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Research Article

Groundwater quality assessment in different volcanic rocks using water quality index in the tropical area, Indonesia

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Abstract

Groundwater is the main water source that is most widely used in the world, one of which is in Indonesia. One of the uses of groundwater is for consumption needs. Therefore, the groundwater used should have good water quality. For this reason, this study aimed to determine groundwater quality in Indonesia during the dry season and make recommendations for groundwater management policies. A total of 211 groundwater samples taken from springs, drilled wells, and dug wells spread across volcanic areas on the islands of Sumatra, Java, Bali, and Sulawesi were collected to test their quality in this research. The method used in this research consisted of 4 analyses: WHO threshold analysis, Piper Diagram, Water Quality Index (WQI), and statistical correlation and regression. Based on the analysis, it was discovered that 47 K^+ samples, 1 Na^+ sample, 5 Ca^{2+} samples, 1 Cl^- sample, 115 HCO_3^- samples, 3 TDS samples, and 3 pH samples exceeded WHO standards. The results of the Piper triangle diagram analysis showed that the majority of groundwater in Indonesia falls into the Unpolluted Groundwater classification (categories D and G), and the results of the WQI analysis also showed that 98% of the groundwater in Indonesia analyzed falls into the excellent and good water categories. The results of statistical analysis of the parameters K^+, Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, HCO_3^-, TDS, and pH showed that all these parameters are strongly and positively correlated with the WQI value.

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Introduction

Groundwater is the world's most widely used water source (Sabino et al., 2020; Jesuraja et al., 2021). Groundwater is widely used due to its quality being comparatively better compared to other water sources (Li et al., 2021). The good water quality that groundwater possesses can occur since it undergoes a filtering process, starting from infiltration to percolation that passes through the unsaturated zone into the saturated zone. Because of its presence and flow through layers of soil and rock, groundwater has specific chemical characteristics that differentiate it from other types of water.

The use of groundwater in the world increases every year (Franz et al., 2022; Hinge et al., 2022) for domestic, industrial, and agricultural purposes (Varol and Davraz, 2015). Increased groundwater use also occurs in Indonesia every year (Hendrayana et al., 2021a, Hendrayana et al., 2021b; Purnama et al., 2023). The increase in groundwater use in Indonesia occurs due to low surface water utilization by the average Indonesian community for domestic needs due to its poor water quality (Hendrayana et al., 2023a), such as river water. Indonesian communities tend to use better quality water in the form of groundwater to fulfill their daily necessity, either in the form of dug wells, drilled wells, or springs (Irawan et al., 2009; Hendrayana et al., 2023b; Razi et al., 2023).

Regrettably, the rising groundwater use is generally accompanied by increasing groundwater pollution (Gorgij et al., 2017; Amiri et al., 2014). Conseqently, studying and understanding groundwater quality before and after utilization is necessary to reduce the impact of groundwater pollution. This practice has been implemented in several countries by conducting a Water Quality Index (WQI) study before utilizing groundwater (Badeenezhad et al., 2020; Ram et al., 2021; Atta et al., 2022). The WQI study provides important information as an initial study of groundwater quality management. In Indonesia, WQI studies before groundwater utilization are still quite rare. The majority of groundwater quality research conducted in Indonesia is generally only performed by comparing water quality with quality standards set by the government (Fathmawati et al., 2018; Hendrayana et al., 2021c; Putra and Wilopo, 2022). In Indonesia, groundwater chemistry research is typically merely focused on studying the hydrogeochemical characteristics of groundwater (Kämpfner et al., 2021; Hartono et al., 2022; Hendrayana et al., 2022).

For this reason, this research aims to determine the WQI of groundwater in Indonesia during the dry season from dug wells, springs, and drilled wells in several regions in Indonesia. The expected result is that this study can determine the suitability status of groundwater in Indonesia at these research locations. It is hoped that the results of the WQI study can be used as recommendations for groundwater experts and the government in managing groundwater in Indonesia.

The study locations are spread across several volcanic areas in Indonesia on the islands of Sumatra, Java, Bali, and Sulawesi (Figure 1). In general, the entire study location falls into the tropical climate classification with high rainfall ranging from 2,000-3,000 mm/year and has similar geological conditions composed of volcanic rock.

