ISSN: 2087-3522
E-ISSN: 2338-1671

Analysis of Groundwater Flow on Hydrogeological for Sustainable Development and Environment in the Ternate Basin, North Maluku Province, Indonesia

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Abstract

The sustainability of water and sanitation management is an important point in the 2021 SDGs program. To support the program, it is important to understand Indonesia's water cycle. Given the variety of characters, topography, and geology between islands in Indonesia can distinguish hydrogeological systems and their interactions with the surrounding environment. The design and management of water resources, especially groundwater, has an important role, considering the basin area is 106 km2, the character of a volcanic island with the name of an active volcano. Topography from 0-8% is a built-up zone, 8-14% is a cultivation zone, 14-45% is a protected forest, and >45% is a stratovolcano peak zone. Island morphology affects groundwater flow patterns. This study aimed to determine the characteristics of groundwater flow in the Ternate basin. Purposive sampling of 56 production wells, transmissivity value, conductivity, aquifer thickness, and topography was analyzed using the Cubic spline interpolation method. The results showed that the direction of flow and groundwater accumulation based on groundwater modeling using the kriging interpolation technique resulted in the interaction of groundwater flow and depression cones in 56 production wells due to the concentration and massive groundwater abstraction in the Ternate Basin. The decrease in groundwater level is fluctuating, from groundwater flows that occur radially-centrifugally, the total reserves of 56 production wells are 46 million m3/day, the average transmissivity value is 2.17 m2/day, production discharge is 51,710 m3/day.

Keywords: groundwater flow, Radial-Centrifugal flow, Transmissivity, Ternate Basin, morphology, stratovolcano.

INTRODUCTION

Groundwater is water that occupies the voids in the geological layer in a saturated state in sufficient quantities [1]. The existence of ground water is highly dependent on the amount of rainfall and infiltration. Another factor that affects the presence of groundwater is the lithological and geological conditions of the local area [2]. Geological structures that have high permeability will facilitate infiltration, on the other hand a compact geological structure has very small infiltration, as a result, rainfall will flow as run-off from upstream to downstream. On the other hand, the conversion of land into settlements and industries, as well as massive forest destruction greatly affects the occurrence of infiltration [3]. In groundwater management, planning, implementation, monitoring and evaluation and even conservation in the Ternate Groundwater Basin, it still refers to the utilization and control of the destructive power of groundwater [4],[5].

Ternate Island is administratively located at coordinates 30 LU-30 LS and 1240–1290 BT, with an area of 5,795.4 km², land area of 250.85 km² consisting of 78 (seventy eight) villages, with a population of 205,204 people in 2021. [6].

Groundwater in the Ternate Basin has a Strato Vollcano typology and the management of water sources as raw water sources is under the control of the Ternate Regional Drinking Water Company. Extraction of groundwater since 1976 through the production wells of the Ternate City Drinking Water Company certainly has an impact on the availability of groundwater and the environment. Through 56 wells with a production capacity of 545 l/s from 874 l/s. The fact is that the population's needs exceed the production capacity, on the other hand it is influenced by drinking water services which are conditioned according to the topography of the study area. The topography of the island of Ternate 0-8% is residential area, 8-14% is cultivated area, 14-45% is protected forest and >45% is the Gamalama Mountain Zone [6],[7]. The analysis of the potential and pattern of groundwater flow in the Ternate Basin is intended to use the Gamalama stratovolcano groundwater through geological characteristics, recharge typology, groundwater

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flow patterns and directions, as well as controlling environmental pollution due to development and population growth that continues to grow.

MATERIALS AND METHOD

The research material is groundwater in Ternate Island, North Maluku Province. Groundwater samples were taken from 56 production wells of the Regional Water Supply Company consisting of dug wells (SG) and drilled wells (SB) by random sampling but representing the entire Ternate Basin area. Administratively, the study area focuses on Ternate Island which is the Ternate Groundwater Basin based on Presidential Decree of the Republic of Indonesia No. 26/2016 concerning the determination of groundwater basins in Indonesia with a basin area of 106 km^2 [1] and located at coordinates 30 N-30 S and 1240–1290 E, as shown below.

