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Hydrogeophysical, Environmental and Groundwater Potential Assessment in the Ternate Basin, North Maluku Province, Indonesia

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Abstract: Ternate Island is a volcanic island resulting from the activity of the Gamalama Volcano which is located in the northern Maluku archipelago, Indonesia. Ternate Island is famous as the only island that produces special spices and is the zero point of the world's spice route because the main producer of cloves is here. As a small island, Ternate Island has several limitations including the availability of water resources. Given the scarcity of surface water on the island of Ternate, groundwater in shallow aquifers and deep aquifers is the main source of fresh water which is important for irrigation activities, tourism, services and supporting urban and industrial infrastructure, as well as drinking water needs for people who live densely and are concentrated in the east. and the southern part of the island which is now the city of Ternate. The phenomenon of groundwater utilization in Ternate City is generally massively carried out to support economic activities in the city of Ternate. The purpose of this study was to evaluate the potential and quality of groundwater resources which are an important part of water management on the island of Ternate by microzoning the quality of groundwater for the sustainability of the city which is famous as the world's spice city based on its groundwater potential. Determination of groundwater samples as many as 67 wells distributed on the island of Ternate, 58 well sample points were categorized as free aquifers (MA-SG) and 7 points of depressed aquifers (SB). Ternate island area of 102 km^2 with volcanic geology in 3 rock categories. Geological distribution also affects the hydrogeological potential and groundwater quality on the island of Ternate. Piper's trilinear diagram and stiff diagram methods were adopted for the assessment of the main ion quality of groundwater and the distribution of groundwater potential was interpolated with cubic splines to obtain correlations between sample points based on basic parameters of volcanic hydrogeology. The total potential for groundwater recharge is 1,291 million m^3/year, there are 5 groundwater quality zones spread among 67 sample points with 76% distribution of elements Calcium Bicarbonate ($CaCO_3$), Sodium Bicarbonate ($NaHCO_2$), magnesium bicarbonate $Mg(HCO_3)_2$ and widely distributed on the island of ternate, while 25% magnesium chloride ($MgCl_2$) and potassium chloride (KCL) are scattered locally on the island of ternate. On an ongoing basis the bicarbonate facies micro-zonation is hydrogeochemical with local flow interactions in volcanic deposits, where infiltration tends to be close to the groundwater sample point, while the chloride facies is a groundwater zone that is correlated with flow patterns from upstream to downstream and has interacted with magma or was intruded. seawater is characterized by high Ca and TDS.

Keywords: Aquifer, Ternate Island, Regional geology, Groundwater potential, Hydrogeochemistry zone.

1. Introduction

The hydrogeology of an area is very dependent on the geological and morphological conditions of the area [1].307). Based on the condition of the Ternate Groundwater Basin (GBA) which is a volcanic island, it is included in the strato volcanic which is characterized by a radial groundwater flow direction, which flows from the top of the strato to the foot of the volcano[2]. Volcanic groundwater quality is generally of good quality. Aquifer productivity from the body to the foot of the volcano is generally high because it is formed by loose volcanic material, especially in young volcanoes[3].

Groundwater is water that occupies the voids in the geological layer in a saturated state in sufficient quantities. The existence of groundwater is highly dependent on the amount of rainfall and infiltration. Another factor that affects the presence of groundwater is the local environmental conditions[2], [3].

Geological structures that have high permeability will facilitate infiltration, on the other hand a compact geological structure has very small infiltration, so that the implications for rainfall will be quite high runoff. On the other hand, the conversion of land into residential and agricultural industries and even massive damage to the upstream zone greatly affects the occurrence of infiltration[4], [5].

Location of the study site

The geological spatial variation of Indonesia and the Ternate Groundwater Basin (GWBA) as a research area of 102 km^2, is presented in Figure 1 below.

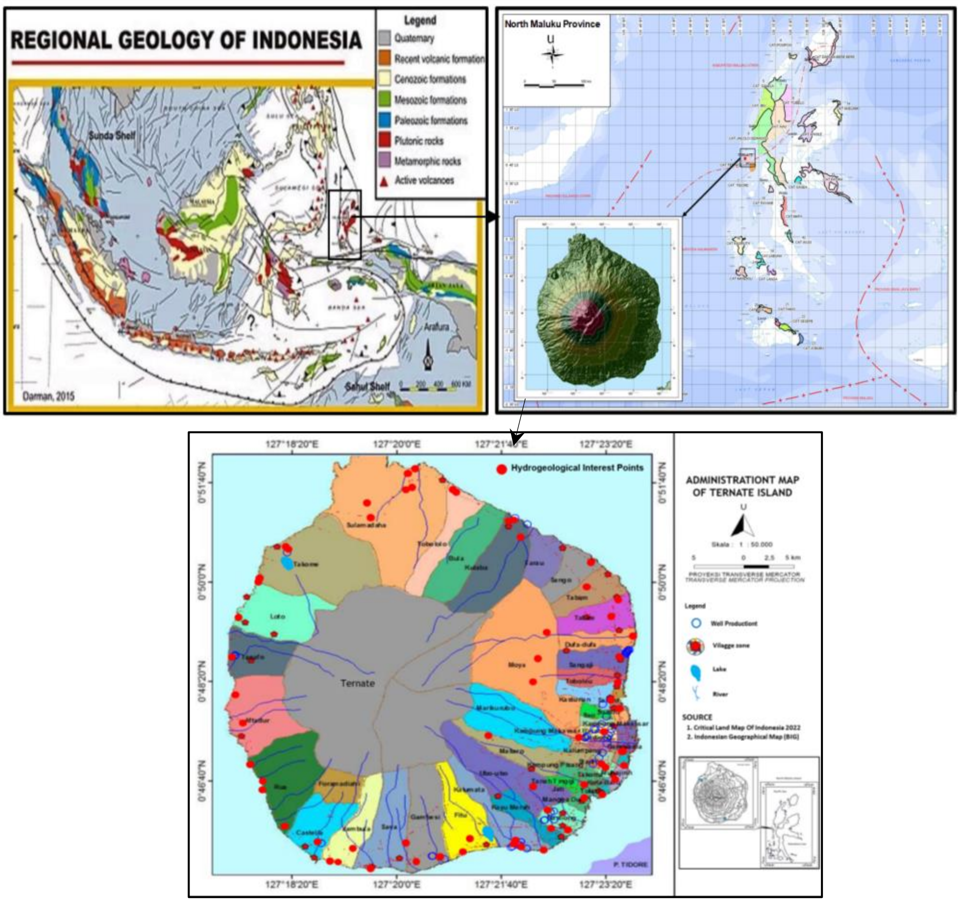

Figure 1 Map of the geological area of Indonesia and the Ternate groundwater basin.

The zoning of groundwater potential and its facies has not been specifically carried out, coupled with the massive extraction of groundwater in the fulfillment of economic activities, which greatly affects the quality and quantity of groundwater. In order to have a good impact on the surrounding environment, groundwater extraction must take into

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account the geological characteristics, aquifer potential, and basic hydrogeological parameters of the study area.