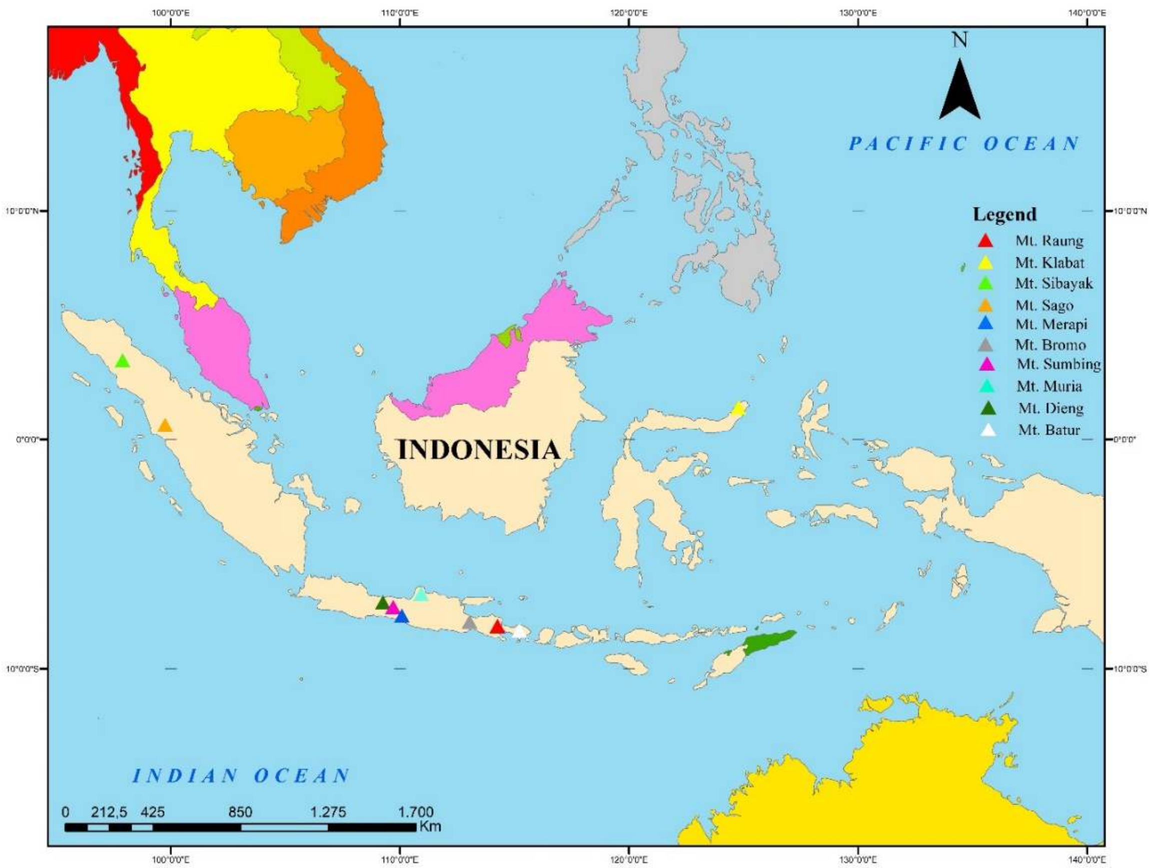

Figure 1. Research area (Source: Administrative Boundary Map, Geospatial Information Agency of Republic Indonesia).

Materials and Methods

The water quality investigation methods used in this research were direct water quality measurements and laboratory quality testing by taking water samples at the research location during the dry season. The analyzed groundwater samples came from springs, dug wells, and drilled wells, with a total of 232 groundwater samples. These samples were obtained by putting the water sample in a 1-liter water sample bottle to be tested in the laboratory. Groundwater quality parameters tested in the laboratory are major ions consisting of K^+, Na^+, Mg^{2+}, Ca^{2+} and minor ions consisting of SO_4^{2-}, Cl^-, and HCO_3^-, while groundwater quality parameters were tested directly in the field using a water checker including temperature, pH, and total dissolved solid (TDS).

Four methods were used to examine groundwater quality at the research location: comparison with WHO standards, Piper Diagram analysis, Water Quality Index (WQI) analysis, and statistical analysis. The WHO standard water quality parameters that were compared with water quality in this study can be seen in Table 1.

$$Wi = wi/\sum^{n}_{i=1} wi \quad (1)$$

$$qi = (Ci/Si) \times 100 \quad (2)$$

$$Sii = Wi \times qi \quad (3)$$

$$WQI = \sum Sii \quad (4)$$

Table 1. Weights and chemical standard of each parameter.

No	Parameter*	WHO Standard	Weight (Wi)	Relative Weight (Wi)
1	pH	8.5	3	0.103
2	TDS	500	5	0.179
3	Cl	250	5	0.179
4	SO_4	250	5	0.179
5	Na	200	4	0.143
6	K	12	2	0.071
7	HCO_3	120	1	0.036
8	Ca	75	3	0.107
9	Mg	50	3	0.107
	Total		28	1

*Note: The units for parameters 2-9 are in mg/L.

The analysis used compared water quality values against WHO quality standards. Piper Diagram analysis was carried out by plotting water quality results on a triangular Piper diagram. The analysis results from the Piper diagram were in the form of pollution classification and pollution sources. WQI analysis was carried out by calculating equations 1, 2, 3, and 4 (Saadat-Noori et al., 2014). The calculation results of equation 2 were then classified according to the classification in Table 2. The results of the WQI analysis were generally in the form of groundwater quality classification. The statistical analysis in this research was carried out using SPSS software in correlation and regression. The results of the correlation analysis were the relationship between two variables, while the correlation values were classified according to Table 3. Multiple linear regression analysis was also performed to measure the strength of the relationship between two or more variables.

