Jurnal Pendidikan Geografi:
Kajian, Teori, dan Praktik dalam Bidang Pendidikan dan Ilmu Geografi, 29(1), 2024, 28-42
ISSN: 0853-9251 (Print): 2527-628X (Online)
DOI: 10.17977/um017v29i12024p28-42

Groundwater quality in coastal area: A case study in Parangtritis Village, Bantul, Yogyakarta, Indonesia

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Paper received: 16-10-2023; revised: 01-12-2023; accepted: 11-01-2024

Abstract

Groundwater in coastal areas is one of the natural resources that is vulnerable to quality degradation due to population activities in coastal areas. This is also the case in Parangtritis Village, a coastal area with various potential regions for the population's welfare, ranging from tourism to agriculture, animal husbandry, and fisheries. Therefore, this study explores groundwater quality in Parangtritis Village, Kretek District, Bantul Regency, Yogyakarta. Groundwater quality data was collected through field surveys based on land use, with water quality parameters including odor, color, nitrate, nitrite, and E. coli. The Minister of Health Regulation Document Number 32 of 2017 was adopted as a benchmark for groundwater quality in the research area. Further, by using the gathered data, the groundwater quality was classified based on limiting parameters. Groundwater quality is distributed based on limiting parameters such as odor, color, nitrite, and E. coli bacteria. Odor and color limitations are found in agricultural areas, tourism areas, and fish farms. Nitrite limitations are found in residential and livestock areas. E. coli bacteria limitations are found in all land use areas.

Keywords: groundwater quality; coastal; land use

1. Introduction

Parangtritis Village is situated in Kretek District, Bantul Regency, Yogyakarta Special Region, Indonesia. Following the literature, Parangtritis Village is part of the southern coastal region of Java, which is characterized by the presence of landform units such as fluviomarine plains, bank shoals, bank, and sand dune complexes (Parangtritis Geomaritime Science Park and Geospatial Information Agency, 2016; Santosa, 2016). The tourism sector in Parangtritis Village has flourished due to its natural landscapes, including sand dunes and beaches, as well as various historical landmarks that are easily accessible. This growth began with the inauguration of Depok Beach in 1998 (Parangtritis Geomaritime Science Park and Geospatial Information Agency, 2016). According to data published in 2020, the area designated for tourism activities in Parangtritis Village covers 125 hectares (Parangtritis Sub-district, 2020). Parangtritis Village's economy is supported not only by the tourism sector but also by food crop agriculture, animal husbandry, and ponds. According to the village potential data in 2020 (Parangtritis Sub-district, 2020), 2501 families cultivate food crops on land ranging from one to 10 hectares. The livestock raised include cows, buffalo, goats, horses, free-range chickens, broiler chickens, and geese, with a total of 4102 owners.

Parangtritis Village offers various potential areas that can benefit the population, including tourism, agriculture, livestock, and fisheries. According to a study conducted by Putri and Wicaksono (2021), economic activities have led to changes in land use on the southern side of Parangtritis Village. The sand dune landform experienced a 20.75 hectare decrease in area from 2015 to 2020 (Putri & Wicaksono, 2021). It has since been repurposed for residential, agricultural, and physical facilities in the tourism sector. It is important to balance land use and regional resource potential with efforts to conserve these resources for sustainable use.

Various economic sector activities have different impacts on the environment. Previous studies have shown that massive economic sector activities in coastal areas have led to a decline in the quality of natural resources (Akbar & Pratiwi, 2023; Akbar, Rudianto, & Isdianto, 2019; Hernández-Cordero, Hernández-Calvento, & Espino, 2017; Kim, You, Chon, & Lee, 2017). The decline in the quality of coastal power sources is due to economic activities prioritizing short-term profits over environmental impact. It is important to prioritize the quality of the environment over short-term economic gains. For example, intensive groundwater utilization to supply the tourism sector in coastal areas has resulted in seawater intrusion, leading to a decrease in groundwater quality. This has also affected agriculture and tourism on the coast.

Groundwater is a natural resource that plays a vital role in human activity. It is utilized to fulfill needs across various sectors, ranging from household to industrial and tourism (S. P Sejati & Saputra, 2022). The quality of groundwater is a crucial variable in its use as it serves as an indicator to determine the physical, chemical, and bacteriological condition of water, which is essential in assessing its suitability. Besides, groundwater quality is subject to spatial and temporal dynamics, thereby, it can vary between locations over time. Changes in groundwater quality can result in a decline from good to poor conditions. Human activity is a dominant factor in this decline (Masoud, Koike, Mashaly, & Gergis, 2016). Among the causes for the decline of groundwater quality, seawater intrusion is one of the common causes. This occurs when the interface zone boundary shifts towards the groundwater system on land, often due to excessive use of groundwater in coastal areas. Additionally, improper management of waste from agricultural, livestock, and tourism activities can also lead to groundwater pollution in these areas.