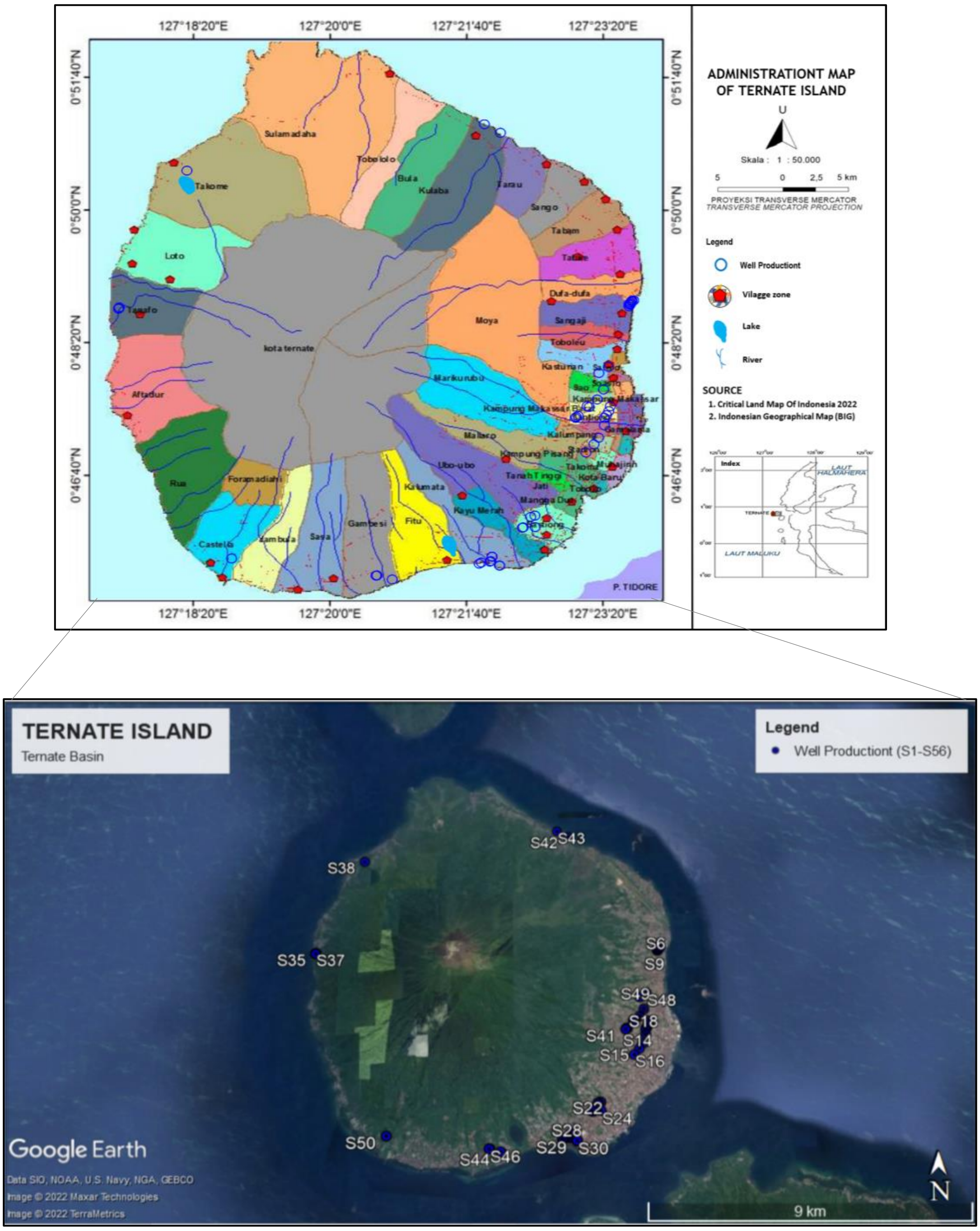


Figure 1. Location Map of the Study Area

The research method consists of field survey methods and spatial analysis. The field survey method includes measuring the coordinates of the geographical position of the well (X, Y), the elevation of the well and the depth of the well and the groundwater level measured at the peak of the dry season and the rainy season. The groundwater elevation and depth data are then converted to obtain the difference to obtain the average groundwater level. In addition, a field survey was also conducted for direct observation of 56 residents' wells based on the physical parameters of the water, such as color, smell and taste.

Climate And Average Rainfall

Ternate is characterized by a tropical humid climate with average monthly precipitation 150-200 mm [20], except during August until October is very low of around 60-90 mm is the average of 2010 – 2019. The amount of rainfall tends increases in February to May and in September to December every year (Fig 1A), temperature range from 24.8 to 28.2^{o}C Fig (1B), while Humidity is ranged from 78 to 85% (Fig 1C)

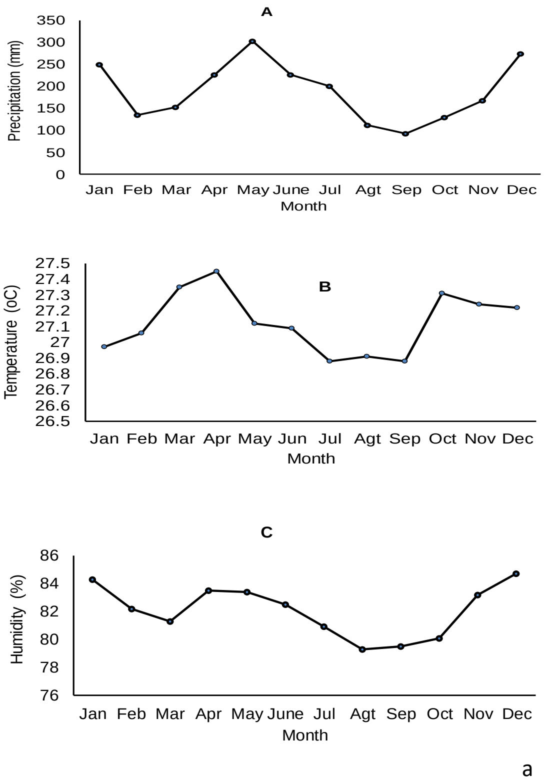
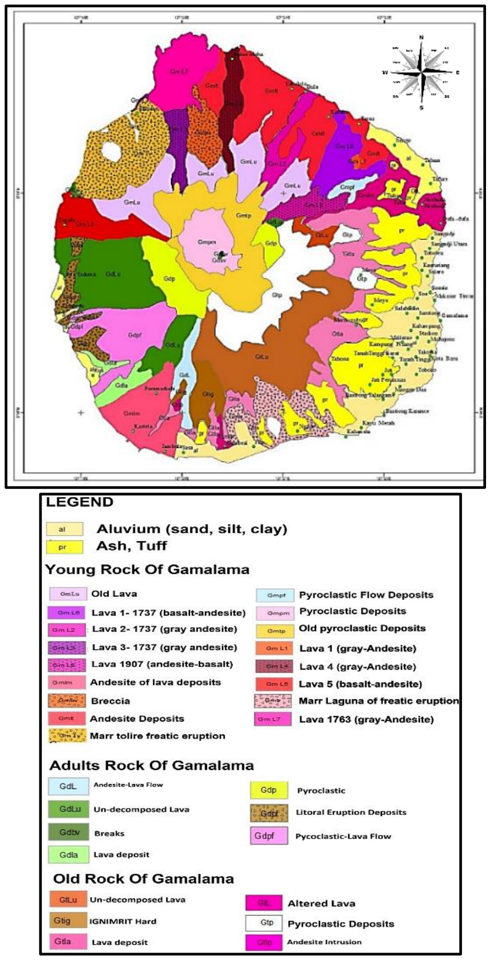