Table 2. WQI Classification.

No	WQI Range	Type of Water
1	<50	Excellent Water
2	50-100	Good Water
3	101-200	Poor Water
4	201-300	Very Poor Water
5	>300	Water Unsuitable for Drinking Purposes

Source: Saadat-Noori et al. (2014).

Table 3. Correlation classification.

No	Correlation Coefficient	Classification
1	0-199	Very Low
2	0.2-0.399	Low
3	0.4-0.599	Moderate
4	0.6-0.799	High
5	0.8-1	Very High

Source: Zhang et al. (2020).

Results and Discussion

Based on this research, groundwater quality values in Indonesia have varying characteristics for the parameters K^+, Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, HCO_3^-, TDS, and pH (Table 4). Details of samples from each parameter can be observed in Table 5.

The K^+ parameter has a value of 0.33-367 mg/L, with 47 out of 211 samples having values exceeding the WHO standard (12 mg/L). The Na^+ parameter has variations ranging from 1.53-733 mg/L, with 1 out of 211 samples having a value exceeding the WHO standard (200 mg/L). The Mg^{2+} parameter has variations ranging from 0.04-29.12 mg/L, with all the sample values below the WHO standard (50 mg/L). The Ca^{2+} parameter has variations ranging from 0.24-292.3 mg/L, with 5 out of 211 samples having values exceeding the WHO standard (75 mg/L). The SO_4^{2-} parameter has variations ranging from 0.486 to 176.74 mg/L, with all the sample values below the WHO standard (250 mg/L).

The Cl^- parameter has varying values ranging from 0.08 to 768.52 mg/L, with 1 out of 211 samples having a value exceeding the WHO Standard (250 mg/L). The HCO_3 parameter has varying values ranging from 2 to 841.8 mg/L, with 115 out of 211 samples having values exceeding the WHO Standard (120 mg/L).

Table 5. List of samples with parameter values exceeding WHO standards.

Parameters	Samples	Concentration	Standard	Parameters	Samples	Concentration	Samples	Concentration	Standard
TDS	DW.VI.52	800.00	500.00	HCO_3	DW.I.2	133	DW.VI.48	204.3	120
	DW.X.72	1,714.00			DW.II.11	193.3	DW.VI.49	155.5	
	DW.X.74	1,129.00			DW.II.12	259.7	DW.VI.52	305	
pH	S.II.8	8.80	8.50		DW.II.13	205.3	DW.VII.53	122	
	S.X.121	9.90			DW.II.14	151	DW.VII.57	146.4	
	AS.X.1	8.74			DW.II.15	145	DW.VII.58	122	
Cl	DW.X.72	768.52	250.00		DW.II.16	302	DW.VII.61	134.2	
SO_4	-	-	250.00		S.II.6	229.5	DW.VII.62	134.2	
Ca	DW.IV.27	79.17	75.00		S.II.7	169.1	DW.VII.63	219.6	
	S.X.117	80.87			S.II.8	181.2	DW.VII.64	122	
	DW.X.72	173.39			S.II.9	217.4	DW.VII.65	158.6	
	DW.X.73	91.09			S.II.10	145	DW.VII.66	183	
	DW.X.74	292.30			S.II.11	157	DW.VII.67	219.6	
Mg	-	-	50.00		S.II.12	151	S.VIII.82	256.2	
Na	DW.X.72	395.37	200.00		S.II.13	199.3	S.VIII.83	122	
K	S.III.22	13.73	12.00		S.II.14	277.8	S.VIII.88	160	
	S.III.32	12.68			S.II.15	302	S.VIII.92	183	
	S.III.34	15.98			S.II.16	132.9	S.VIII.93	200	
	BH.III.8	17.77			S.II.17	145	DW.VIII.68	240.95	
	DW.III.17	13.46			S.II.18	253.7	DW.VIII.69	125.05	
	DW.III.18	23.57			S.II.19	265.7	S.IX.94	240.4	
	DW.III.19	12.19			S.III.22	207.4	S.IX.95	228.4	
	DW.III.20	69.82			S.III.23	186.05	S.IX.96	240.4	
	DW.III.22	17.62			S.III.24	146.4	S.IX.97	144.2	
	DW.III.23	18.39			S.III.26	122	S.IX.98	216.4	
	DW.III.24	13.18			S.III.32	210.45	S.IX.99	276.5	
	S.III.35	15.77			S.III.33	183	S.IX.102	120.2	
	S.III.36	13.40			S.III.34	183	S.IX.104	348.6	
	S.IV.37	12.15			BH.III.8	329.4	S.IX.105	384.6	
	S.IV.40	12.27			BH.III.9	195.2	S.IX.107	336.6	
	S.IV.42	17.54			DW.III.17	195.2	S.IX.108	180.3	
	BH.IV.10	24.15			DW.III.18	195.2	S.IX.109	240.4	
	DW.IV.25	22.40			DW.III.19	219.6	S.IX.110	180.3	
	DW.IV.27	17.72			DW.III.20	201.3	S.IX.111	192.3	