Groundwater in coastal areas is one of the vulnerable natural resources that may experience declining due to population activities. In parts of Temon District, Kulon Progo Regency, Yogyakarta, a decline in groundwater quality has been observed. In Temon District, groundwater quality has declined due to changes in its chemical composition. Consequently, some groundwater now exceeds clean water quality standards in terms of electrical conductivity (Gusman et al., 2020; Putriany & Sejati, 2023). The degradation of groundwater resources occurring due to extensive human activities has also been observed in other coastal regions, including Majene, Tuban, Pekalongan, and Ternate, Indonesia (Febriarta, 2020; Joesidawati, Suwarsih, & Sari, 2019; Robo, Sofyan, & Banapon, 2019; Yusman, Palippui, & Apriansah, 2019). The changes in groundwater chemical structure, which later lead to the exceeding water quality parameters from the standard clean water conditions, occur due to seawater intrusion (Purnama, 2021; Purwanto, Nugroho, & Haty, 2015; Putriany & Sejati, 2023; Vienastra, 2021) and the entry of pollutants from anthropogenic activities into the groundwater system (Khan & Paul, 2023; Putranto, Widiarso, & Susanto, 2017; H. Ullah, Naz, Alhodaib, Abdullah, & Muddassar, 2022). Further, the dominant sand material in coastal areas, combined with shallow groundwater conditions, enables the occurrence of groundwater pollution. Groundwater pollution can cause a change in the chemical features of groundwater, which may exceed the standard criteria for clean water quality.

Water quality inventories can serve as a source of information to assess current groundwater conditions and determine whether there has been a decline in groundwater quality in Parangtritis Village. A previous study examined the groundwater quality in Parangtritis Village in 2014 using electrical conductivity parameters (Adji, Wicaksono, & Nurjani, 2017). However, the identification of groundwater quality based solely on electrical conductivity is deemed as not comprehensive. Therefore, this research explores the quality of water in Parangtritis Village using a more diverse range of parameters, including color, odor, nitrate, nitrite, and E. Coli bacteria. The study's results can serve as a source of information on coastal groundwater quality, particularly in Parangtritis Village, Bantul Regency, Yogyakarta Special Region, Indonesia.

2. Method

The study was carried out in Parangtritis Village, Kretek District, Bantul Regency, Yogyakarta Special Region, Indonesia. The research site covers an area of 967 hectares and is located at UTM coordinates 420000-428000 E and 9112700-9116300 N. The area is divided into different landform units, including riverbanks, natural embankments, alluvial plains, marine fluvial plains, shoal banks, river banks, sand dune complexes, and structural hills (Santosa, 2016). The research area consisted mainly of sand dunes, sandbars, marine fluvial plains, and alluvial plains with flat to gentle slopes (Santosa, 2016). The map of the research area is presented in Figure 1.

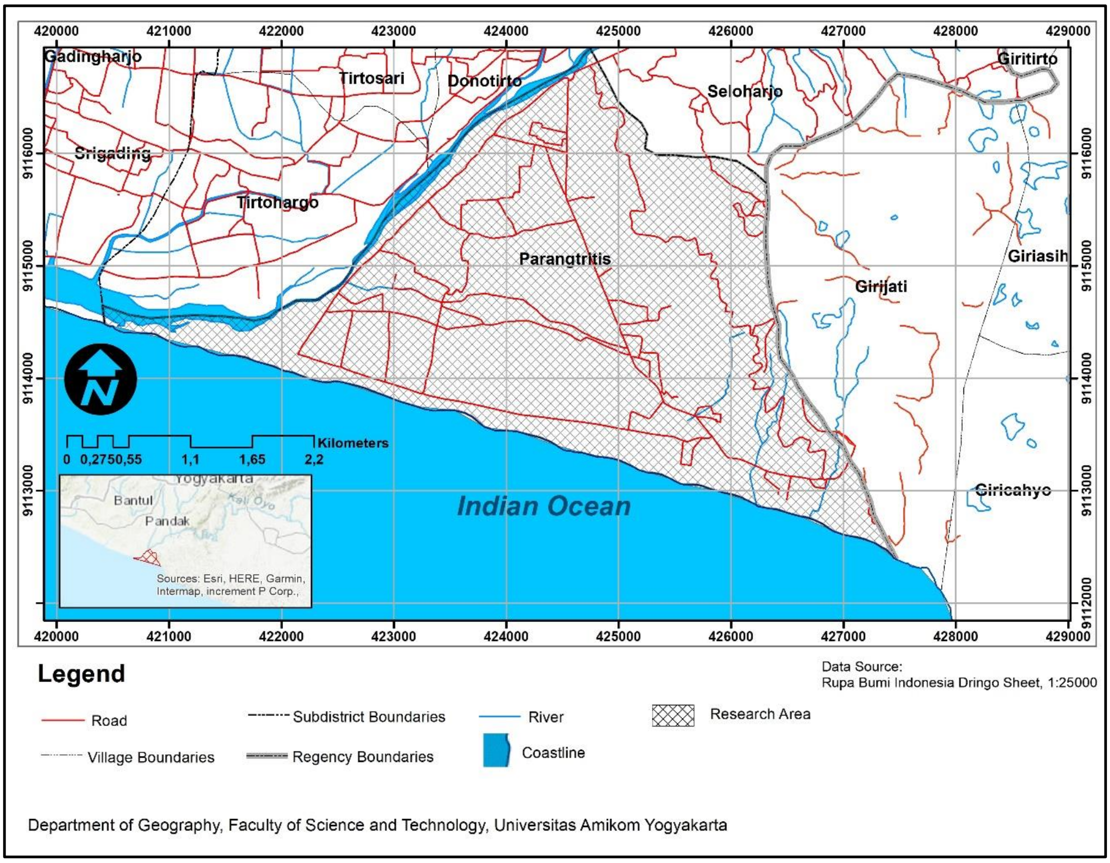

Figure 1. Map of Research Area

Groundwater quality was evaluated using primary data collected in March 2023 through field surveys of groundwater samples obtained from excavated wells. Sample collection locations were determined using a purposive sampling method based on the dominant land use in the research area. The spatial distribution of the sample location is shown in Figure 2.