Figure 2. Precipitation (A), temperature (B) and humidity (C) in Ternate

Geology and hydrogeology setting

The geology of the study area is divided into 3 rock segments, including old Gamalama volcanic rock, this volcanic rock is geomorphologically clear, Gamalama stratovolcano is dominated by low hills and undulating hills and there is no karst morphology. On the other hand, a small portion of Gamalama stratovolcano and its geological distribution consists of on mature gamalama and young gamalama volcanic rocks [7],[8]. The existence of these 3 rock segments can be found geographically in each of the different zones on the island of Ternate. These three rock segments serve as the basis for the identification of the potential and pattern of groundwater flow in the Ternate groundwater basin

The regional geology of Ternate clearly shows that the rock zones in the three segments can be disting uished, including the distribution of old Gamalama rocks whose traces of rock are commonly found in the western segment of the island of Ternate (Gamalama stratovollcano), the distribution of mature Gamalama rocks is found in the southern segment, while the distribution of adult Gamalama rocks is found in the southern segment. Young Gamalama rocks are found in the northern segment of the Gamalama stratovollcano[7]. The clarity of the spatial distribution of Gamalama stratovolcano and its facies can be seen in the Ternate regional geological map in **Figure 2** below.



Source: Improvement of Bronto, 1980

Figure 3. Facies distribution and typology of the Ternate Basin

Figure 3 is the distribution of facies in the Ternate Basin, and the distribution is dominant on the lower slope of the Gamalama Stratovolcano, stretching from north to south of the island. Ash, tuff, sand silt, and clay are the dominant rock facies distribution. The topography of the Gamalama stratovolcano tends to be gentle on the lower slopes and is conical above it to the top of the Gamalama volcano. This topography will affect the pattern of surface water flow and subsurface flow (groundwater flow) [9]. The flow interaction can be determined by Types of Volcanic Sediment Aquifers young rock - between and old rock is Fractures and between grains, as shown in the geological profile in Figure 4.[8]Figure 3 is the distribution of facies in the Ternate Basin, and the distribution is dominant on the lower slope of the Gamalama Stratovolcano, stretching from north to south of the island. Ash, tuff, sand silt, and clay are the dominant rock facies distribution. The topography of the Gamalama stratovolcano tends to be gentle on the lower slopes and is conical above it to the top of the Gamalama volcano. This topography will affect the pattern of surface water flow and subsurface flow (groundwater flow) [9]. The flow interaction can be determined by Types of Volcanic Sediment Aquifers young rock - between and old rock is Fractures and between grains, as shown in the geological profile in Figure 4.[8]

Groundwater flows that occur in volcanic typology can be divided into local groundwater flows, intermediate groundwater flows, and regional groundwater flows. Local groundwater flow occurs because of the different natural conditions that vary. Thus, the flow pattern is different or random. The area of the local groundwater flow varies greatly so it is necessary to be careful in determining the aspects that influence it. Regional groundwater flow is groundwater flow that flows directly to the discharge area and is in the same basin (the dominant influence of gravity), and so also intermediate groundwater flow, which is dominantly influenced by volcanic rocks [9],[10]. From **Figure 3**, the interpretation of groundwater flow is radially flowing following the geological profile in the Ternate Basin as shown in the following figure:

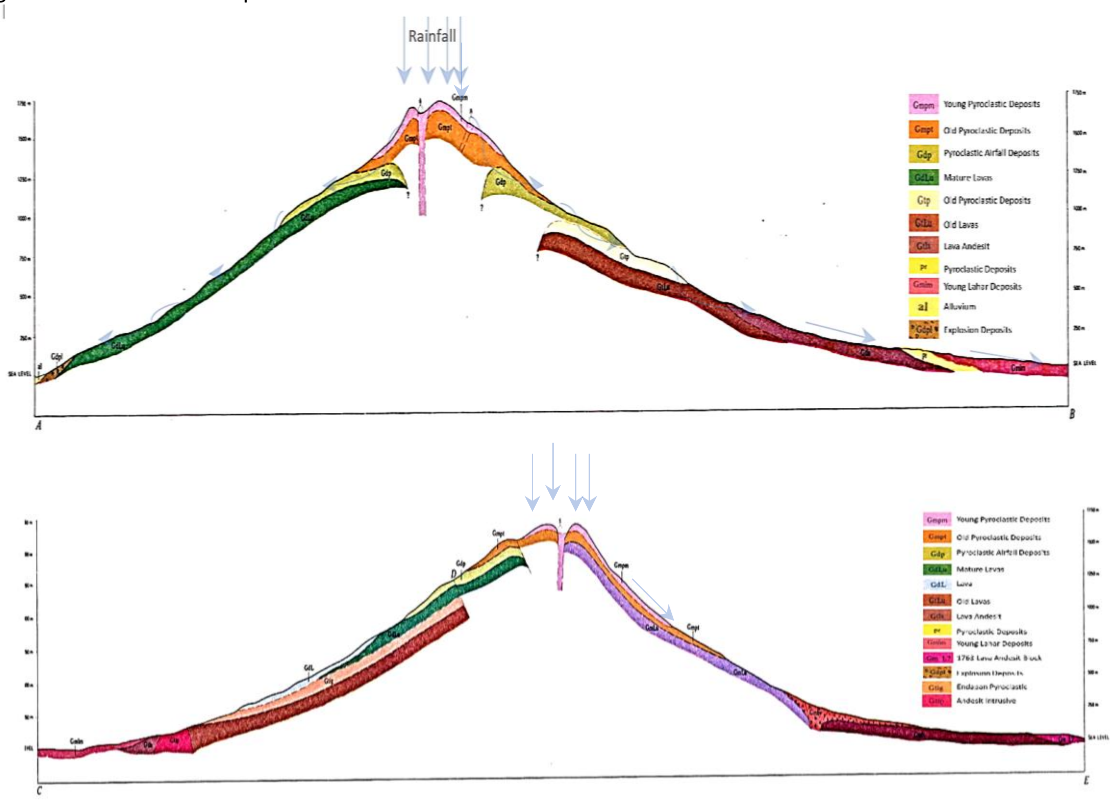


Figure 4. Profil Geological Regioal map of Ternate, A-B (East West, Southeast direction and C-E (North south, east direction)

Groundwater potential is influenced by the geological structure and precipitation of the study area, from the geological profile above is dominated by sediment in the form of siliciclastic, which is less solid, then the value of rock (*aquifer*).

Transmissivity is measured using the Long Period Test on production wells using the Thiem method with the assumption that the flow to the well is steady radial flow/Steady-state) and in a drawdown condition with constant time and without a piezometer so that the hydraulic gradient becomes constant throughout the flow, the value of transmissivity (T) can be measured by the following equation.

$$\boldsymbol{T = \frac{2,3\,Q}{2\pi(S_1 - S_2)} \mathbf{Log}\ [\frac{r_2}{r_1}]}\ \ \textbf{for} > 1 \text{ piezometer}$$

If the piezometer is ignored, so $T = \frac{2,3\,Q}{2\pi Sw} \text{Log } [\frac{r_e}{r_w}]$

according to (1946), value of Log $[\frac{r_e}{r_w}]$=3,33 so that and value of Transmisivitas can be measured by the following equation $T = \frac{1,22\,Q}{Sw}$

Where:

T	= Transmisivitas aquifer (m^2/det)
Q	= Pumped well discharge (m^3/det)
S_1	= Pisometer water level drop 1 (m)
S_2	= Piezometer water drop 2 (m)
r_1	= Distance piezometer 1 to pump (m)
r_2	= Distance piezometer 2 to pump (m)
r_w	= Pumped well radius (m)
r_e	= Well influence radius
S_w	= Pump well water level drop (m)

For the total water level subsidence in the well (GWL) it is expressed as:

SW = BQ + CQ2

Where:

Sw = Total water level drop (m)
BQ = Loss of pressure in the aquifer (m)
CQ2 = High pressure loss in the well (m)

RESULT AND DISCUSSION

Hydrogeology And Enviroment In Ternate Basin

The results of field observations, it is known from **Figure 2**, Ternate Regional Geological Map, shows that the activity of the Gamalama stratovolcano is the dominant form of Ternate Island (gamalama stratovolcano) with various rock avilions [7]. This is evidenced by the traces of the presence of rocks scattered in the three segments, the distribution of rocks in general in the form of volcanic rocks that dominate the geomorphology of the island of Ternate is grouped into 3 categories, including the geomorphology of the top of the Gamalama stratovolcano, the geomorphology of the body of the Gamalama stratovolcano, the geomorphology of the lower slopes of the Gamalama stratovolcano. The three zones were analyzed for groundwater flow patterns to their potential.

The geomorphology of the volcanic peak is the morphology found in the central part of the island of Ternate, starting from an elevation of 1250-1715 masl, an area of ± 3.36 km2. This zone consists of holocene volcanic rock (Qhv) at its peak, generally composed of loose sand-sized material. The peak of Gamalama is conical (strato), so that the groundwater flow pattern occurs radially-centrifugally (spreading from the origin), meaning that the river from the top of the volcano spreads towards the foot of the Gamalama volcano. The land in this morphological unit has not been touched by the activities or cultivation activities of the local community, so the land is still in the form of forests and shrubs in a beautiful environment, this zone becomes a groundwater recharge zone [8].

The geomorphology of the middle slope of the Gamalama stratovolcano is a morphology with an area of ± 42 km2, starting from an elevation of 150-1250 msl. This morphological unit is composed of Holocene Volcanic Rock (Qhv) where this body part is generally composed of loose material, consisting of breccia, lava and igneous rocks. The pattern of groundwater flow in this morphology is also a radial-centrifugal pattern after infiltration. The land in this morphological unit is still in the form of forest, partly in the form of plantations, and locally there are residential areas [8].

Mean while, the geomorphology of the lower slope of the Gamalama stratovolcano is a morphology that spreads around the outer part of the island with an area of ± 56.9 km2, starting from the coast to an elevation of 150 meters above sea level. This morphology is composed of Holocene Volcanic rocks (Qhv) and is generally composed of loose material, breccias, and lava [8]. The distribution of groundwater flow is also radial-centrifugal, the watershed from the top to the bottom slope is an intermittent river that flows only when it rains. Land on the lower slope morphology is the center of development on the island of Ternate [8], [9] that groundwater analysis on volcaniclastic rocks for small islands requires several stages including analysis of flow for deep aquifers, flow of shallow aquifers, flow of rocks and environmental degradation due to regressive erosion, considering the local distribution of the aquifer and the presence of lenses, as well as the density of sediments that have not been well compacted. This is the uniqueness of flow analysis in volcanic sediments.

The results of measurements in the elevation field (position of the well with sea level) based on (Table 1) range from 7 to 111 meters, as well as the depth of the groundwater level also varies between 2.42 to 60 meters. Meanwhile, the decrease in groundwater level due to massive groundwater extraction ranges from 0.18-7 meters/year. The elevation and depth of the groundwater table are then converted by calculating the difference between the two to obtain the average/year groundwater level which will be analyzed using software with the groundwater level reduction value in **table 1** below.