Parameters	Samples	Concentration	Standard	Parameters	Samples	Concentration	Samples	Concentration	Standard
	DW.IV.28	29.52			DW.III.21	149.45	S.IX.112	144.2	
	DW.IV.29	20.11			DW.III.22	179.95	S.IX.113	132.2	
	DW.IV.30	15.34			DW.III.23	152.5	S.IX.114	156.3	
	DW.IV.31	25.88			DW.III.24	219.6	S.X.116	158.6	
	DW.IV.32	31.55			S.III.35	231.8	S.X.117	244	
	DW.IV.34	14.83			S.III.36	207.4	DW.X.72	366	
	DW.IV.36	13.85			S.IV.37	190	DW.X.73	305	
	S.VI.64	17.00			S.IV.38	150	DW.X.74	841.8	
	DW.VI.52	367.00			S.IV.39	180	DW.X.75	317.2	
	DW.VII.53	29.00			S.IV.40	140	DW.X.76	280.6	
	DW.VII.54	15.55			S.IV.41	130	DW.X.77	500.2	
	DW.VII.55	16.76			S.IV.42	200	DW.X.78	439.2	
	DW.VII.56	15.29			S.IV.45	150	DW.X.79	170.8	
	DW.VII.61	12.69			S.IV.47	130	DW.X.80	353.8	
	DW.VII.62	21.87			BH.IV.10	410	DW.X.81	280.6	
	DW.VII.63	15.32			DW.IV.25	270	DW.X.82	390.4	
	DW.VII.64	16.79			DW.IV.26	200	DW.X.83	256.2	
	DW.VII.65	18.25			DW.IV.27	300	DW.X.84	292.8	
	DW.VII.66	13.78			DW.IV.28	400	AS.X.1	231.8	
	DW.VII.67	35.77			DW.IV.29	250			
	S.VII.77	14.84			DW.IV.30	220			
	BH.VII.15	12.54			DW.IV.31	400			
	BH.VII.16	12.75			DW.IV.32	330			
	BH.VII.17	19.07			DW.IV.34	170			
	DW.VIII.68	18.70			DW.IV.35	160			
	DW.VIII.71	15.30			DW.IV.36	140			
	S.IX.104	19.00			S.V.49	112			
	DW.X.72	53.30			BH.V.14	19.51			

The TDS parameter ranges from 10 to 1,714 mg/L, with 3 out of 211 samples having values exceeding the WHO Standard (500 mg/L). The pH parameter ranges from 5-10, with 3 of the 211 samples having values exceeding the WHO Standard (8.5). The overall results of major and minor ions in volcanic areas have the same range as other studies in Indonesia for each major and minor ion (Irawan et al., 2009; Purnomo and Pichler, 2015). These compariative outcones of the WHO standard cannot be compared with those of the Indonesian standard due to variations in parameter specifications. Notably, the Indonesian standard solely prescibes quality standard for Cl^-, TDS, SO_4^{2-}, and pH parameters (Riyanto and Cahyadi, 2023). The Indonesian standard delineates lower thresholds for these four parameters compared to the WHO standard, with specific values set at Cl^- 300 mg/L, TDS 1000 mg/L, and SO_4^{2-} 300 mg/L. Pollution simulation methodologie in Indonesia predominantly focus on rivers, addressing chemical parameters excluding major and minor ions, biological elements, and heavy metals (Hendrayana et al., 2023a).

Table 4. Range of groundwater quality values in Indonesia.

mg/L	K^+	Na^+	Mg^{2+}	Ca^{2+}	SO_4^{2-}	Cl^-	HCO_3^-	TDS	pH
Minimum	0.33	1.53	0.04	0.24	0.486	0.08	2.00	10.00	5.00
Average	10.17	32.70	8.51	27.58	16.39	18.57	140.53	132.53	6.83
Maximum	367.00	733.00	29.12	292.30	176.74	768.52	841.80	1,714.00	10.00
Deviation	26.11	60.75	6.41	26.26	23.25	56.82	99.01	155.48	0.79

The results of the Piper diagram analysis in the upper triangle diagram show that after plotting groundwater samples on the Piper diagram, most samples fell into the dominant unpolluted groundwater classification code G. This is also reinforced by data distribution in the lower right triangle is dominant in code D with the Unpolluted Groundwater classification. However, disparities were found in the lower left triangle, displaying that a minority of samples fall into code A of unpolluted water classification (Figure 2).