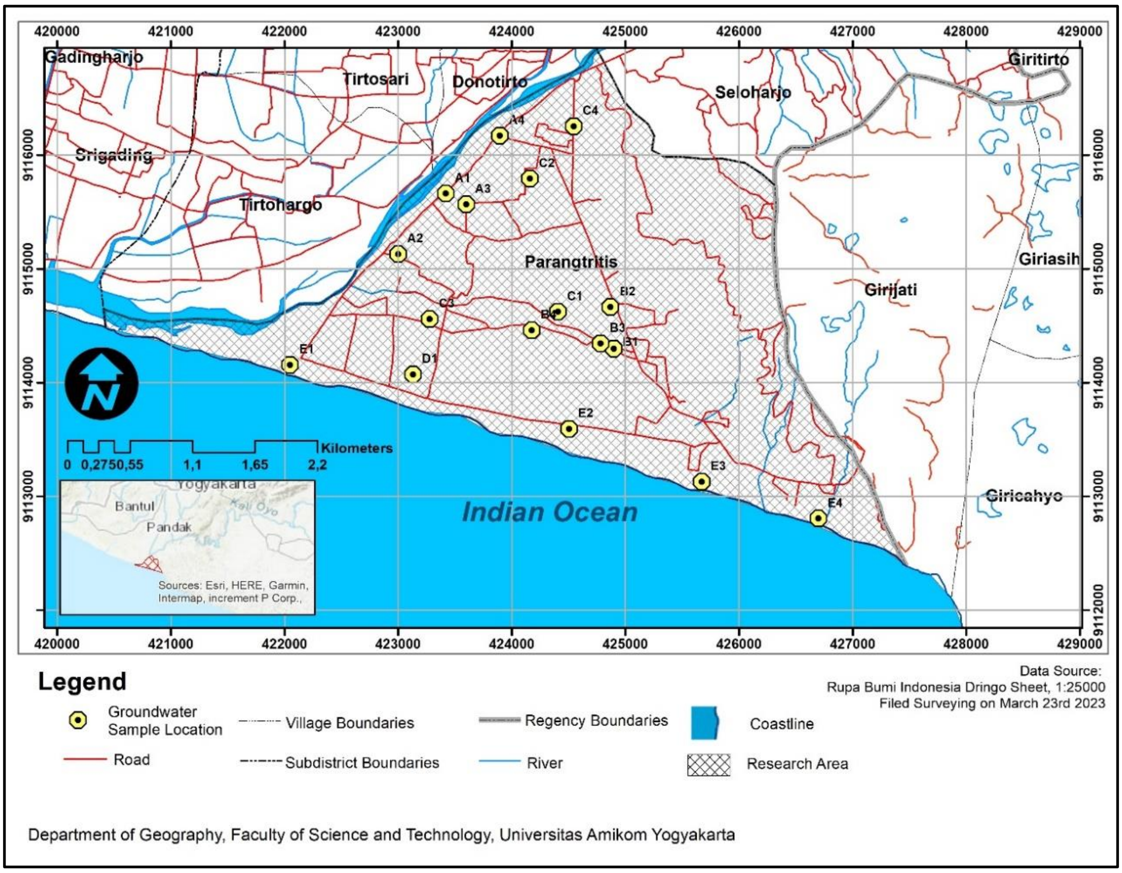

Figure 2. Map of Groundwater Samples Location

Table 1 displays the main codes for sample locations, consisting of letters A, B, C, D, and E. Meanwhile, Figure 2 presents the sample code plotting, which is integrated with numbers. For instance, code A1 represents the first sample taken at a residential location; code B2 represents the second sample taken at a farm location; code C3 represents the third sample taken at a farming location, and so forth.

Table 1. Main Code of Sample Location

No	Code of Sample Location	Description
1	A	Settlement
2	B	Livestock
3	C	Agriculture
4	D	Ponds
5	E	Tourism

Figures 3 and 4 provide a visualization of the field conditions under which groundwater samples were collected. Figure 3 shows the sampling locations in residential and livestock areas, while Figure 4 displays the sampling locations in agricultural, pond, and tourism areas.

Figure 3. Sampling Locations in Residential Areas (A) and Livestock Areas (B)

Figure 4. Groundwater Sampling Locations in Agricultural Areas (C), Pond Areas (D), and Tourism Areas (E)

The water quality parameters used in this research include odor, color, nitrite, nitrate, and Escherichia coli (E. coli) bacteria (Ministry of Health Republic of Indonesia, 2017). Groundwater color and odor data were collected on-site at the sampling location. Meanwhile, nitrate, nitrite, and E. coli data were garnered by testing groundwater samples at the Hydrology and Water Quality Laboratory, Faculty of Geography, Gadjah Mada University, Indonesia.