Table 1. Results of Elevation and Groundwater Level Measurements from 56 Well

LOCATION	WELL	BACKUP	SW	T	WD	AT	ELEV	WGL	Well Depth
		l/S	m	m2/Day	m3/day	m	msl	msl	msl
AKEGAALE	S-1	22	0.54	2	604.8	4	9	5.05	8
	S-2	12	0.48	2	604.8	4	9	4.97	8
	S-3	12	0.27	5	864	4	9	5.48	7
	S-4	21	0.39	5	1382.4	4	9	5.27	7
	S-5	14	0.43	2	604.8	4	10	5.64	9
	S-6	17	0.46	3	1123.2	4	11	6.70	9
	S-7	16	0.46	2	604.8	4	7	3.03	8
	S-8	14	1.02	1	691.2	3	7	3.94	6
	S-9	66	0.7	1	1209.6	5	7	2.42	9
	S-10		0.97	2	1209.6	5	7	2.42	9
KALUMPANG	S-11	22	0.23	6	1036.8	3	18	15.28	5
	S-12	16	0.18	6	777.6	3	22	19.29	5
	S-13	18	1.35	2	1209.6	4	22	18.09	8
	S-14	19	0.35	5	1296	3	22	18.95	6
	S-15	21	2.94	2	1468.8	6	20	13.60	13
	S-16	9	0.18	4	518.4	2	21	18.83	4
	S-17	27	1.9	2	1555.2	3	23	19.80	6
	S-18	24	1.86	4	1555.2	6	30	23.66	13
SKEEP II	S-19	16	1.68	5	950.4	3	35	31.88	6
	S-20	24	2	4	1555.2	39	62	22.80	78
	S-21	20	1.3	4	1209.6	40	63	23.00	80
UBO-UBO	S-22	24	0.44	5	1468.8	4	24	19.86	8
	S-23	24	0.44	6	1728	4	24	19.86	8
	S-24	10	0.39	2	518.4	2	18	15.94	4
	S-25	24	0.44	5	1468.8	4	22	17.86	8
	S-26	20	0.44	4	1296	4	25	20.86	8
	S-27	10	0.44	4	259.2	4	25	20.86	8
KALUMATA	S-28	10	0.86	1	518.4	3	8	4.93	6
	S-29	10	0.81	1	518.4	3	8	5.40	5
	S-30	12	0.6	2	691.2	3	6	2.68	7
	S-31	12	0.88	1	691.2	3	6	2.68	7
	S-32	12	2.76	1	691.2	5	8	3.42	9
	S-33	20	1.67	1	1209.6	5	8	2.60	11
	S-34	7	1.67	1	1036.8	5	8	2.60	11
	S-35	7	1.67	1	1036.8	5	8	2.60	11
TOGAFO	S36	6	0.72	1	345.6	4	8	4.12	8
	S37	6	0.72	1	345.6	4	8	4.12	8
	S38	6	0.72	1	345.6	4	8	4.12	8
TAKOME	S-39	15	0.72	3	259.2	4	8	4.12	8
SKEEP I	S-40	17	3.36	3	1036.8	34	53	18.98	68
	S-41	15	7	3	259.2	38	58	19.98	76
	S-42	18	6.86	3	1209.6	37	59	21.98	74
BULA	S-43	8	0.37	2	432	4	8	4.33	7
	S-44	8	1.4	2	475.2	5	8	3.20	10
FITU	S-45	10	0.72	7	345.6	4	86	82.12	8
	S-46	20	0.72	7	1296	4	87	83.12	8
	S-47	20	0.72	7	1296	4	88	84.12	8
SALERO & SOA	S-48	30	0.72	7	2073.6	4	92	88.12	8
	S-49	10	0.72	7	691.2	4	93	89.12	8
	S-50	30	0.72	6	2073.6	4	94	90.12	8
KASTELA	S-51	15	0.72	7	864	4	97	93.12	8
TUBO	S-52	7	0.34	4	604.8	51	66	15.05	102
	S-53	7	0.18	5	604.8	54	65	11.15	108
	S-54	7	0.41	4	604.8	53	70	17.08	106
	S-55	7	0.24	4	604.8	53	75	22.35	105
	S-56	7	0.44	4	604.8	54	111	57.15	108
Total		875			52.402				

From **table 1** it is known that the lowest groundwater level is 0.18 m located at S-53 located in the TUBO sub-district and 7 m is at well S-41 located in SKEP. The decrease in groundwater level in the Ternate Basin is dominantly located in the AKEGAALE zone in the north of the island, KALUMPANG-SKEP in the middle of the island, KALUMATA-FITU in the south of the island of Ternate with an average of 0.56 m. The dominant groundwater subsidence is caused by the intensity of groundwater use which is higher than other zones in the Ternate groundwater basin. The use of groundwater as drinking water to meet the needs of the inhabitants of the island of Ternate with high intensity can result in the groundwater level getting deeper[12],[13] that the use of groundwater from an aquifer system with high intensity and exceeds the average amount of recharge can causes a continuous decrease in the groundwater level and a reduction in groundwater reserves in the aquifer which causes the groundwater level to become deeper and even the occurrence of a depression cone which results in environmental changes in the zone [14]. The interaction of groundwater subsidence with the massive groundwater extraction is also determined by the value of the groundwater level at the beginning of operation until the groundwater level measurement is carried out in 2020 as can be seen in **Figure 5** below.