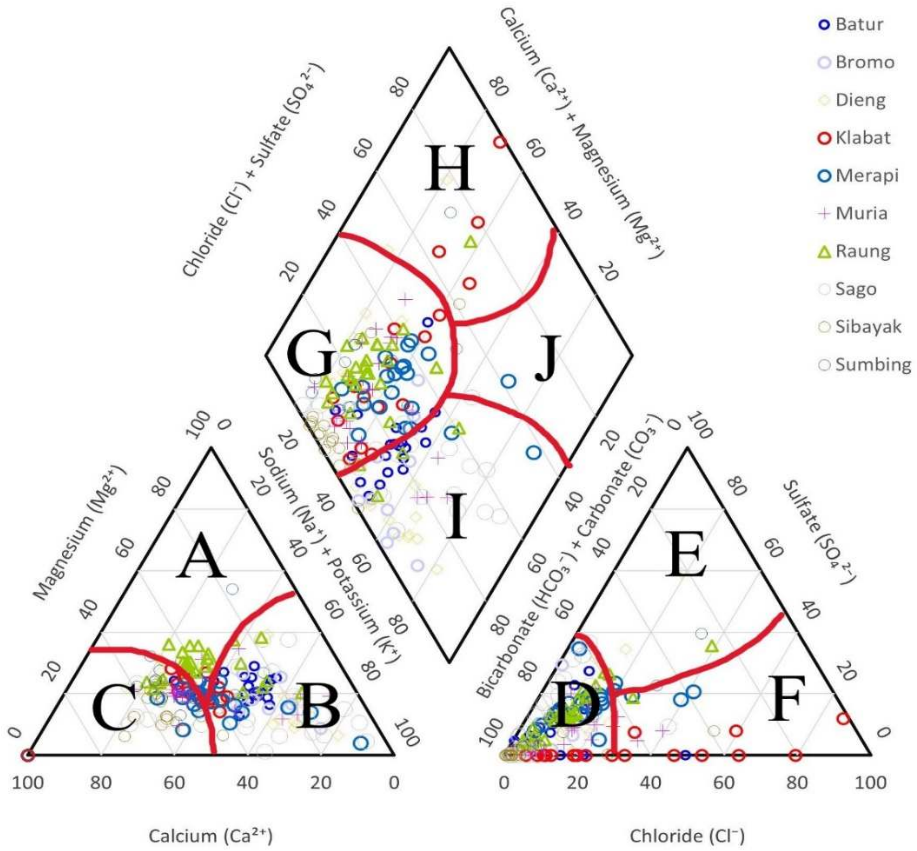

Figure 2. Piper diagram analysis of several groundwater in Indonesia.

The data distribution in the lower left triangle is dominant in code B with the sodium enrichment classification. Several minority data are included in the other codes, namely code H (calcium/magnesium sulfate pollution), I (sodium enrichment), J (sodium chloride contamination from natural sources), E (sulfate enrichment), F (chloride enrichment), and C (calcium enrichment). Overall, the analysis suggested that the majority of groundwater samples in Indonesia aligned with the unpolluted groundwater classification, as depicted across the three triangles.

The groundwater quality index analysis results in Indonesia conducted through the WQI method indicated predominantly positive outcomes. This is signified by 203 samples that fall into the excellent water classification while an additional 45 samples fall into the good water classification (Table 6). There is only 1 sample that is classified as poor water (DW.X.74) found in a dug well near the beach, 1 sample that is classified as very poor water (DW.X.72) in a dug well near the beach, and 1 sample unsuitable for drinking purposes (DW.VI.52) found in one of the dug well. These results exhibited that 98% of groundwater quality in Indonesia is still included in the good water quality classification for springs, drilled wells, and dug wells. The results of WQI groundwater in Indonesia show that groundwater in Indonesia is equally good and excellent compared to WQI in other countries in Iran, Ghana, China, India, and Brazil (Amiri et al., 2014; Varol and Davraz, 2015; Boateng et al., 2016; Li et al., 2021; Franz et al., 2022; Hingge et al., 2022). Poor groundwater quality (poor and very poor quality) is found on average near the coast (Gorgij et al., 2017; Jamshidzadeh, 2020; Prusty and Farooq, 2020; Sabino et al., 2020) due to increasing river pollution in the downstream areas and the influence of influx from seawater. This pattern of reduced groundwater quality near coastal areas is a common phenomenon observed not only in Indonesia but also in various countries worldwide.

Table 6. Classification of groundwater water quality index in Indonesia.