The research was conducted on Ternate Island (figure 1), North Maluku Province, Indonesia. Geologically, this area is located between three major tectonic plates, the Pacific Plate, the Eurasian Plate and the Australian Plate. Ternate Island is administratively located at the coordinates of 3^0 NL 3^0 SL and 124^0–129^0 EL, consisting of 78 villages with a population of 205,204 people 2021.

2. Materials and Methods

2.1 Regional Geological and Hydrogeology Setting

Ternate Island was formed by the volcanic activity of Mount Gamalama which occurred above the subduction zone and predominantly tilted to the east with a small angle[2]. The morphology of the island of Ternate with Mount Gamalama is generally gentle on the coast but gets steeper to the peak zone. The rock on the island of Ternate consists of three generations: waste rock from Gamalamaapi activity consisting of old Gamalama rock, Adult Gamalama rock, and young Gamalama rock[6].

Gamalama's old rock remains were found in the southeast and south of Ternate Island. Its peak is known as Bukit Melayu and extends from northeast to southwest. The mature Gamalama waste rock is located on the lower slopes of the western part of Ternate Island. Its peak, known as the Holy Hill or the Mount of Medina, stretches from west to east. Young rocks from the remains of the Gamalama volcanic activity are found in the northern part with the peak known as Arafat Hill or Piek van Ternate, considered a lava flow area. Regional geology of ternate, North Maluku[7]. (figure 2).

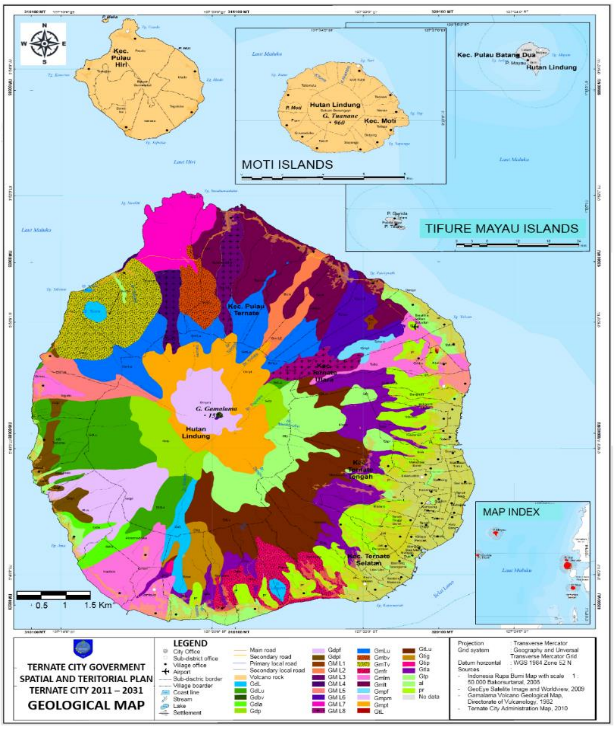

Figure 2. Geological map of Ternate

The results of field observations based on Figure 1 show that the activity of the Gamalama stratovolcano is very dominant in forming Ternate Island. This activity is evidenced by traces of the presence of rocks scattered in three segments on the island of

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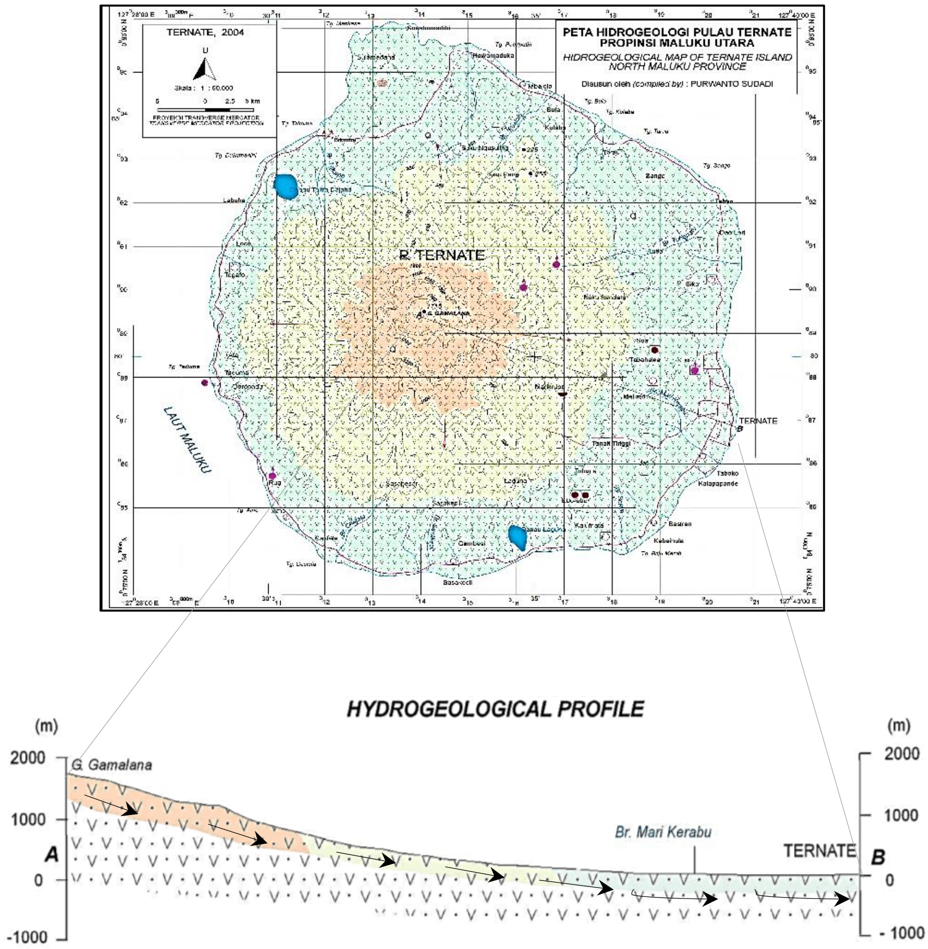
Ternate, the distribution of volcanic rocks dominates the geomorphology of the island of Ternate and consists of 3 morphological categories, including peak geomorphology, island body geomorphology (middle), and island subslope geomorphology. This morphology is the focus for groundwater potential on the island of Ternate and the influence of lithology and morphology that slopes towards the coast are analyzed for groundwater facies on the island of Ternate for the sustainability of the city of Ternate,[2],[8]. Hydrogeology is a measure to determine the groundwater potential of an area, generally small islands have unique hydrological characteristics. Its characteristics are low rainfall, small rain catch, high runoff, and high vulnerability to seawater intrusion,[9] The hydrogeological character of the island of Ternate can be seen in Figure 3.