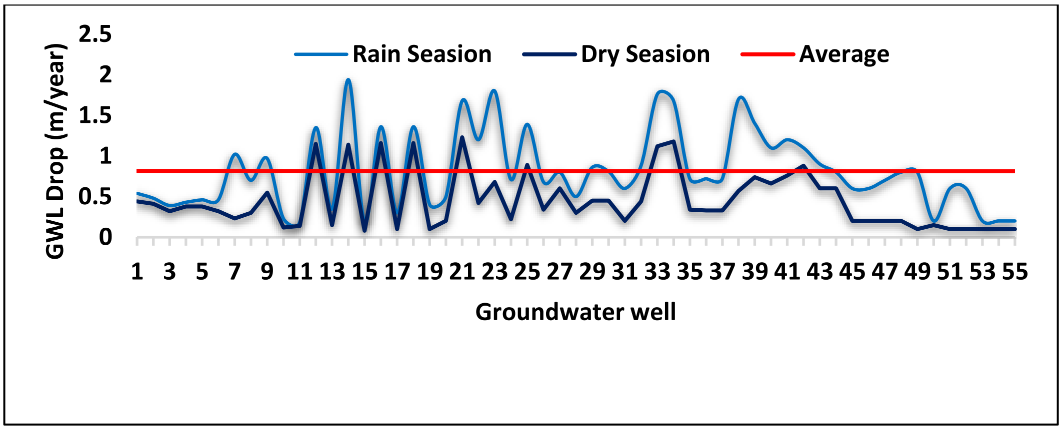


Figure 5. Production Well Groundwater Level Fluctuation

Figure 5 has shown that fluctuations in groundwater level decline at the peak of the season (dry-rain) with an average groundwater level decline of 0.56 m/year. The quality of drinking water is an important parameter to remember the use of groundwater in the Ternate Basin in meeting the needs of its population, so the transmissivity value of the aquifer in the production well as a parameter for passing water is used the US Institute's standard transmissivity value. Dep Of The Interior, 1977 as shown in table 2 below:

Table 2. Table of Transmissivity Values and Groundwater Quality

Transmissivity	Groundwater Potential	
	Domestic	Irrigation
< 1	Not Good	Very Not good
1-8	Medium	Very Not good
8-50	Good	Very Not good
50-300	Very good	Bad
300-1000	Very good	Medium
1000-10.000	Very good	Good
>10.000	Very good	Very good

Table 2 has shown that the quantity of volcanic groundwater with 56 groundwater interest points in the Ternate Basin has a transmissivity value between 1-8 in the medium category for drinking water and not good for irrigation. This value certainly has a positive impact on the development of water resources on the small island of Ternate.

The value of this transmissivity is suspected to be strongly influenced by the level of humidity considering that air humidity has an important role in the hydrological cycle, especially in the formation and growth of clouds associated with rain events. Analysis of basic and monthly observations at the Babulla Ternate class I station was carried out using a regression model, namely classical regression, weighted regression such as figure 2, and humidity of the island of Ternate during 2010-2019 as shown in **Figure 6** below.

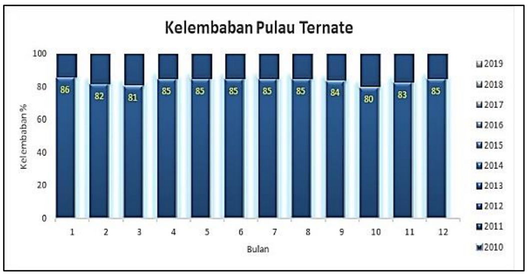


Figure 6 Ternate Island Humidity Value

Figure 6 shows that the annual average humidity level from 2010-2019 was 86% in January, tending to fall to 81% on the March average. This humidity certainly gives the same pattern as the pattern of rainfall on the island of Ternate which has a dominant influence on the decrease in groundwater level in each well. If the interpretation of the data from the Indonesian Agency for Meteorology, Climatology and Geophysics shows that the humidity level on the island of Ternate is on average 82% in the last decade with the category of increasing moderate to high in the previous 30 years. The CH pattern for the period 1971-1990 also shows the same overall category on the island of Ternate with an average of 1890,442 mm/year [10]. This CH condition can provide infiltration inputs with a medium-high average for the stratovolcano zone.

Further analysis of the potential for shallow groundwater (unsaturated zone), this is done, considering that 56 production wells are located in the middle and lower slope zones that spread widely and locally towards the coast (alluvium zone), the movement of groundwater flows in a radial direction so that the recharge value is obtained. Shallow groundwater recharge based on the configuration of the aquifer which is dominantly spread on the coast to the middle slope of the Gamalama Stratovolcano, where the position of the unsaturated ground water table is relatively shallow in the range of 0.50-10 msl which is dominated by young gamalama volcanic deposits, the quantity of groundwater is not depressed by using the recharge coefficient value which is divided into 3 zones, peak zone, middle zone and the gamalama foot zone between 0.2 - 0.3, the groundwater recharge power value (recharge) in the Ternate basin can be seen in Table 3 below.

Table 3. The recharge value of the Ternate groundwater basin.

Lithology	Location	groundwater recharge coefficient (%)	Annual Rainfalll (mm)	Luas Area (km^2)	Recharge (million m^3/year)
Strato Vollcano Gamalama (young rock of deposits)	Upper Slope	0.2	1890.442	1.875	0.709
	Midlle Slope	0.2	1890.442	37.330	17.643
	Lower Slope	0.3	1890.442	63.130	35.803
			Total Value		**54.155**

Table 3 shows that the amount of unconfined groundwater recharge in the Ternate CAT is as much as 54.155 million m^3/year. From the total value of groundwater recharge in table 3 above, for the interpretation of the depositional environment and ground water flow patterns (Flow Net Groundwater) it is important to carry out sustainable use of groundwater for the needs of the population which is increasing from year to year and to support development programs on the island of Ternate in a holistic manner. holistic. The results of the analysis that have been described previously are then determined on the results of data interpretation of other parameters that cannot be measured and or limited data in the Ternate Basin which results in no measurement at that point because of the high slope and prone to landslides, then the next analysis is based on the interpretation of stochastic values. with an interpolation approach in the surfer-kriging software in order to obtain a good distribution of the groundwater table and the direction of groundwater flow in the Ternate Basin [12]. Lithological distribution in the Ternate Basin, as described previously, becomes important in environmental analysis regarding the deposits formed and can be interpreted for the distribution of the aquifer in the groundwater flow map in the Ternate Basin, which can be seen in Figure 7 below.