The spectrophotometric method was used to conduct nitrate and nitrite tests, utilizing equipment such as test tubes, pipettes, beakers (25 ml), measuring flasks, and spectrophotometers. The testing process for both nitrates and nitrites was similar: a chemical solution was mixed with the water sample, and the resulting absorbance was measured using a spectrophotometer. The only difference between the tests was the specific chemical solution and wavelength used. The solution for the nitrite test consisted of $NaNO_2$, acid sulphalinic, $C_{10}H_7NH_2$, HCl, CH_3COONa, and distilled water. The spectrophotometer was set to a wavelength of 520 nm. For the nitrate test, the solution contained $NaNO_3$, $C_7H_5NaO_3$, H_2SO_4, NaOH, and Na_2EDTA, along with distilled water. The spectrophotometer wavelength used for the nitrite test was 410 nm. The test for Coli bacteria was conducted using the standard method known as the most probable number (MPN). The equipment used for these tests included incubation tubes, filter membranes, and selective media. The change in color of the media indicates the presence of Coli bacteria in the test sample. The tests include predictive and complementary tests.

The descriptive analysis of groundwater quality data was conducted to explain its condition. This test was completed following the Republic of Indonesia Ministry of Health Regulation Document Number 32 of 2017 (Ministry of Health Republic of Indonesia, 2017). The water quality standards used were the environmental health quality standards for water for sanitation and hygiene purposes. Figure 5 shows the research flow diagram.

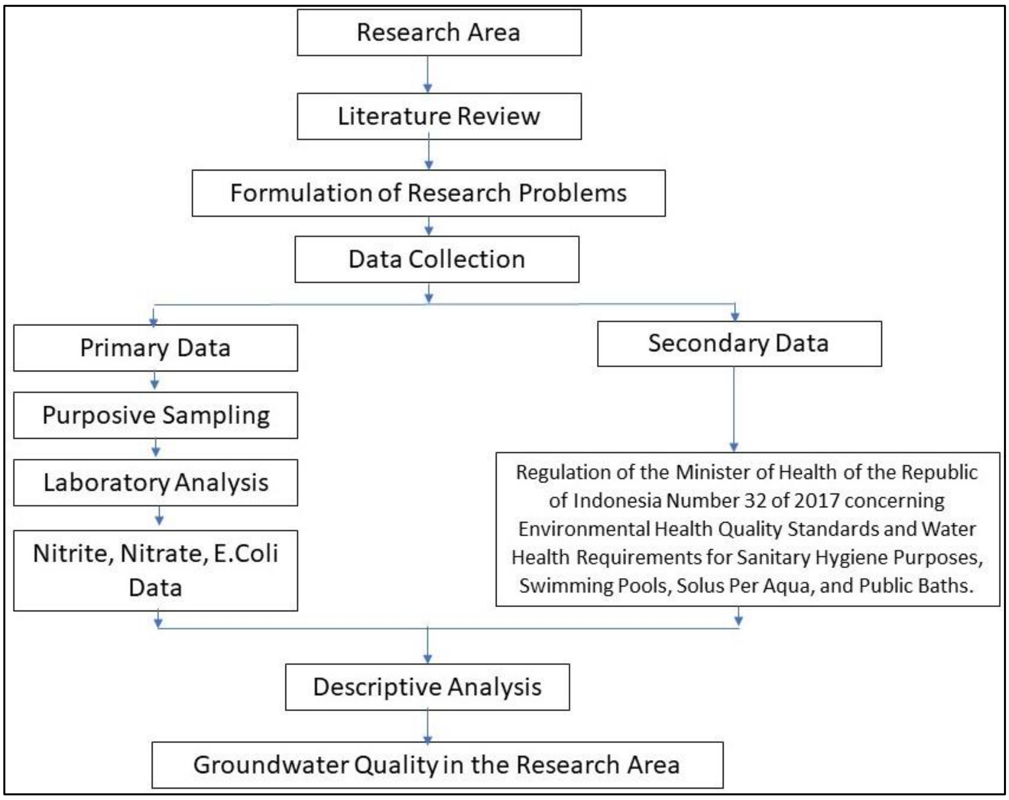

Figure 5. Diagram of the Research Flow

3. Results and Discussion

3.1. Groundwater Conditions based on Physical Parameters in the Research Area

This research employed physical parameters such as odor and color of groundwater. These qualitative parameters facilitate the identification of groundwater conditions at the sampling location (Effendi, 2003). Odor and color parameters have been commonly used in preliminary studies related to water quality. In good quality, groundwater is typically colorless, odorless, and tasteless (Ministry of Health Republic of Indonesia, 2017). The groundwater conditions in the research area based on physical parameters are shown in Table 2, with the rightmost column of the table providing information on the standard color and odor of water for sanitation and hygiene purposes.