Source: Own Study

Figure 3. Hydrogeologycal Profil Of Ternate

For geomorphology of the middle slope with an area of ± 42.10 km², from an elevation of 160-650 masl. Holocene Volcanic Rocks (Qhv) with lithology generally dominant in the form of breccia and non-solid lava. The geomorphology of the peak of Ternate Island is at an altitude of 650-1715 masl, with an area of ±3.36 km², the lithology of Holocene volcanic rocks (Qhv), generally composed of low compact material produced by lava flows. The flow pattern that occurs is radial-centrifugal. The type of river that flows in this zone is intermittent. The morphology of the island of Ternate has not been much touched by the cultivation activities of the local community, it is still a very fertile forest.

This zone is thought to be a good catchment, the typology of the land is generally still in the form of forests, plantations, and springs and there are local residents' settlements. While the geomorphology of the lower slopes is spread over an area of ± 56.09 km^2, starting from the coast of the island to a height of 160 meters above sea level with Holocene (Qhv) rocks, the lithology is generally in the form of breccia, lava that is not compact. The land in this morphology is used for plantations and residential centers and there are several springs. This morphological zone is the focus of research while still paying attention to lithology for the development of groundwater chemical facies. The main cause of the potential and quality of groundwater is rich in Na^+ minerals and anion elements in the form of Chloride (CL^-) and sulfate minerals (SO_4^{2-}) tend to be found in alluvial plains. To answer this question, a chemical analysis of groundwater was carried out at the selected sample points.

2.2 Climate and Profile of Ternate Island

Ternate is characterized by a tropical humid climate with average monthly precipitation of 180-250 mm, except from August until October is very low around 90-120 mm,[2] The amount of rainfall tends to increase from February to May and from September to December every year (Fig 3A), and a temperature range from 24.8 to 28.2°C Fig (3B), while Humidity is ranged from 78 to 85% (Fig 3C),

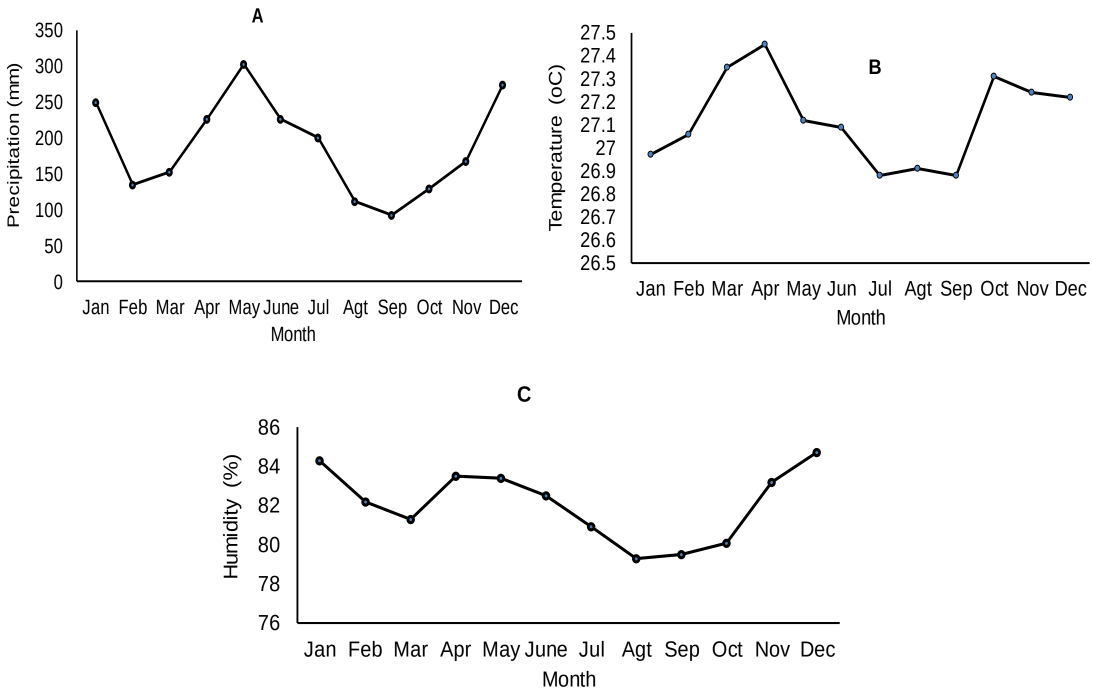


Figure 4. Precipitation (A), temperature (B), and humidity (C) in Ternate

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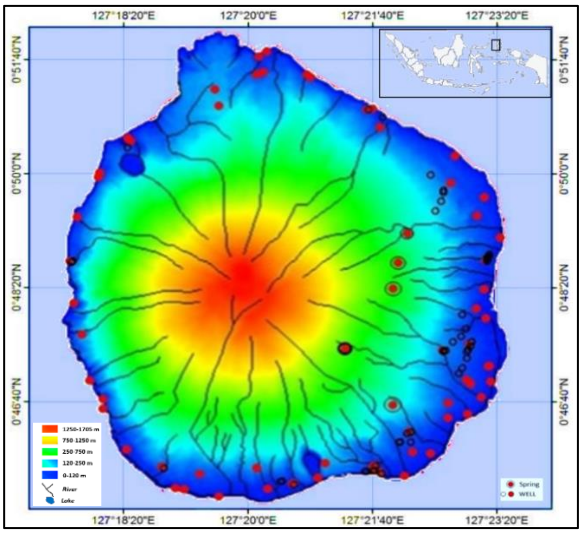
2.3 Hydrogeological Parameters Groundwater Sample of Collection and Laboratory Analyses



Source: Own Study

Figure 5. Distribution of Groundwater Samples on Ternate Island (DEM)

The parameter that will be used to carry out hydrogeological calculations on the island of Ternate is the recharge coefficient for determining the potential of free groundwater and transmissivity (T), slope, and the cross-sectional width of the segment is determined by the Darcy equation for the compressed groundwater potential[10].

$$\mathbf{Q = T.i.L} \quad (1)$$

Where:

Q = Potential of groundwater (m^3/day)

T = Transmissivity aquifer (m^2/day)

i = Hydraulic Slope (%)

L = Cross-sectional width (m)

while the distribution of potential and groundwater quality at 67 sample points of wells and springs in the Ternate Groundwater Basin, North Maluku Province, Indonesia, based on the sample map as shown in Figure 4 can be described in (Table1).