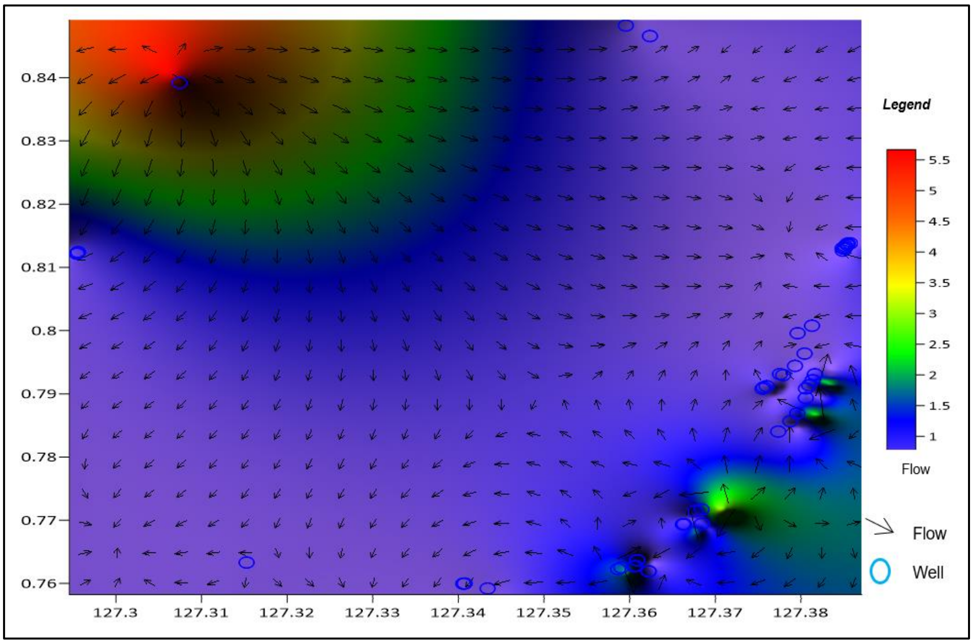


Figure 7. Groundwater Flow Of 3D

From **Figure 7** it can be seen the pattern of groundwater flow in the Ternate Basin, it is clear that the depression cones that occur in 56 production wells greatly affect the pattern of groundwater flow in the Ternate Basin. The depression cone occurs due to massive groundwater extraction and visualization of the dominant depression occurs in the south of the island of Ternate, although almost all zones have depression cones. The direction of groundwater flow radially follows the topography of this volcanic island and empties into the coast of the island of Ternate. This is a separate note that the development of the island is expected to pay attention to the interaction of surface water and groundwater for holistic environmental sustainability on the island of Ternate.

Based on the elevation of the groundwater table and the direction of groundwater flow as shown in Tables 1, 2 3 and Figure 7 above, the recharge zone is part of a basin characterized by groundwater flow in the saturated layer flowing away from the groundwater table. In the recharge zone, the direction of groundwater flow near the surface is downward, while the release zone is part of a basin characterized by groundwater flow in the saturated layer flowing towards the groundwater table, this is clearly seen in Figures 8.a, 8.b below.

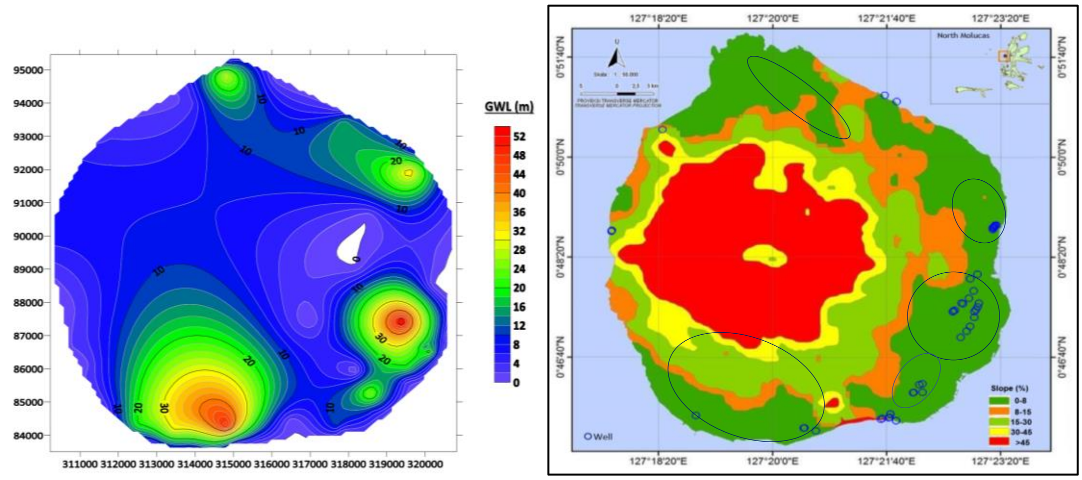


Figure 8. a). Cone Zone of Depression 2D & b). Thopograpic Map of Ternate Island

Figures 7 and **8** are very clear that there is a real environmental degradation in the Ternate Basin, the damage to the subsurface environment has a massive impact on land subsidence in the production well zone, this must be realized as early as possible to properly manage this volcanic island environment. The threat of environmental degradation can be seen spatially from the hydrogeological heritage (56 production wells) which are continuously and massively used to fulfill basic human needs on the island of Ternate with this spice island icon. On the other hand, the interpretation of morphology, flow direction, cone depression that occurred in the 56 production wells with the level of land erosion, run off and groundwater flow in the Ternate Basin can be seen in **Figures 9.a** and **9.b** below.