The research area is dominated by various land uses, including tourism, residential, livestock, agricultural, and pond areas. Data in Table 2 suggests that the groundwater in residential, livestock, and agricultural areas is clear and odorless, while groundwater in ponds and tourist areas is observed as cloudy and smelly due to suspended sand material, similar to the findings reported by Oyedele (2009) and Ullah et al. (2022). Groundwater suspension occurs in the sand dune and gisik shoal complex due to the interaction of fine-grained sand with groundwater (Adji, Wicaksono, & Said, 2013; Santosa, 2016; Santosan & Adji, 2018). This process increases interaction in suspended material, resulting in cloudy groundwater. Additionally, smelly groundwater is more common in tourist areas than in other areas. Additionally, the massive presence of pollutants in the groundwater system is likely the cause of smelly groundwater. In coastal tourism areas, pollutants also come from seawater intrusion (Putriany & Sejati, 2023) and scattered toilets and food stalls in the area (Akbar et al., 2019; El Mountassir & Bahir, 2023; Vienastra, 2021). The residual from the food waste and toilets contains bacteria. Besides, the dirt on the soil surface decomposes and leaches into the groundwater saturation zone. Faecal matter from toilets also decomposes anaerobically, which further causes odor.

Table 2. Groundwater Conditions based on Color and Odor Parameters

Code of sample location	Land use	Color	Odor	Standard from Regulation of the Minister of Health of the Republic of Indonesia Number 32 of 2017
A1	Settlement	Clear	No smell	Colorless and odorless
A2	Settlement	Clear	No smell	Colorless and odorless
A3	Settlement	Clear	No smell	Colorless and odorless
A4	Settlement	Clear	No smell	Colorless and odorless
B1	Livestock	Clear	No smell	Colorless and odorless
B2	Livestock	Mossy clear	No smell	Colorless and odorless
B3	Livestock	Clear	No smell	Colorless and odorless
B4	Livestock	Clear	No smell	Colorless and odorless
C1	Agriculture	Clear	No smell	Colorless and odorless
C2	Agriculture	Clear	No smell	Colorless and odorless
C3	Agriculture	Clear	No smell	Colorless and odorless
C4	Agriculture	Murky	Smelly	Colorless and odorless
D1	Pond	Murky	Smelly	Colorless and odorless
E1	Tourism	Clear	No smell	Colorless and odorless
E2	Tourism	Murky	Smelly	Colorless and odorless
E3	Tourism	Murky	Smelly	Colorless and odorless
E4	Tourism	Murky	Smelly	Colorless and odorless

3.2. Groundwater Conditions based on Chemical Parameters in the Research Area

Nitrate and nitrite are chemical parameters used to identify the chemical conditions of groundwater in the research area. Nitrate is formed through the complete oxidation of nitrogen compounds in water (Effendi, 2003; Ministry of Health Republic of Indonesia, 2017). Excessive use of urea or artificial fertilizers, household and industrial waste, decomposing organic matter, as well as domestic waste are the sources of nitrates in groundwater. The process of nitrate entering the groundwater system occurs both directly and indirectly. In the direct process, nitrate is carried by liquid waste in the groundwater system. Indirectly, it occurs due to the leaching process of pollutant sources on the ground surface. Then, leachate containing nitrate reaches the groundwater saturation zone (Killpack & Bucholz, 2022; Niu, Wang, Loáiciga, Hong, & Shao, 2017; Rusydi, Naily, & Lestiana, 2015; Sadewa Purba Sejati & Adji, 2013). The results of the nitrate test are shown in Table 3, with the right column providing information on the water nitrate standards for sanitation and hygiene purposes.

Table 3 shows that groundwater nitrate levels vary greatly, ranging from less than 0.08 mg/l to 44.32 mg/l. Four locations have particularly high nitrate levels, including location A3, a residential area with nitrate levels of 21.25 mg/l; locations B1 and B3, the livestock areas with nitrate levels of 44.32 mg/l and 22.39 mg/l, respectively; and location E4, a tourist area with nitrate levels of 18.10 mg/l. These variations in nitrate levels are likely caused by differences in land use intensity.

Table 3. Groundwater Conditions based on the Nitrate Parameters

Code of Sample Location	Land use	Nitrate (mg/l)	Maximum nitrate levels (mg/l) based on Regulation of the Minister of Health of the Republic of Indonesia Number 32 of 2017
A1	Settlement	0.57	10
A2	Settlement	<0.08	10
A3	Settlement	21.25	10
A4	Settlement	1.02	10
B1	Livestock	44.32	10
B2	Livestock	<0.08	10
B3	Livestock	22.39	10
B4	Livestock	1.08	10
C1	Agriculture	1.31	10
C2	Agriculture	0.17	10
C3	Agriculture	0.28	10
C4	Agriculture	2.33	10
D1	Pond	1.06	10
E1	Tourism	5.94	10
E2	Tourism	0.82	10
E3	Tourism	0.76	10
E4	Tourism	18.1	10

Sample points B1 and B3 are livestock areas with high nitrate levels caused by abundant and poorly managed livestock waste. These areas present larger number of livestock compared to sample points B2 and B4. Additionally, high nitrates are also found in residential area A3 because the study was conducted at a resident's house, which served as a center for onion peeling activities. The improperly managed piles of shallot skins can rot and leach, causing nitrate particles to reach the groundwater saturation zone. High levels of nitrate have also been found in samples taken from the tourist area, particularly at sample point E4, located on Parangtritis Beach. Groundwater samples were collected from a bathroom located in the Parangtritis Beach area, which is in close proximity to stalls and restaurants. Elevated nitrate levels in these four locations indicate the presence of pollutants from domestic, livestock, and tourism activities that have infiltrated the groundwater saturation zone.