Table 1. Hydrogeological Interest Points on Ternate Island, North Maluku, Indonesia

No	Code	Elev (masl)	Depth (m)	Well type	Well Diameter m/inch	SWL (m)	EC (µS/cm)	Temp (⁰C)	pH	TDS (mg/l)
1	MA.1	14	0		0	0	306	30	6.8	215
2	MA.2	102	0		0	0	152	28	7	101
3	MA.3	402	0		0	0	44	28	7	31
4	MA.4	308	0		0	0	70	27	7	46
5	MA.5	46	0	Springs	0	0	48	28	7.8	36
6	MA.6	162	0		0	0	147	27	7.9	99
7	MA.7	3	0		0	0	650	31	7	432
8	MA.8	11	0		0	0	1485	29	7.4	996
9	MA.9	342	0		0	0	123	27	7	82
10	SG.1	58	36.76		1	29	331	30	6.6	257

11	SG.2	19	4,6		1	4	754	30	6.9	516
12	SG.3	17	2.85		1	1	312	33	6.9	209
13	SG.4	21	5.56		1	3	530	32	6.7	249
14	SG.5	24	15		1	9	693	32	6.8	451
15	SG.6	24	13.09		1	11	693	32	6.8	451
16	SG.7	11	1.6		1	1	614	30	6.7	409
17	SG.8	11	1.55		1	1	633	29	7.1	439
18	SG.9	29	20.63		2	19	321	27	6.6	213
19	SG.10	10	3		1	2	486	30	6.7	325
20	SG.11	18	4.3		1	3	458	29	6.7	307
21	SG.12	13	2.1		1	1	725	30	6.8	486
22	SG.13	21	8.7		1	7	677	30	7.2	453
23	SG.14	12	2.75		1	2	543	29	6.8	362
24	SG.15A	43	14.7		1	14	516	29	6.7	344
25	SG.15B	19	1.85		1	1	521	29	6.7	347
26	SG.16	15	2.1		1	1	518	29	6.7	345
27	SG.17	37	23.05		2	22	570	30	6.6	383
28	SG.18	24	9.4		1	8	523	28	6.6	355
29	SG.19	13	2.6		1	2	885	29	6.8	589
30	SG.20	17	8.4	Un-	1	8	377	29	6.7	251
31	SG.21	13	6.28	saturated	1	6	468	28	7	314
32	SG.22	3	5.65	Zone	1	5	395	29	6.8	267
33	SG.23	13	5.25	Aquifer	1	2	395	29	6.8	267
34	SG.24	24	16.5		2	15	158	31	7.2	106
35	SG.25	14	2		2	2	158	31	7.2	106
36	SG.26	13	2.85		2	2	2190	33	7.8	1467
37	SG.27	22	7.41		8	6	412	29	7.7	275
38	SG.28	17	9.9		1	6	826	29	6.9	554
39	SG.29	8	2.5		1	2	107	31	7.4	74
40	SG.30	14	5.1		8	5	3600	37	7.4	2393
41	SG.31	93	3.68		1	3	604	32	7.9	394
42	SG.32	82	3.5		2	3	596	32	7.9	395
43	SG.33	13	6.8		1	6	596	32	7.9	395
44	SG.34	8	1.8		1	2	248	32	7.3	168
45	SG.35	12	2.1		2	1	595	29	7.7	400
46	SG.36	12	2.5		1	2	798	28	7.2	533
47	SG.37	15	5.6		2	3	369	29	7.3	247
48	SG.38	13	2.25		1	2	352	29	7.1	235
49	SG.39	13	3.8		1	2	430	29	7.2	278
50	SG.40	27	6.46		1	6	348	29	6.7	233
51	SG.41	25	6.72		1	6	4030	29	7.5	2113
52	SG.42	36	2.2		1	2	516	30	7.1	344
53	SB.1	19	60		6	3	895	31	6.8	599

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54	SB.2	40	72		6	25	899	30	6.8	599
55	SB.3	70	105		6	54	895	30	6.8	599
56	SB.4	40	60		6	23	895	29	6.8	599
57	SB.5	54	80		6	33	895	29	6.8	599
58	SB.6	10	8		8	3	568	28	6.7	377
59	SB.7	14	9.9		8	6	895	30	6.8	599
60	SB.8	32	34.7	Saturated Zone Aquifer	8	4	106	29	7.3	71
61	SB.9	22	9.3		4	7	109	29	7.3	72
62	SB.10	92	120		6	6	112	29	7.3	86
63	SB.11	13	7.7		8	6	1300	33	7.2	983
64	SB.12	38	110		8	29	489	29	6.5	449
65	SB.13	32	100		1	22	544	29	6.5	400
66	SB.14	18	100		8	19	568	29	6.5	520
67	SB.15	61	110		8	50	568	29	6.5	400

3. Methods

The cubic spline of QGIS and piper diagrams were adopted as methods for the analysis of hydrogeological points of interest and groundwater distribution based on facies and hydrogeochemistry of groundwater in the Ternate Basin in a comprehensive manner and distribution of potential and groundwater quality for sustainable development of Ternate City with 67 hydrogeological points of interest in the Ternate Basin, North Maluku province, Indonesia (table1).

3.1 Sampling and Analytical Techniques

The output of the quantitative data analysis is a map of the distribution of hydrogeological points and the distribution of the groundwater table for the groundwater potential of the study area. Furthermore, a hydrophysical and environmental analysis was carried out based on morphology and lithology to interpret the flow direction and groundwater facies on the island of Ternate to support micro-zonation of groundwater quality, both in the free aquifer zone and the confined aquifer, such as the sample points in Figures 1 and 4.

This paper estimates groundwater recharge from rainfall by empirical methods, including an analysis of the recharge coefficient for baseflow separation techniques. Climatic data obtained from the Regional Meteorology and Geophysics Agency 1 Babullah Ternate, the basic parameters of the aquifer including Transmissivity (T), Hydraulic Slope (i), and Area Segments were selected as many as 9 zones within the Ternate island area to estimate the magnitude of the rainfall recharge component, the potential for depressed aquifers and water balance.

4. Results and Discussion

4.1 Ternate Basin Aquifer Potential

To describe the potential of aquifers in the Ternate Basin, 67 well points as sample points were used in this research, consisting of 58 shallow wells (SG) spread over Ternate Island, an average well depth of 1.6 m– 38 m and 9 deep well points (SB) with an average depth of 40 m-120 m, visually the groundwater potential can be described based on qubic spline analysis on QGis software by interpolating to obtain correlations between well sample points in this research, the correlation used is connecting the outermost sample points, considering the complexity of the morphology of the study area when measuring the sample point, setting the SWL at maximum pont at a tolerance of 80 for single band, for interpolated surface extraction of 1-3 m interpolated, vector geometry is processed and determination of polygons and counters, then cubic spline interpolation (CSI) is considered appropriate. and efficient in the model for determining the potential and distribution of groundwater in the island of Ternate (figure 6).

