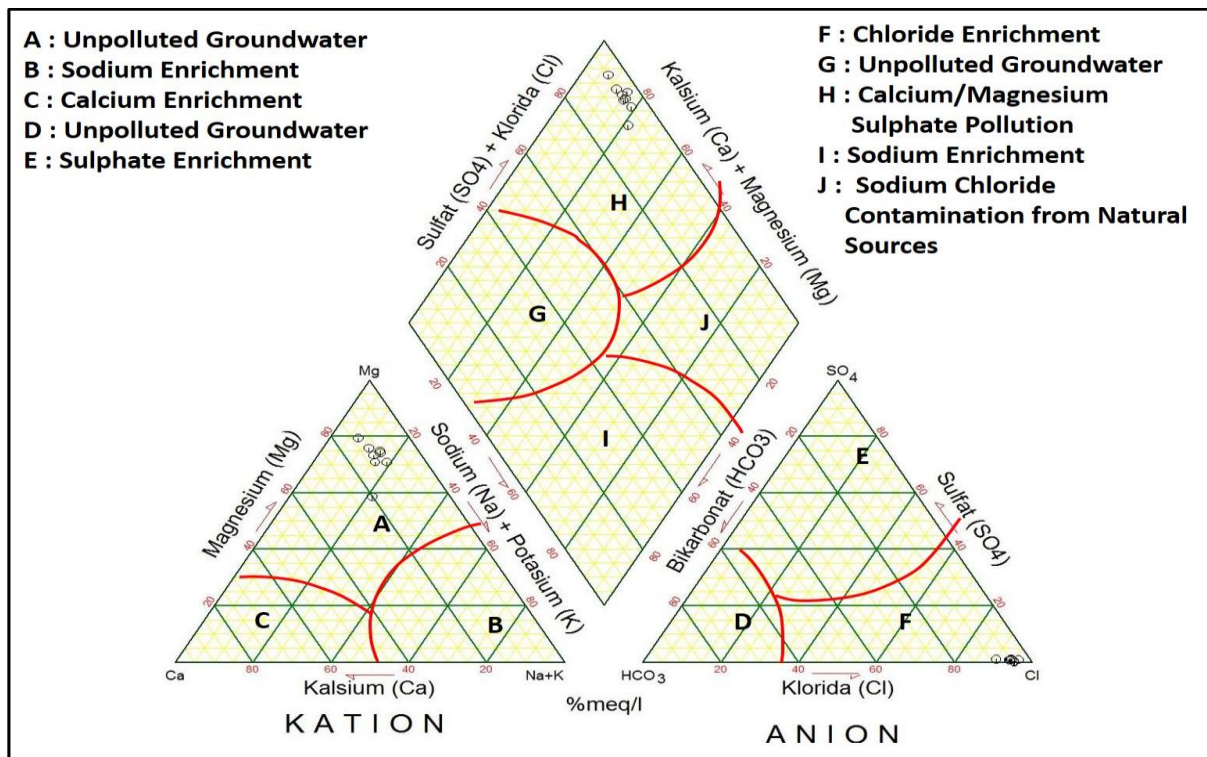


Figure 3. The triangular piper diagram of the hydrochemical characteristics of the groundwater in Panggang Cay.

The rectangular Piper diagram strongly supports the results of the previous discussion (Figure 4). All of the groundwater samples (marked with red dots) occupy the section of saline water (Type VI). This type of groundwater develops due to the influence of seawater intrusion. Other studies in Panggang, Pramuka, and Pari Cays in 2017 affirm that the seawater intrusion process changes the water type from CaCO_3 to MgCl_2 [7,10,23,24,29]. Also, previous research concludes that the densely populated cays in Kepulauan Seribu are adversely affected by moderate to severe case of seawater intrusion [7,10,24].