Nitrite serves as a parameter to identify the chemical condition of groundwater in the research area. It is a derivative of ammonia resulting from nitrogen oxidation and a temporary condition of the oxidation process between ammonia and nitrate (Effendi, 2003). Nitrite can originate from the use of nitrogen fertilizer, industrial waste, and household or domestic waste (Febriarta, 2020; Zahra & Putranto, 2021). Table 4 summarizes the results of the groundwater nitrite test, with the right column providing information on the water nitrite standards for sanitation and hygiene purposes.

Table 4 shows the variations in groundwater nitrite levels, ranging from 0 mg/l to 1 mg/l. Locations A2, B1, B3, B4, C1, C2, E1, and E4 are observed to experience groundwater pollution, as listed in Table 4. Groundwater with high nitrite levels has also been identified in residential, livestock, agricultural, and tourist. Livestock areas contribute the most to groundwater nitrate levels in the study area. However, a concentration of 1 mg/l of nitrate can still be tolerated as it is the maximum threshold limit for nitrate in groundwater according to clean water quality standards. Accordingly, nitrate levels that exceed this limit indicate environmental problems in the research area.

Table 4. Groundwater Condition based on the Nitrite Parameter

Code of Sample Location	Land use	Nitrite (mg/l)	Maximum nitrate levels (mg/l) based on Regulation of the Minister of Health of the Republic of Indonesia Number 32 of 2017
A1	Settlement	0	1
A2	Settlement	1	1
A3	Settlement	0	1
A4	Settlement	0	1
B1	Livestock	1	1
B2	Livestock	0	1
B3	Livestock	1	1
B4	Livestock	1	1
C1	Agriculture	1	1
C2	Agriculture	1	1
C3	Agriculture	0	1
C4	Agriculture	0	1
D1	Pond	0	1
E1	Tourism	1	1
E2	Tourism	0	1
E3	Tourism	0	1
E4	Tourism	1	1

3.3. Groundwater Condition based on Biological Parameter

Escherichia coli (E. coli) was used as an indicator of groundwater quality as its presence indicates fecal contamination (Febriarta, 2020; Sejati, 2020; Zendehbad, Mostaghelchi, Mojganfar, Cepuder, & Loiskandl, 2022). Table 5 shows the results of the E. coli test for groundwater samples with the standards for E. coli bacteria for sanitation hygiene purposes are explained in the rightmost column in the table.

As presented in Table 5, all groundwater samples contained varying amounts of E. coli bacteria. The fluctuations in E. coli levels are attributed to human domestic activities and livestock land use. Additionally, excessive use of manure in agricultural areas may also result in high levels of E. coli bacteria due to livestock waste infiltrating the soil and contaminating the groundwater (Sejati & Saputra, 2022). In addition to the aforementioned factors, high levels of E. coli bacteria in the area are also attributed to the proximity of septic tanks in residential areas to groundwater sources. Similarly, in tourist areas, the abundance of public bathroom facilities has also been found as a significant contributor to the high concentration of E. coli bacteria.

Table 5. Groundwater Conditions based on the E. Coli Parameter

Code of Sample Location	Land use	E. coli (MPN/100ml)	Maximum levels of E.coli (MPN/100 ml) based on Regulation of the Minister of Health of the Republic of Indonesia Number 32 of 2017
A1	Settlement	9	0
A2	Settlement	43	0
A3	Settlement	75	0
A4	Settlement	14	0
B1	Livestock	120	0
B2	Livestock	43	0
B3	Livestock	120	0
B4	Livestock	75	0
C1	Agriculture	210	0
C2	Agriculture	≥2400	0
C3	Agriculture	1100	0
C4	Agriculture	210	0
D1	Pond	4	0
E1	Tourism	23	0
E2	Tourism	23	0
E3	Tourism	4	0
E4	Tourism	4	0

3.4. Groundwater Quality based on Water Quality Standards

The quality of groundwater in this research area was determined through observations, recordings, and laboratory tests on groundwater samples. The benchmark for groundwater quality test was adopted from the Regulation of the Ministry of Health of the Republic of Indonesia Number 32 of 2017. The data on color and odor parameters indicates that groundwater quality that does not meet clean water standards is often found in agricultural, pond, and tourism areas. This is due to the water being cloudy and having an odor. Ideally, as a source of clean water, groundwater must be clear and odorless. Additionally, following the nitrite levels, the quality of groundwater in the research area generally meets clean water requirements. The maximum level of nitrite for clean water is 1 mg/l. The data analysis results suggest the absence of groundwater exceeding the nitrite limit in the research area. The only groundwater with nitrate levels exceeding the maximum threshold for clean water requirements (more than 10 mg/l) was found in four sample locations, namely residential areas with location code A3, livestock areas with codes B1 and B3, and tourism areas with location code E4. The detailed information regarding the groundwater nitrate based on clean water quality standards in the research area is illustrated in Figure 6.