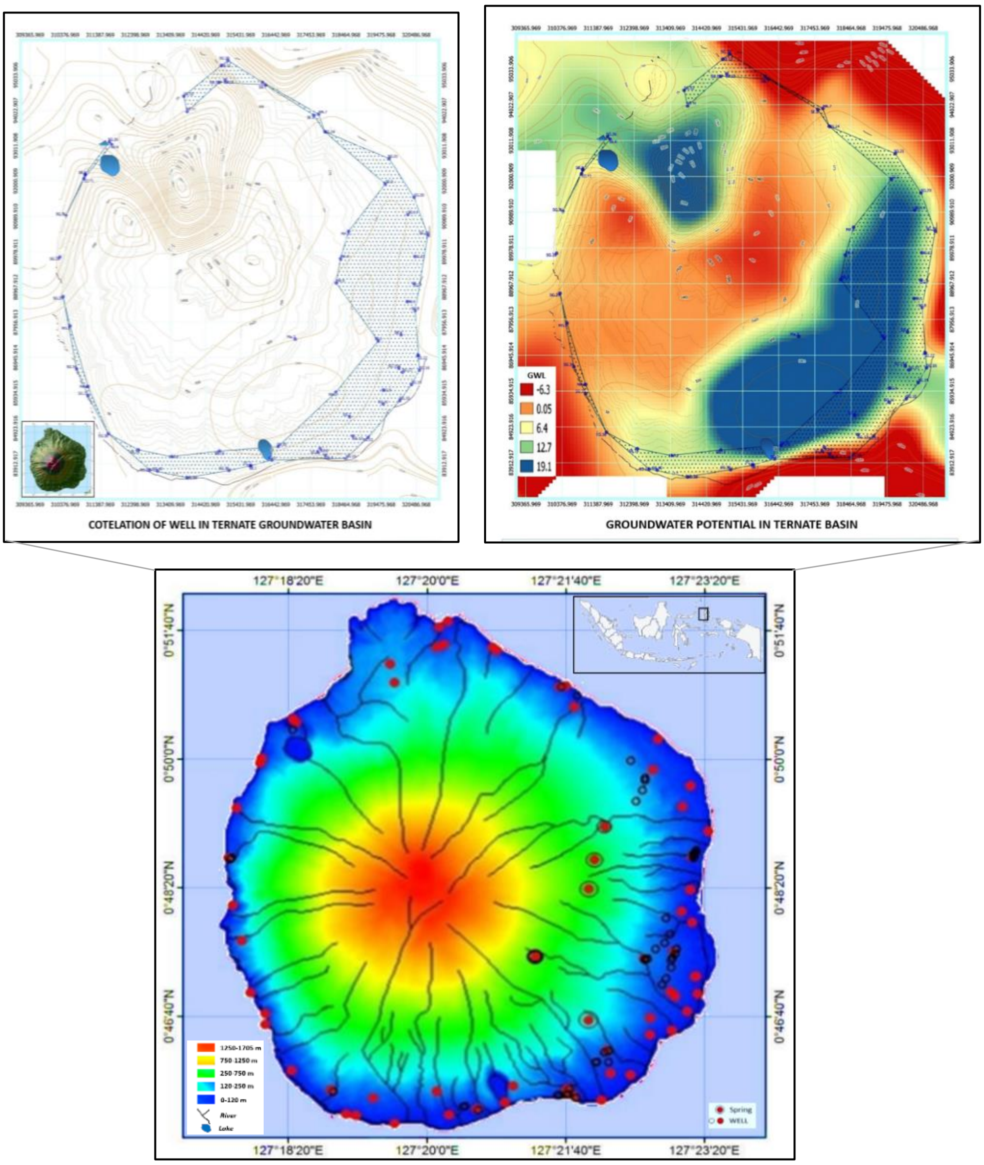

Figure 6. Correlation and distribution of Potential Groundwater Area (GBA) in Ternate

The same thing is also done in identifying the groundwater level to get the direction of groundwater flow on the island of Ternate. The main characteristic of volcanic aquifers is that they have good groundwater potential and quality. To determine the potential for groundwater recharge, the study area still pays attention to the basic hydrogeological parameters and the Darcy equation is adopted to determine the potential value of groundwater in the Ternate Basin (Ternate Island). Different from previous researcha,[2], [10–14]

Figure 6a shows that the correlation between the hydrogeological point of interest (well) and the distribution of the groundwater table is between 0.46-54 m. The average data for artesian wells has a depth of 100 m, this shows that the aquifer thickness is between 20-50 m so that the aquifer production category is high. The morphology of the island of Ternate has previously shown that the distribution of 3 rocks (aquifers) from the activity of the Gamalama volcano also shows the potential for groundwater in each rock segment with fairly good permeability (table 2-3). High production is found on the lower slopes of the island of Ternate which spreads to the shoreline as a constant head (figure 6b) the distribution of the groundwater table is correlated with the hydrogeological point analyzed. The cubic spline interpolation method was adopted to determine the distribution of the unrecorded groundwater level and to determine the point that effective and considered ideal for sustainable groundwater extraction on the island of Ternate. Consistent with this result is also conveyed by,[15]. The basin-scale hydraulic properties can be estimated using groundwater level fluctuation data. The geological and hydrogeological components of an area as well as the main role of the value of the hydraulic conductivity to its groundwater potential

The centrifugal radial flow pattern has a characteristic where the flow direction is in all directions and leads to a point in 2D visuals to facilitate the analysis of the distribution of facies and contaminants to groundwater carried through the flow that passes through the soil media. The characteristics of groundwater flow like this are strongly influenced by the shape of the volcanic cone that encircles the island of Ternate. Parallel flow has characteristics and directions of flow that are parallel to each other. For groundwater flow distribution, the hydrogeological interest points of MA.3 were analyzed spatially and temporally starting from a height of 402 m which is relatively parallel from upstream to the coast of Ternate in a steady state. This interaction is influenced by the Gamalama Volcano deposit with a hilly morphology that surrounds the island of Ternate.,[2], [16]. The spatial-temporal results shown in Figure 6a-& b, are then analyzed for sustainability, considering population growth is a good correlation to facilitate the determination of groundwater sample points, considering the morphology and volcanic geology for groundwater distribution. It is strongly suspected that large-scale groundwater extraction is carried out and has a negative impact on the environmental sustainability of an area, both groundwater quality, groundwater level decline, and of course environmental damage,[17]. then analyzed quantitative data between morphological zones of the island of Ternate

4.2 Free Aquifer Zone on Ternate Island

The distribution of groundwater level is from 0-18 m for shallow groundwater, while the artesian groundwater is spread locally between 35-50 m and still follows the morphology of the ternate island, there are two basins and their potential (figure 6a-b), in the lower zone of Mount Gamalama there is a basin large area on the northeast-southeast side of the island of Ternate and a small local potential basin in the upper-middle zone of the island of Ternate at an elevation of 425 msl (figure 6b). jika dikorelasikan dengan beberapa penelitian sebelumnya, [19], [20]The specific groundwater configuration in

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shallow groundwater was analyzed empirically based on the infiltration coefficient between 20%-30% taking into account the lithological conditions between the upper, middle and lower zones of the morphology of the island of Ternate, then the groundwater potential was 52.98 million m3/year (table 2). The geology and morphology are different from previous research, [13], [18], [20].