No	Code	WQI	Classification	No	Code	WQI	Classification
1	S.I.1	20.08	Excellent Water	107	BH.V.14	9.23	Excellent Water
2	S.I.3	19.05	Excellent Water	108	DW.V.37	17.05	Excellent Water
3	S.I.4	23.18	Excellent Water	109	DW.V.38	11.26	Excellent Water
4	S.I.5	19.14	Excellent Water	110	DW.V.39	17.28	Excellent Water
5	BH.I.1	19.10	Excellent Water	111	DW.V.40	12.50	Excellent Water
6	BH.I.2	18.46	Excellent Water	112	DW.V.41	26.75	Excellent Water
7	BH.I.3	17.14	Excellent Water	113	DW.V.42	22.19	Excellent Water
8	BH.I.4	17.08	Excellent Water	114	DW.V.43	16.38	Excellent Water
9	BH.I.5	17.36	Excellent Water	115	S.VI.59	7.38	Excellent Water
10	BH.I.6	18.39	Excellent Water	116	S.VI.60	9.15	Excellent Water
11	BH.I.7	17.86	Excellent Water	117	S.VI.61	18.50	Excellent Water
12	DW.I.1	17.90	Excellent Water	118	S.VI.62	18.77	Excellent Water
13	DW.I.2	25.57	Excellent Water	119	S.VI.63	6.34	Excellent Water
14	DW.I.3	22.35	Excellent Water	120	S.VI.64	28.35	Excellent Water
15	DW.I.4	18.16	Excellent Water	121	S.VI.65	5.95	Excellent Water
16	DW.I.5	24.25	Excellent Water	122	S.VI.66	8.87	Excellent Water
17	DW.I.6	23.80	Excellent Water	123	S.VI.67	9.63	Excellent Water
18	DW.I.7	28.78	Excellent Water	124	S.VI.68	9.34	Excellent Water
19	DW.I.8	29.47	Excellent Water	125	S.VI.69	19.28	Excellent Water
20	DW.I.9	18.32	Excellent Water	126	S.VI.70	12.62	Excellent Water
21	DW.I.10	22.89	Excellent Water	127	S.VI.71	8.01	Excellent Water
22	DW.II.11	40.74	Excellent Water	128	S.VI.72	7.80	Excellent Water
23	DW.II.12	45.65	Excellent Water	129	S.VI.73	18.91	Excellent Water
24	DW.II.13	44.18	Excellent Water	130	S.VI.74	8.08	Excellent Water
25	DW.II.14	30.78	Excellent Water	131	S.VI.75	16.83	Excellent Water
26	DW.II.15	29.60	Excellent Water	132	DW.VI.44	12.80	Excellent Water
27	DW.II.16	49.26	Excellent Water	133	DW.VI.45	28.25	Excellent Water
28	S.II.6	41.55	Excellent Water	134	DW.VI.46	20.37	Excellent Water
29	S.II.7	34.20	Excellent Water	135	DW.VI.47	8.84	Excellent Water
30	S.II.8	35.95	Excellent Water	136	DW.VI.48	4.44	Excellent Water
31	S.II.9	38.55	Excellent Water	137	DW.VI.49	35.21	Excellent Water
32	S.II.10	28.30	Excellent Water	138	DW.VI.50	17.81	Excellent Water
33	S.II.11	26.76	Excellent Water	139	DW.VI.51	20.06	Excellent Water