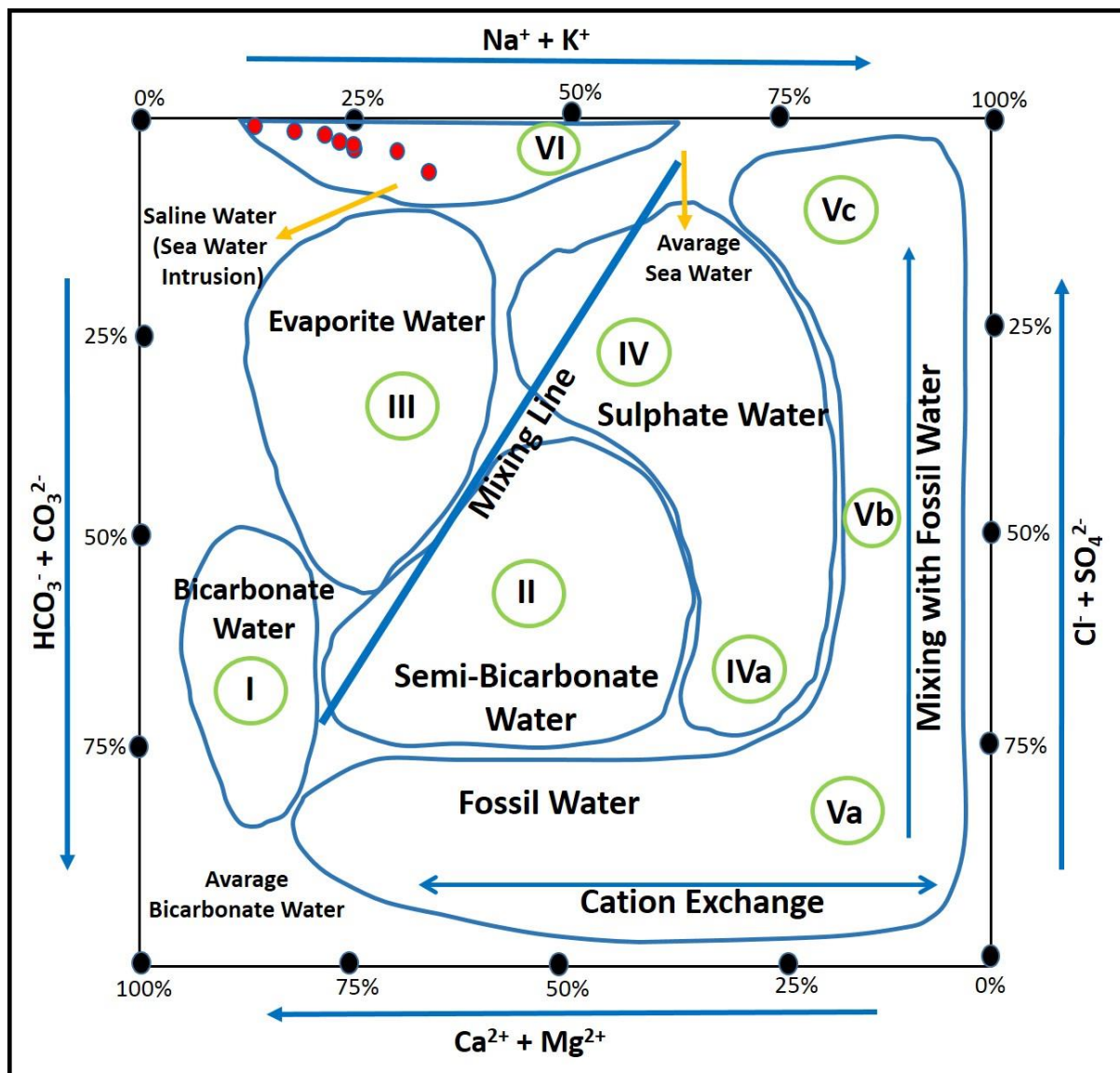


Figure 4. The rectangular piper diagram of the hydrochemical characteristics of the groundwater in Panggang Cay.

Conclusions

The analysis revealed that the groundwater in Panggang Cay was contaminated. The pollution occurred as a result of (1) seawater intrusion (as evidenced by high levels of magnesium, sodium, potassium, and chloride) and (2) domestic waste pollution (as indicated by high BOD, COD, and total coliform). Contamination by seawater intrusion in Panggang Cay is corroborated by the triangular Piper diagram that illustrates the presence of chloride enrichment by natural causes, as well as by the rectangular Piper diagram that shows groundwater samples clustered in Type-VI groundwater (saline water) due to the effects of seawater intrusion. As a conclusion, the groundwater in Panggang Cay in dry seasons is not safe for drinking water sources.

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