Table 2. Calculation of Unconfined groundwater recharge (free aquifer) in Ternate

Lythology	Rock Zone	Recharge Coefficien (%)	Annual Rainfall (mm/year)	Area (km^2)	*Recharge area* (million m3/year)
Gamalama	Upper Zone	0.2	1890.44	3.36	1.27
stratovolcano	Midle Zone	0.25	1890.44	42.10	19.90
(young rock)	Bottom Zone	0.30	1890.44	56.09	31.81
			Total	**101.55**	**52.98**

Source: Own Study

The results are in table 2. Calculation of Unconfined groundwater recharge (free aquifer) in Ternate becomes a reference for estimating the potential for groundwater in deep wells and their hydrogeochemistry on Ternate Island to be developed as the only source of drinking water in this volcanic island. Based on previous studies, [12], [20–23], where there are fundamental differences in geology, morphology and lithology. This is intended to obtain groundwater quality between zones that can be used as a potential as well as a source of drinking water and for other economic activities.

4.3 Saturated Aquifer Zone In Ternate Island

Like free groundwater, the potential for compressed groundwater on Ternate Island has a characteristic flow (radial-centrifugal) spreading from the peak zone to the discharge area at the foot of the island of Ternate. Based on the 3 rock segments in Ternate Island above, the analysis of groundwater potential in deep wells (SB) uses the Darcy equation. Based on Figures 3, 4, and 6, as well as Table 2, the pattern of groundwater flow according to the hydrogeological profile of Ternate with groundwater flow is radial-tangential from the peak zone to the foot of the Ternate island between segments, including the value of groundwater transmissivity (T), hydraulic gradient (i)), and the width of the groundwater flow segment (L). The results of the analysis of the potential for groundwater subsidence are shown in table 3 below. Based on the flow segment in previous research, for the development of a developing city such as the city of Ternate with the branding of the Spice City, [12], [21–23]deep groundwater (SB) becomes a reference to be managed because it has good water quality.

Table 3. Calculation of Compressed Groundwater Flow Patterns (Saturated Aquifer Zone)

Flow Segment	Zone	Transmisivitas (T) (m^2/day)	Hydrolic Slope (i)	Segmen Wigth (L) (m)	Debit (Q) (m^3/day)
NE-SE	1	6537.60	0.014	2500	233.490.38
	2	6537.60	0.010	2600	169.977.60
	3	3559.68	0.011	4400	174.027.06
SE-N-W	4	27.65	0.012	6200	2.016.73
	5	27.65	0.013	1400	483.84
	6	27.65	0.020	2100	1.161.22
	7	27.65	0.020	4800	2.654.21
W-S-SE	8	6537.60	0.014	3800	354.905.38
	9	6537.60	0.014	3200	298.867.69
Total		**29820.67**	**0.128**	**31000**	**1.237.584.11**

Source:Own Study

Vulnerability to groundwater quality in Ternate Island is generally said to be good. only 10% polluted, but prone to seawater and magma intrusion from the activity of Mount Gamalama, therefore the potential for free groundwater (SG) and deep groundwater (SB) is shown in table 2-3 and figure 6. Total groundwater potential on the island of Ternate is 1,291 million m^3/day,[2]. This potential is of course different in the kart area even in the facies and hydrogeochemistry of groundwater in other small islands due to different rainfall and hydrogeological parameters. as has been previously investigated,[5], [17], [24-25]

Table 1 and Table 2 represent the total value of groundwater potential in Ternate Island, while Figure 6 is a spatial-temporal visual result, resulting from the interpretation of rainfall infiltration, geological character, hydrogeological profile of the study area, considering groundwater flow and its contaminants are important references. in the analysis of groundwater quality itself. Different from that developed in previous research[16], [17], [26-27]

5. Groundwater Quantity

Groundwater quantity is groundwater originating from recharge, where rainwater is directly or from groundwater flow to the discharge area and does not take into account the potential for groundwater reserves. Analysis of groundwater quality is intended so that groundwater management on Ternate Island is based on groundwater potential that does not cause environmental damage due to massive groundwater extraction exceeding its recharge capacity. It should be known together, that water is a good solvent, so it can dissolve substances from the rocks that come into contact when the flow of the resistant water takes place. Mineral materials that can be contained in water due to interactions with rocks with water fluids, in general the dominant elements are $CaCO_3$, $MgCO_3$, $CaSO_4$, $MgSO_4$, NaCl, Na_2SO_4, SiO_2, and so on, with a note that if the water contains a lot of calcium and magnesium ions, it is known as water. hard and if less, then the water is declared soft water. In contrast to previous research,[17], [25] and different geology, rainfall and lithology from previous research conducted,[28-29].

Ternate island groundwater facies may reflect the complex quality effects of subsurface hydrochemical processes that occur between mineral ions in the lithology and the groundwater itself. the basic difference with previous studies, [7], [13]is the distribution of elevation and rock lithology in contaminants with the groundwater flow itself. This

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condition facilitates the determination of the aquifer zone for sustainability analysis. The groundwater quality of volcanic islands in Ternate Island is based on WHO standards, for assessing groundwater quality in micro-zoning at sample points for shallow aquifers and artesian aquifers, it is intended that sustainable management of water resources can be carried out properly as well,[2], [17], [28], [32]. (table 4).

Table 4 Summary statistics from analytical data and groundwater samples in the study area exceeding the limits set by WHO for drinking purposes

Parameter	Min	Max	Mean	Guideline values
pH	6.88	7.99	7.37	6.5–8.5
EC (μS cm^{-1})	81	2360	483.06	1500
TDS (mg l^{-1})	60	1748	357.74	1000
CaCO3(mg l−1)	33.8	496.3	158.14	300
Ca2+ (mg l^{-1})	6.5	56.4	30.00	200
Mg2+ (mg l^{-1})	2.9	94.6	19.95	150
Na+ (mg l^{-1})	10	442	58.87	200
K+ (mg l^{-1})	1.8	50.4	8.93	20
HCO3− (mg l^{-1})	49.5	372.8	161.05	240
Cl− (mg l^{-1})	8.6	875	100.48	250
SO4−2 (mg l^{-1})	0	127.6	21.30	250
NO3− (mg l^{-1})	0.4	60.6	10.52	50
CO3 2−	0.01	1.55	0.34	-
Fe3+ (mg l^{-1})	0	0.9	0.11	0.05 – 0.3
Mn2+ (mg l^{-1})	0.05	2	0.21	50
NH4+ (mg l^{-1})	0	2.4	0.22	1.5
NO2 (mg l^{-1})	0	1.08	0.05	3
SiO2 (mg l^{-1})	25.6	37.7	31.53	100

The results of the content of dissolved minerals in groundwater on the island of Ternate are generally dominant in **EC, TDS**, and **Fe** above the standard, while other parameters in the category meet WHO standards. Average This parameter is important for the sustainability of the city in managing groundwater resources on the island of Ternate, considering the character of a volcanic island with a very high potential for magmatic intrusion and seawater intrusion. On the other hand, the element of **$CaCO_3$** is also very influential on the distribution of water, considering that this element can increase the scale that can clog pipes that hinder the groundwater distribution system on the island of Ternate through the piping system from groundwater sources. In contrast to those produced in previous studies,[2], [13] The same is true for the industry by using heating systems for its operations, even in other applications, such as the operation of steam boilers for power plants or even engines for small-medium industries on the island of Ternate. Slightly different from the research design developed,[33]. The sustainability of developing cities such as the city of Ternate on a volcanic island that is prone to disasters.