No	Code	WQI	Classification	No	Code	WQI	Classification
34	S.II.12	25.61	Excellent Water	140	DW.VI.52	348.17	Water unsuitable for drinking purpose
35	S.II.13	31.96	Excellent Water	141	DW.VII.53	54.26	Good Water
36	S.II.14	47.80	Excellent Water	142	DW.VII.54	37.82	Excellent Water
37	S.II.15	52.70	Good Water	143	DW.VII.55	39.40	Excellent Water
38	S.II.16	33.27	Excellent Water	144	DW.VII.56	36.72	Excellent Water
39	S.II.17	25.80	Excellent Water	145	DW.VII.57	32.03	Excellent Water
40	S.II.18	56.13	Good Water	146	DW.VII.58	28.20	Excellent Water
41	S.II.19	45.27	Excellent Water	147	DW.VII.59	23.64	Excellent Water
42	S.III.20	44.56	Excellent Water	148	DW.VII.60	31.92	Excellent Water
43	S.III.21	29.25	Excellent Water	149	DW.VII.61	38.29	Excellent Water
44	S.III.22	48.03	Excellent Water	150	DW.VII.62	43.63	Excellent Water
45	S.III.23	44.20	Excellent Water	151	DW.VII.63	50.15	Good Water
46	S.III.24	32.19	Excellent Water	152	DW.VII.64	43.83	Excellent Water
47	S.III.25	28.51	Excellent Water	153	DW.VII.65	47.24	Excellent Water
48	S.III.26	28.54	Excellent Water	154	DW.VII.66	44.17	Excellent Water
49	S.III.27	22.53	Excellent Water	155	DW.VII.67	62.50	Good Water
50	S.III.28	19.50	Excellent Water	156	S.VII.76	32.40	Excellent Water
51	S.III.29	23.64	Excellent Water	157	S.VII.77	35.30	Excellent Water
52	S.III.30	22.44	Excellent Water	158	S.VII.78	70.93	Good Water
53	S.III.31	19.47	Excellent Water	159	S.VII.79	24.58	Excellent Water
54	S.III.32	42.14	Excellent Water	160	S.VII.80	25.30	Excellent Water
55	S.III.33	37.70	Excellent Water	161	S.VII.81	25.87	Excellent Water
56	S.III.34	42.49	Excellent Water	162	S.VIII.82	39.22	Excellent Water
57	BH.III.8	53.13	Good Water	163	S.VIII.83	25.90	Excellent Water
58	BH.III.9	38.25	Excellent Water	164	S.VIII.84	31.10	Excellent Water
59	DW.III.17	39.29	Excellent Water	165	S.VIII.85	24.67	Excellent Water
60	DW.III.18	52.35	Good Water	166	S.VIII.86	28.76	Excellent Water
61	DW.III.19	42.29	Excellent Water	167	S.VIII.87	28.19	Excellent Water
62	DW.III.20	91.20	Good Water	168	S.VIII.88	29.19	Excellent Water
63	DW.III.21	36.00	Excellent Water	169	S.VIII.89	20.31	Excellent Water
64	DW.III.22	43.29	Excellent Water	170	S.VIII.90	28.26	Excellent Water
65	DW.III.23	44.39	Excellent Water	171	S.VIII.91	26.78	Excellent Water
66	DW.III.24	41.97	Excellent Water	172	S.VIII.92	40.99	Excellent Water
67	S.III.35	41.31	Excellent Water	173	S.VIII.93	33.68	Excellent Water
68	S.III.36	40.85	Excellent Water	174	BH.VIII.18	26.04	Excellent Water
69	S.IV.37	33.07	Excellent Water	175	BH.VIII.19	48.07	Excellent Water
70	S.IV.38	31.36	Excellent Water	176	DW.VIII.68	47.32	Excellent Water
71	S.IV.39	32.56	Excellent Water	177	DW.VIII.69	28.63	Excellent Water
72	S.IV.40	37.32	Excellent Water	178	DW.VIII.70	29.28	Excellent Water
73	S.IV.41	27.65	Excellent Water	179	DW.VIII.71	31.98	Excellent Water
74	S.IV.42	38.23	Excellent Water	180	S.IX.94	35.89	Excellent Water
75	S.IV.43	18.65	Excellent Water	181	S.IX.95	28.51	Excellent Water
76	S.IV.44	24.24	Excellent Water	182	S.IX.96	32.80	Excellent Water
77	S.IV.45	27.15	Excellent Water	183	S.IX.97	25.33	Excellent Water
78	S.IV.46	21.13	Excellent Water	184	S.IX.98	37.75	Excellent Water
79	S.IV.47	32.34	Excellent Water	185	S.IX.99	32.55	Excellent Water
80	BH.IV.10	65.88	Good Water	186	S.IX.100	37.03	Excellent Water
81	DW.IV.25	57.68	Good Water	187	S.IX.101	22.65	Excellent Water
82	DW.IV.26	42.04	Excellent Water	188	S.IX.102	22.66	Excellent Water
83	DW.IV.27	62.92	Good Water	189	S.IX.103	22.55	Excellent Water
84	DW.IV.28	73.43	Good Water	190	S.IX.104	49.39	Excellent Water
85	DW.IV.29	51.20	Good Water	191	S.IX.105	42.77	Excellent Water
86	DW.IV.30	52.55	Good Water	192	S.IX.106	18.56	Excellent Water
87	DW.IV.31	65.13	Good Water	193	S.IX.107	50.67	Good Water
88	DW.IV.32	67.14	Good Water	194	S.IX.108	28.03	Excellent Water

No	Code	WQI	Classification	No	Code	WQI	Classification
89	DW.IV.33	37.02	Excellent Water	195	S.IX.109	27.89	Excellent Water
90	DW.IV.34	43.38	Excellent Water	196	S.IX.110	24.00	Excellent Water
91	DW.IV.35	32.95	Excellent Water	197	S.IX.111	31.32	Excellent Water
92	DW.IV.36	32.08	Excellent Water	198	S.IX.112	26.38	Excellent Water
93	S.V.48	14.58	Excellent Water	199	S.IX.113	22.03	Excellent Water
94	S.V.49	20.78	Excellent Water	200	S.IX.114	34.79	Excellent Water
95	S.V.50	16.37	Excellent Water	201	S.IX.115	24.31	Excellent Water
96	S.V.51	19.13	Excellent Water	202	S.X.116	30.79	Excellent Water
97	S.V.52	14.75	Excellent Water	203	S.X.117	41.05	Excellent Water
98	S.V.53	15.60	Excellent Water	204	S.X.118	23.27	Excellent Water
99	S.V.54	19.06	Excellent Water	205	S.X.119	21.14	Excellent Water
100	S.V.55	17.99	Excellent Water	206	S.X.120	21.55	Excellent Water
101	S.V.56	20.53	Excellent Water	207	S.X.121	20.00	Excellent Water
102	S.V.57	17.31	Excellent Water	208	S.X.122	23.84	Excellent Water
103	S.V.58	14.77	Excellent Water	209	DW.X.72	226.73	Very Poor Water
104	BH.V.11	17.72	Excellent Water	210	DW.X.73	45.50	Excellent Water
105	BH.V.12	18.93	Excellent Water	211	DW.X.74	171.31	Poor Water
106	BH.V.13	19.82	Excellent Water				