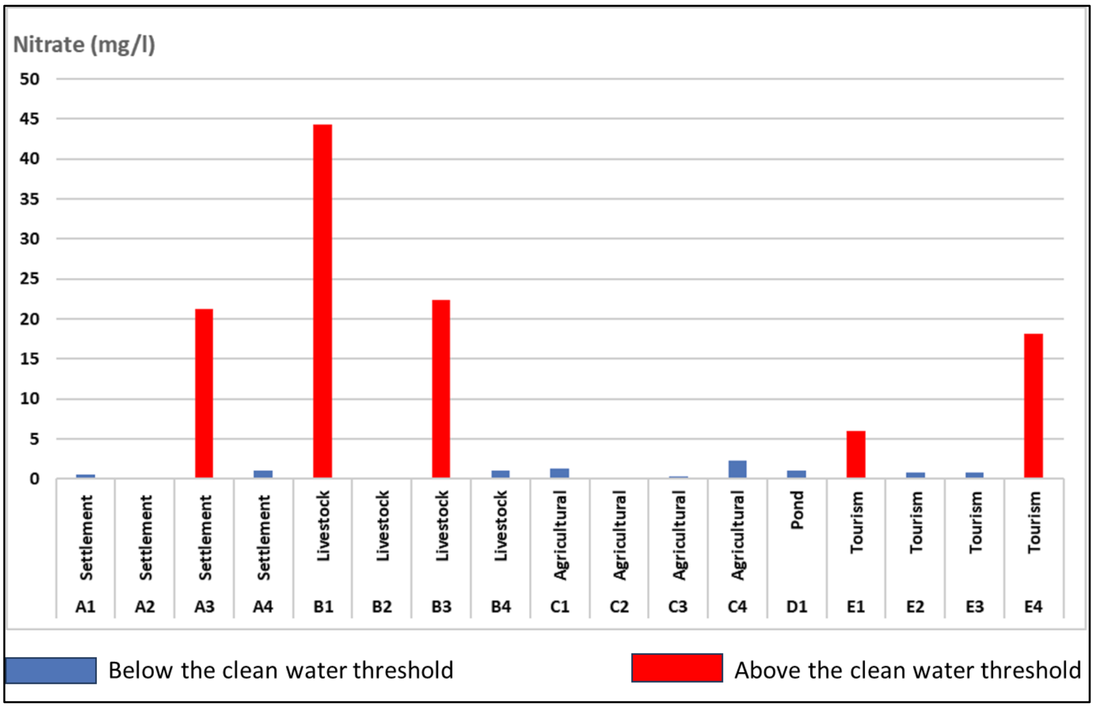

Figure 6. Nitrate Graph based on Clean Water Quality Standards

The bacteriological test results for the groundwater in the research area show the samples' failure to meet the clean water quality standards due to the presence of E. coli exceeding 0 MPN/100 ml. Figure 7 displays a graph of E. coli levels in the groundwater samples.