While the determination of groundwater facies is a function of lithology, the kinetic process in the solution in the aquifer zone has provided information that the flow pattern in the aquifer zone has described the groundwater facies and fluid flow typology at the sample points tested. Considering that during the groundwater flow process, the pump in each operating well will react with the rock chemistry that is passed by the water fluid (flow between grains), groundwater samples will contain chemical elements. The results of this groundwater facies analysis were carried out to determine the quality of groundwater in Ternate Island using the Piper Diagram and the stiff diagram at the research site,[34].

The results of the analysis of groundwater samples from point to point (figure 5a), plotted into a Piper diagram, obtained 3 groundwater facies. The first facies is Calcium-Bicarbonate found in 16 sample points for shallow wells (MA), found in 1 artesian well (SB), and 6 sample points for Springs (MA). The results of the analysis did not show the dominant cation element at the sample point, but the dominant anion in $CO3^{+}$. In this case, it can be categorized that the main elements of this zone are calcium chloride ($CaCl_2$), calcium nitrate ($Ca(NO_3)_2$), calcium sulfate ($CaSO_4$), magnesium chloride ($MgCl_2$), magnesium nitrate ($Mg(NO_3)_2$), and magnesium sulfate ($MgSO_4$) was dominant (Fig. 6). This result is 70% different from previous research,[2], [25]

The second facies is $MgCL_2$ (Magnesium Chloride), which includes 3 shallow groundwater (SG) sample points, and Springs (MA) sample points without artesian wells. The results of the analysis showed that the main cation values were Ca^{+} and Mg^{+}, while the anion was Cl. the dominant groundwater facies in cluster 2 are not much different from facies 1 (figure 7). While the third facies is Potassium Chloride (KCL) which is present in each 1 groundwater sample, both at the MG, SB, and MA sample points. The results of the analysis show that the dominant cation elements are $\mathbf{Na^{+}}$ and $\mathbf{K^{+}}$, while the anion is $\mathbf{Cl^{-}}$ [33], [35]. This zone is the main typology of groundwater at high EC and TDS and exceeds the limits permitted by WHO for drinking purposes.

Given the importance of groundwater facies analysis, this research focuses on the three groundwater zones from Figure 2 by selecting hydrogeological parameters that are considered sufficient to represent each zone, then the groundwater quality parameters between zones are compared with WHO standards and analyzed using a pipper diagram to see groundwater quality parameters,[4],[28]. In each zone. These results are recommended as an important part of research on the quality and potential of groundwater and its effect on the environment in the study area for further use in water management in the city of Ternate.

In Piper's trilinear diagram it consists of three components, the lower left side represents the cations (magnesium, calcium, and sodium plus potassium), the lower right side represents the anions (chloride, sulfate, and carbonate and bicarbonate), and the correlation plotting the two sides represent the matrix transformation of cations and anions,[2], [29]. Each sample was normalized with the number of cations = 100% and the number of anions = 100%). The distribution of cations and anions in shallow wells (SG), Artesian wells (SB), and springs on the island of Ternate can be seen in the following figure.

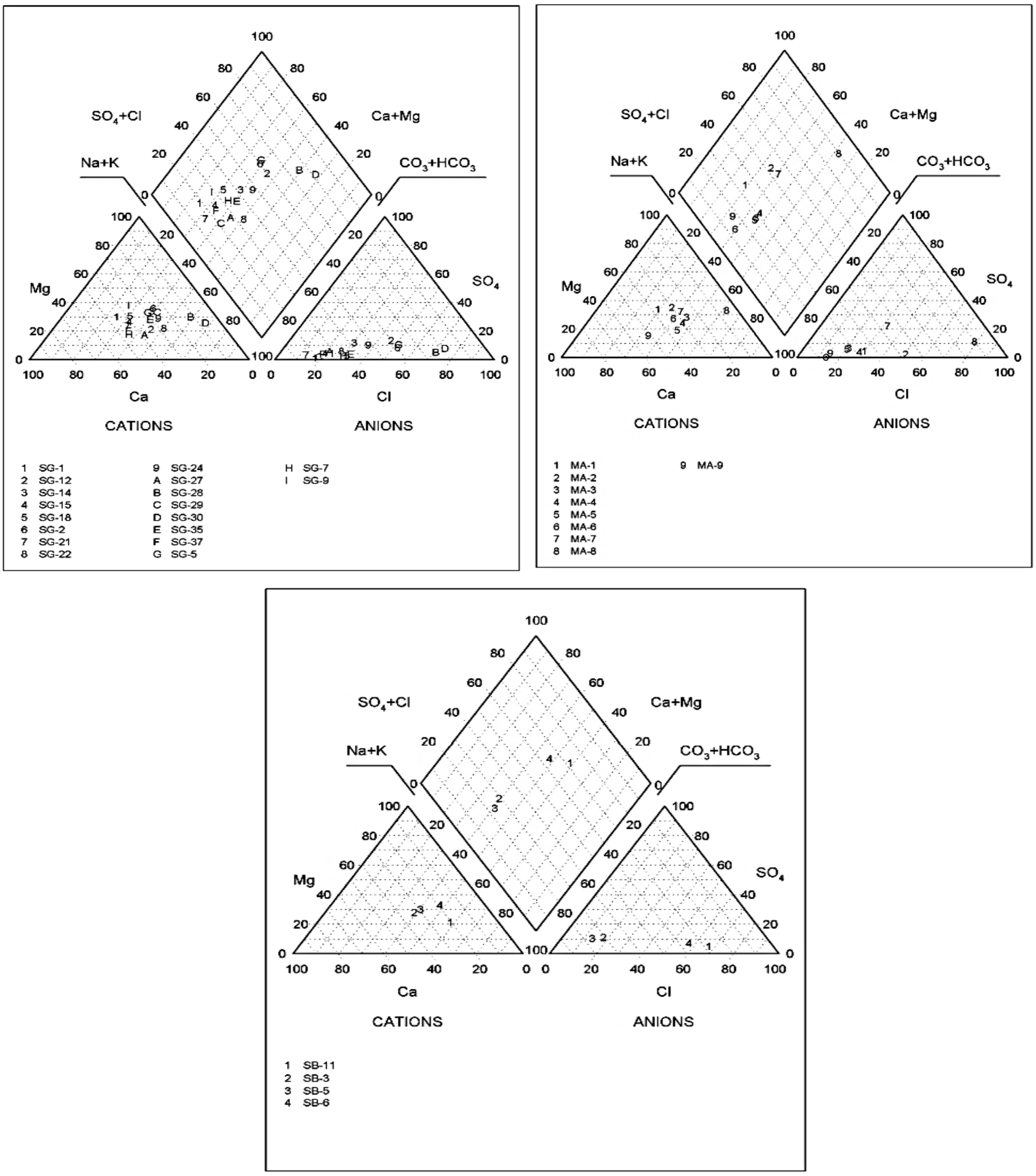

Figure 7 The Groundwater Piper's trilinear diagram for Facies in Ternate GBA

Water hardness in the main groundwater and springs indicates the high concentration of mineral substances in the water in the sample. Hard water can affect the cleaning process with soap and can form a kind of scale deposit, especially in pipe installations. In the artesian groundwater sample, the content of Na^+ and K^+ is high, with the Cl^- anion indicating the dominant salinity in the groundwater. As predicted at the beginning of this research, the minerals contained in volcanic rocks and dominant are different from previous research,[2], [5-6], [32].