The results of the correlation analysis revealed that all parameters have a positive linear relationship with WQI, and almost all parameters have a strong linear relationship with WQI (Table 7). Parameters strongly correlated with WQI are K^+, Na^+, Ca^{2+}, SO_4^{2-}, Cl^-, and HCO_3^-. These results proved that these six parameters significantly affect WQI operations. The parameters TDS and Mg^{2+} are known to have a positive linear correlation but are low, so they do not appear to strongly influence WQI. The results of the strong correlation between WQI and the parameters K^+, Na^+, Ca^{2+}, SO_4^{2-}, Cl^-, and HCO_3^- are considered on par with the research conducted (Varol and Davraz, 2015; Boateng et al., 2016; Jesuraja et al., 2021).

The outcomes of multiple linear regression analysis (Table 8) produce a constant value of 7,678, indicating that in the absence of any alterations in the independent variables (K^+, Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, HCO_3^-, and TDS), thus the dependent variable (WQI) will have a value of 7,678. The significance value for all variables is known to be 0.000. The significance value is <0.05. Thus, it can be concluded that all variables have a significant influence on the WQI variable.

The regression coefficient on the K^+ (X1) variable is + 0.984. This positive correlation shows that if the K^+ variable experiences a significant increase of 1 point while the other independent variables have a fixed value, then the value of the WQI variable will increase by 0.984.

This also applied to other variables, all of which have a positive correlation and will increase the WQI value by the amount displayed in Table 8 for every variable increase of 1 point. In the table, it is known that the regression coefficient on the variable Na^+ (X2) is + 1.052; on the variable Mg+ (X3), it is + 0.945, on the variable Ca^{2+} (X4) it is + 1,080, on the variable SO_4^{2-} (X5) it is + 0.913, on the Cl^- (X6) variable is + 0.900, on the HCO_3^- (X7) variable is + 1,040, and on the TDS (X8) variable is + 1,064. The same patterns are also found in other studies, which revealed that the parameter variables of K^+, Ca^{2+}, Mg^{2+}, Cl^-, Na^+, TDS, and pH had a significant influence on WQI (Prusty and Farooq, 2020; Franz et al., 2022).

Table 7. Correlation results between parameters.

Variable	K^+	Na^+	Mg^{2+}	Ca^{2+}	SO_4^{2-}	Cl^-	HCO_3^-	TDS	pH	WQI
K^+	1									
Na^+	0.860*	1								
Mg^{2+}	0.276*	0.297*	1							
Ca^{2+}	0.223*	0.315*	0.066	1						
SO_4^{2-}	0.391*	0.505*	0.503*	0.517*	1					
Cl^-	0.333*	0.619*	0.099	0.494*	0.460*	1				
HCO_3^-	0.262*	0.442*	0.379*	0.771*	0.461*	0.340*	1			
TDS	0.476*	0.691*	0.224*	0.748*	0.615*	0.883*	0.645*	1		
pH	0.012	0.066	-0.033	0.380*	0.090	0.093	0.360*	0.232*	1	
WQI	0.837*	0.906*	0.353	0.626*	0.640*	0.683*	0.626*	0.858*	0.205	1

Note: (*) indicates a significant correlation between two parameters.

Table 8. Multiple linear regression results.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	7.678	.142		54.249	.000
	K^+	.984	.015	.484	64.591	.000
	Na^+	1.052	.068	.147	15.370	.000
	Mg^{2+}	.945	.081	.044	11.690	.000
	Ca^{2+}	1.080	.049	.155	22.255	.000
	SO_4^{2-}	.913	.073	.050	12.423	.000
	Cl^-	.900	.069	.118	13.118	.000
	HCO_3^-	1.040	.067	.109	15.623	.000
	TDS	1.064	.061	.194	17.347	.000

a. Dependent Variable: WQI

Conclusion

Based on research conducted in this paper, it has been established that 98% of groundwater quality in Indonesia falls within the excellent and good categories, with only 2% of exceeding the standard threshold locally in several locations. Furthermore, groundwater across Indonesia predominantly maintains classification within the unpolluted groundwater category. The elements K^+, Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, HCO_3^-, TDS, and pH are also known to influence the quality of groundwater in Indonesia strongly. In summary, the overall quality of groundwater in Indonesia remains highly suitable for consumption as drinking water.

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