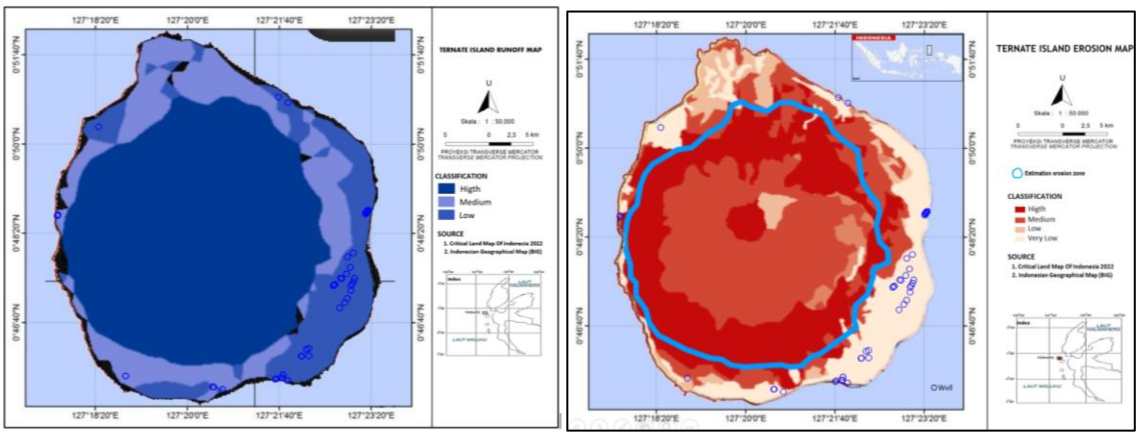


Figure 9. a). Run-off 2D of Ternate island & b). Erosion Map of Ternate Island

Figure 9 is a visualization of the spatial classification of runoff and erosion zones on the island of Ternate. In that zone, there are also production wells with a total production of 545 l/d (46 million m3/day). The threat of erosion and high surface water runoff is avoided as early as possible by reducing the depression zone with productive land conservation. Otherwise, the threat of environmental degradation cannot be avoided early on. Several things must be done to maintain the sustainability of water and soil on this volcanic island, including the preservation of groundwater, protection of groundwater, where efforts to maintain the existence and prevent environmental degradation, especially in the environment in contact with groundwater, both in the recharge zone, discharge and discharge zones. On water bodies caused by groundwater flow, maintenance of groundwater, namely efforts to maintain groundwater interest points from the results that have been previously analyzed to keep groundwater potential available, preservation of groundwater, namely efforts to maintain the condition and environment of groundwater so that it is always available continuity and quality, control of groundwater, monitoring, periodic recording of changes in quantity, quality, and environmental changes caused by the dynamics of environmental change itself [15], [16].

CONCLUSIONS

Based on the results of studies and analyzes that have been carried out, several conclusions can be formulated, including:

1. Physiographically, the geology of the study area can be grouped into 3 main geomorphological segments, namely peak geomorphology, gamalam stratovolcano body geomorphology and downslope geomorphology of gamalam stratovolcano.
2. Geographically, the anticlinorium and synclinorium zones of the Gamalama stratovolcano can be analyzed for groundwater flow patterns based on transmissivity (T) parameters and other aquifer parameters in the Ternate Basin based on the typology of the three rock segments for 56 production wells.
3. The Ternate Groundwater Basin with an area of 106 km2 consists of breccia aquifer lithology, lava and tuff
4. The existence of the production wells of the Regional Water Company of Ternate City are widespread and local in the Ternate Basin
5. The total production of 56 wells is 595 l/d and the distribution of the groundwater level varies between 2 – 57 msl of the total production of 56 wells. Production results in a depression cone with an average groundwater level decline of 0.56/year
6. The average aquifer parameter has good production with a transmissivity (T) of 2.37 m2/day, a conductivity (K) of 0.54 m2/day, aquifer thickness and fluctuating groundwater level between zones influenced by local elevation.
7. Average production discharge is 52,402 m3/day, aquifer production is 31.7% from 145 million m3/year with potential groundwater reserves of 64.3%.
8. Conservation of water and soil is important, considering that land use is getting smaller due to the conversion of built-up land, population growth from year to year increases which is linear in groundwater use, low groundwater recharge, threats of erosion and surface water runoff on the island of Ternate, and the massive extraction of groundwater. It is important that groundwater is carried out in zones that are aligned with production wells for the sake of sustainable groundwater management in order to support development properly

ACKNOWLEDGMENTS

The author would like to thank the Promoter, Head of the Indonesian Groundwater Center and Environmental Geology for discussions during guidance, inter-professional collaboration with researchers from both the Indonesian geologist association, North Maluku, the Forum for the Association of Indonesian Environmental Experts in North Maluku for data input during the activity. this research. The author would also like to thank the Indonesian Meteorology and Geophysics Agency for Ternate Station, the Ternate City Regional Planning and Research Agency, the Akegaale Regional Drinking Water Company, Ternate City, the work team on groundwater studies in North Maluku, Head of the River Basin Center, Director of PT. Mitra Usaha Abadi always implements Well Drilling activities in the study area, the gentlemen of Supervision, Control, in drilling and their families in facilitating field surveys as well as all friends, relatives, relatives of the Indonesian Groundwater Group and colleagues within the Faculty of Engineering, Khairun University for their input during the writing of the paper. this.

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