Groundwater resources in Ternate show a flow pattern that is influenced by seawater intrusion at low elevations, while in the medium and upstream zones, magma intrusion is not widespread but localized. This is indicated by the presence of the dominant element $MgCl_2$ in some groundwater samples. Specifically in the shallow well zone on the southern coast of the island at the sample points SG-2, SG-12, SG-15, MA-2, and in the north segment at the MA-7 point. While the element Kalium Chloride (KCL) is dominant in the north-west segment of the island at the sample point SG-26, it is also found at the sample point SB-11 in the north segment and MA-8 on the south-west coast of the island of Ternate. This varying hydrogeochemical difference is due to the influence of volcanic deposits that spread radially during eruptions in the past. These results were not found in several previous studies,[2], [18], [24]

Thus the typology of groundwater in the Bicarbonate facies on the island of Ternate is a type of groundwater facies that has not undergone a long flow process, this indicates that the Bicarbonate facies in GBA is a groundwater zone that has a catchment area that is relatively close to the sample point as a groundwater source where groundwater flows and flows. the interaction tends to be very close to the water source studied at GBA Ternate. While the Chloride groundwater facies is groundwater whose interactions and flow patterns have undergone a very long process in its flow, even the typology of groundwater in this facies tends to be intrusive (seawater or magmatic). The distribution is shown in Figure 7 for shallow groundwater (SG), Artesian groundwater, and Figure Springs (MA) in Ternate Island. The results of the hydrogeochemical analysis on the piper diagram of groundwater facies at GBA Ternate for the dominant facies in the unsaturated aquifer and the saturated zone. These results also show that the hydrogeochemistry of groundwater in the Ternate Basin is controlled by subsurface lithology so that it can be interpreted using subsurface lithology parameters based on groundwater geochemical information. These results provide additional information for previous studies, [36–40].

A Stiff diagram was adopted as a graphical representation of the chemical analysis of the samples selected in this research. It is known that this method is widely used, but in this study, it is considered appropriate to be adopted in displaying the main composition of the tested groundwater samples. The polygonal pattern created from the parallel Cartesian diagram extending on both sides of the vertical axis is intended for all correlated ions between sample points as shown in Figure 6. Cations are plotted in milliequivalents/ltr in the diagram. This system shows that the dominant ion from the plotting results becomes a fairly fast visual comparison to the point of the tested water sample or can be contaminated with different water sources on study (Figure 8)

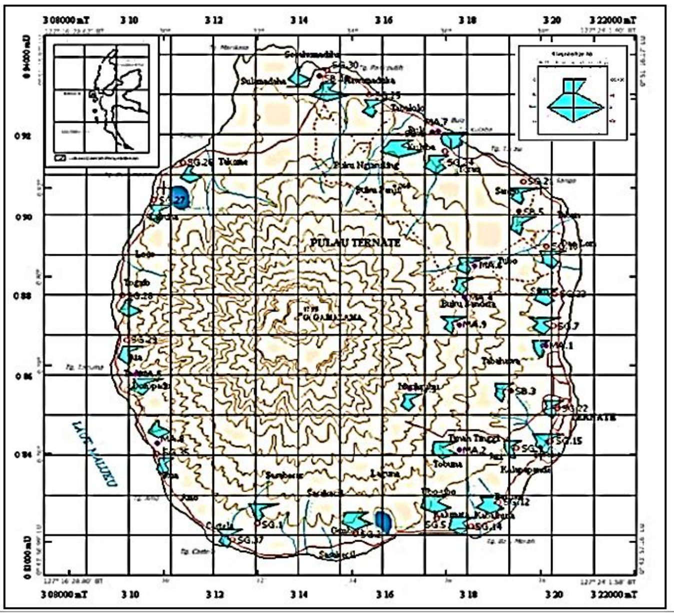

Figure 10. Distribution Map of Ternate Island Groundwater Quality (own study_Overlay of Stiff Diagram Results)

6. Conclusion

Several important points were obtained from the analysis in this study, including the management of volcanic groundwater on Ternate Island must still pay attention to the potential and chemical distribution of groundwater for the sustainability of the city of Ternate, both in terms of water quality and the environment and its sustainability. The map of groundwater distribution and water quality analyzed based on the hydrogeochemical facies of groundwater in the Ternate Basin, becomes a local groundwater potential, especially on the coast of Ternate Island which consists of large basins and small basins controlled by island morphology in groundwater flow and contaminants controlled by lithology in subsurface aquifers. , both free aquifers and confined aquifers with 3 groundwater facies.

Calculation of the quantity of groundwater in the free aquifer is 52.98 million m^3/day and 1,239 million m^3/day, this potential will develop if we look at the influence of high rainfall in recent years caused by the Elnino in the northern part of the island of Ternate and or the Maluku islands, Indonesia.

The lithology of the Gamalama stratovolcano aquifer with 3 (three) zones, including an upper zone of 3.36 km^2, a middle zone of 42.10 km^2, and a lower zone of 56.09 km^2 as groundwater recharge zones in Ternate is the main feature in this study.

The total potential for groundwater recharge is 1,291 million m^3/year, there are 5 groundwater quality zones spread among 67 sample points with 76% distribution of elements Calcium Bicarbonate ($CaCO^3$), Sodium Bicarbonate ($NaHCO_2$), magnesium bicarbonate $Mg(HCO_3)_2$ and widely distributed on the island of ternate, while 25% magnesium chloride ($MgCl^2$) and potassium chloride (KCL) are scattered locally on the island of ternate. On an ongoing basis the bicarbonate facies micro-zonation is hydrogeochemical with local flow interactions in volcanic deposits, where infiltration tends to be close to the groundwater sample point, while the chloride facies is a groundwater zone that is correlated with upstream-downstream flow patterns and has interacted with magma or was intruded. seawater is characterized by high Ca and TDC. As well as the potential for groundwater and groundwater quality, its availability is local and dominated EC, Mg and Fe.

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As supplementary information, herewith is presented the Nomenclature:

GBA	= Groundwater Area	(km^2)
GWL	= Groundwater Level	(m)
masl	= Meters Above Sea Level	(m)
Q	= Potential of groundwater flow	(m^3/day)
T	= Transmissivity aquifer	(m^2/day)
L	= Cross-sectional width	(m)
%	= Recharge Coofficien	(%)

Abbreviations

QGIS	= Quantum Geografis Information System
i	= Hydraulic Slope
SG	= Dug well
SB	= Boreholes
MA	= Water Springs

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