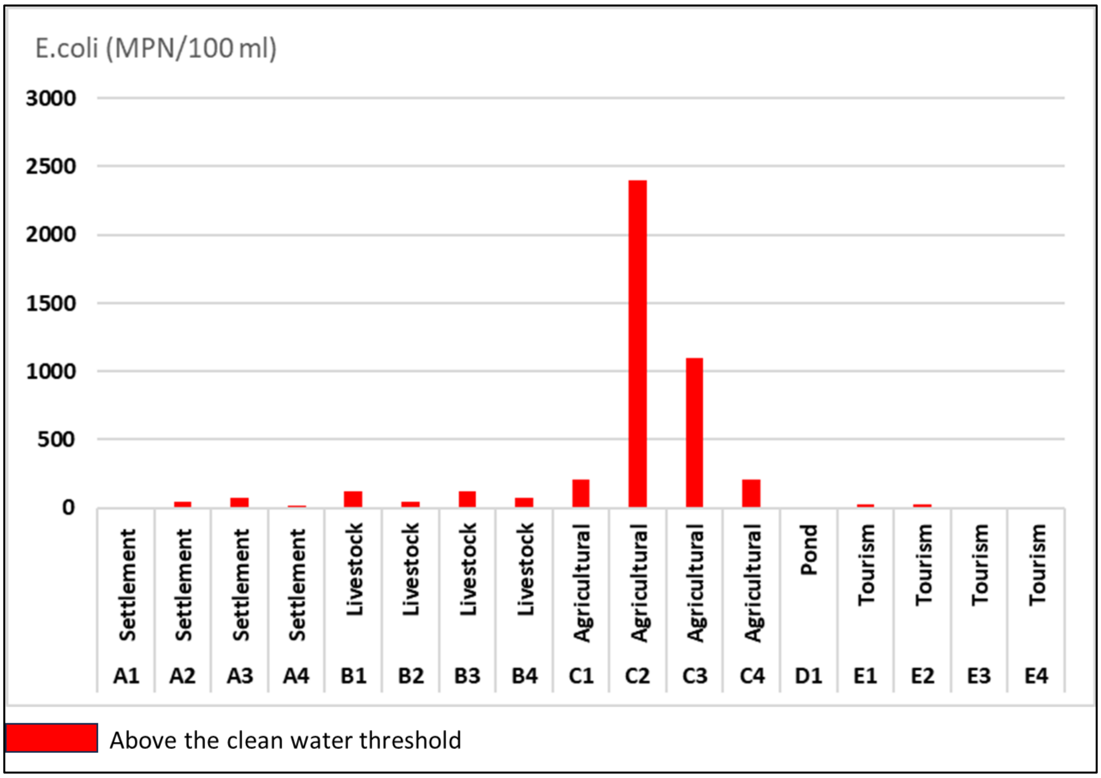

Figure 7. E.coli Graph Based on Clean Water Quality Standards

Groundwater quality was assessed through the physical, chemical, and biological parameters analysis. From the physical parameters, the majority of the groundwater is in good condition as it is clear and odorless. However, the condition of groundwater quality in the research area cannot be determined solely based on smell and color. In particular, chemical and biological pollutants, such as nitrates, nitrites, and E.coli, cannot be detected through the odor and color parameters. Therefore, it is necessary to conduct nitrate and E. coli tests to determine the quality of the water. The results of these tests should be used to evaluate the water quality, along with the results of odor and color observations. Even clear and odorless water may have nitrate and E.coli levels exceeding clean water quality standards.

The classification of the groundwater quality was carried out based on the physical, chemical, and bacteriological parameters. The concept of water quality limitations has been proposed by Sejati & Adji (2013). The study area's groundwater quality is classified based on limiting parameters, which are water quality test parameters that exceed the threshold of water quality standards used. It is important to note that limiting parameters should be used objectively and without subjective evaluations. Based on the limiting parameters, groundwater quality in the study area can be classified into four categories, namely groundwater with color limitations, groundwater with odor limitations, groundwater with nitrate limitations, and groundwater with E. coli limitations. Table 6 displays the groundwater quality in the study area based on these parameters.

Table 6. Distribution of Limiting Parameters for Groundwater Quality

Limiting parameters	Land use
Color	Some agricultural areas
	Aquaculture area
	Some tourist areas
Smell	Some agricultural areas
	Aquaculture area
	Some tourism areas
Nitrate	Partly residential area
	Part of the livestock area
	Some tourist areas
E. coli	Residential area
	Aquaculture area
	Farm area
	Agricultural area
	Tourism area

The quality of groundwater in the research area is affected by the material conditions in the aeration and saturation zones, as well as the land use in the area. The gathered data suggested that the research area contains horizontally and vertically distributed sand material in both zones, with excellent permeability. Previous studies have assigned significant importance to sand material as a variable in modeling groundwater pollution (Adji et al., 2013; Sejati & Saputra, 2022; Sejati, 2020; Vrba & Zoporozec, 1994). The sand with high permeability facilitates the movement of pollutants towards the groundwater-saturated zone.

Land use has a significant impact on groundwater quality. The majority of the population in Parangtritis Village are farmers, reaching 2,955 people (Parangtritis Sub-district, 2020). These farmers cultivate a variety of crops, including rice, chilies, shallots, and secondary crops.

Livestock farming is also prevalent in the village, with cows, goats, and poultry being popular. In Parangtritis Village, many residents earn their living as entrepreneurs, totalling 1,673 people. These entrepreneurs are closely tied to the tourism sector, with some opening stalls and accommodations to cater to tourists visiting the area.

In addition, population and tourism activities also significantly affect the environment, particularly the quality of surrounding groundwater. Research and observations in the area indicate that agricultural, livestock, and tourist areas have the worst impact, leading to groundwater contamination. This fact is closely related to population activities being carried out continuously, resulting in waste from both agriculture and livestock and domestic waste produced from tourist areas.

Apart from the population activities, high levels of nitrate, nitrite, and E. coli bacteria are caused by the distance between the septic tank and the groundwater wells in the study area. There are also other sources of pollution in the study area around the wells, such as garbage and household waste, which leach into the groundwater. Therefore, in order to prevent and reduce groundwater pollution, the residents of Parangtritis village need to adopt environmental and groundwater management policies, carry out spatial planning in Parangtritis village, construct waste disposal tanks, manage cattle barns, and conserve groundwater in order to ensure groundwater availability and maintain groundwater quality.

4. Conclusion

Groundwater quality varies throughout the study area. Based on the results of data analysis, groundwater with good physical quality does not always present good chemical and biological conditions. This was observed in several samples. Groundwater samples that were clear and odorless had nitrate, nitrite, and E. coli bacteria counts that exceeded the threshold for clean water quality standards. The findings also suggest that the groundwater quality in this study was classified using the limiting parameters. Odor and color-limiting parameters affect groundwater quality in certain agricultural, tourism, and aquaculture areas. Meanwhile, nitrite-limiting parameters affect groundwater quality in some residential and livestock areas. E. coli bacteria limiting parameters affect groundwater quality in all land use areas. In general, groundwater quality in the study area is influenced by both natural and land use factors. Sand material distributed horizontally and vertically in the aeration and saturation zones of the study area facilitates the transport of pollutants from settlements, agriculture, livestock, aquaculture, and tourism to the groundwater saturation zone.

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