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Groundwater Potential in Unconfined Aquifers Using a Landform Approach in Gorontalo City

Karina Meiyanti Maulana[1], Langgeng Wahyu Santosa[1], Tjahyo Nugroho Adji[1]

[1] *Faculty of Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia*

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Corresponding author:
Karina Meiyanti Maulana
Email:
karinameiyanti@mail.ugm.ac.id

ABSTRACT

This research aimed to determine the potential of the unconfined aquifer in Gorontalo City based on the landform approach. The landforms in Gorontalo City consist of alluvial plains of lake deposits, floodplains of river deposits, alluvial fans of lake deposits, hills of structural fractures of reef limestones, hills of structural fractures of pinogu volcanic rocks, and hills of intrusive bone diorite. The method used consisted of a meteorological approach in the southern hills of Gorontalo City and a dynamic approach on the plains of Gorontalo City. The calculation of groundwater availability using a meteorological approach is 421.561,67 m^3/year in the structural limestone reef fractures hill, 1.198.975,33 m^3/year in the structural pinogu volcanic fractures hill, and 373.062,86 m^3/year in the intrusive bone diorite hill, with a total of groundwater availability using the meteorological approach, is 1.993.599,87 m^3/year. Groundwater availability using a dynamic approach was 2.621.535,19 m^3/year or a discharge of 49,26 lt/sec (large) in the alluvial plain of lake sediment, discharge of 17,19 lt/sec (large) in the floodplain of river sediment, and discharge of 16,65 lt/sec (large) in the alluvial fan of lake sediment. The potential value of groundwater using the dynamic method is greater than the meteorological approach because of the amount of evapotranspiration, surface runoff, and crop coefficient.

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1. INTRODUCTION

The availability of decent water is needed in fulfilling the essential components of life, namely the availability of sufficient and evenly distributed in every region in Indonesia. Water plays a significant role in maintaining an ecosystem's sustainability, so the availability, utilization, and sustainability of water resources are crucial things that must be considered (Handayani et al., 2019). Water, as a basic need for living things, especially humans, creates consequences for the sustainability of its resources. The sustainability of this resource can be seen from the continuous availability of water. Residents, to meet their daily water needs, usually use groundwater, and this is because groundwater is considered to have a large quantity and is also of better quality (Santosa & Adji, 2014).

The increase in population can also raise concerns about the existence of groundwater in the future (Ristiawan & Purnama, 2016). Groundwater availability is strongly influenced by rainfall conditions, slope level, vegetation type, rock nests, and graduations (Todd & Mays, 1980; Ristiawan & Purnama, 2016). An inventory of the potential availability of groundwater can be carried out using three approaches, namely the rainwater recharge approach, the static approach, and the dynamic approach. The calculation of static water availability describes an aquifer as a container that can hold groundwater with a specific volume or capacity, where groundwater is considered stagnant (Santosa & Adji, 2014).

The use of groundwater in Gorontalo Province for irrigation purposes originating from groundwater has started since 1990 until now. It is growing along with the increase in population and other economic activities. Utilization of groundwater, especially in the Limboto-Gorontalo groundwater basin area (including Gorontalo City), is the first groundwater development area in Gorontalo Province managed by the Directorate of Irrigation, Department of Public Works (Pranantya & Rengganis, 2010). Excessive use of groundwater can cause significant environmental impacts, such as a decrease in the groundwater level, which, of course, can negatively impact groundwater availability to meet the population's needs. The decline in groundwater levels in urban areas has occurred a lot, as seen in several studies. Supriyadi et al. (2013) researched lowering the groundwater level in the City of Semarang, Syahruddin (2012) researched lowering the groundwater level in the City of Makassar, and Hendrayana et al. (2021) conducted a study of changes in the groundwater level in the Yogyakarta-Sleman Groundwater Basin which as a whole occurs due to overuse in groundwater due to an increase in the intensity and amount of its use.

Landforms are one of the objects of geomorphological study, emphasizing the process, method, time, and materials that form the earth's surface. The object of study includes the composition of the earth's surface both on land and on the seabed. In addition to the formation process, geomorphology also looks at future developments that have an environmental context (Verstappen, 1983). Surface constituent materials, in this case, geological and geomorphological conditions, greatly determine groundwater availability in an area (Adji & Sejati, 2014). Geological conditions can affect the flow direction of groundwater flow and the type and thickness of aquifers (Santosa & Adji, 2014). According to Todd & Mays (1980) and Walton (1970), differences in the type of lithology can affect groundwater availability. Lithology, stratigraphy, and geological structure can be studied through a geomorphological approach, especially in landforms (Zeffitni, 2010).

Gorontalo city is divided into two types of landscape: the hilly areas in the south and the lowlands from the center to the north of Gorontalo City. Geographically, this city is bordered by Tomini Bay in the south, Bone Bolango Regency in the east, Gorontalo Regency and Lake Limboto in the west, and Gorontalo Regency and Bone Bolango Regency in the north. The topographical condition of Gorontalo City is plain, with three rivers that flow into Tomini Bay (BPS, 2022). Gorontalo Province generally has three main physiographical zones whose landscape is divided based on geological structures and rocks. The physiographical zones are the Tilongkabila-Boliohuto North Mountain Zone, the Paguyaman-Limboto Interior Plains Zone, and the Bone-Tilamuta-Modello South Mountain Zone. Gorontalo City is in the Paguyaman-Limboto Interior Plain Zone (Brahmantyo, 2009; Manyoe & Bahutalaa, 2017), which is also the Gorontalo Groundwater Basin area (Energy and Mineral Resources Ministerial Regulation No.2 of 2017).

Residents still use groundwater in Gorontalo City through dug wells and drilled wells. Even though most of them no longer use it for consumption, they are still used for non-consumption purposes. Because groundwater use is still high in Gorontalo City, it is necessary to analyze groundwater availability, which can be done with a landform analysis unit. There is a significant relationship between geology-geomorphology and groundwater conditions, so this study can determine groundwater's potential resource distribution (Adji & Sejati, 2014). Jusuf (2015), in his research in Gorontalo City, used the geoelectrical method to map groundwater basins. The results of Jusuf's research (2015) only estimate the thickness of the aquifer from the Gorontalo City groundwater basin. Wumu et al. (2022) also researched aquifer characteristics in Kota Tengah District, Gorontalo City, using the geoelectric method. Wumu et al. (2022) explained the characteristics of the aquifer based on the type of rock at the geoelectric location and the thickness of the aquifer using an administrative unit of analysis (District). In general, in addition to estimating the thickness of the aquifer, this study also calculated the potential estimation of groundwater stored in unconfined aquifers in Gorontalo City based on the landform unit.

The calculation of groundwater potential in Gorontalo City is carried out using two different calculation approaches based on the existing landform. Interpretation of geological data, remote sensing imagery, and morphological appearance. The topographic map shows six landform units: Alluvial Plains of Lake Sediment, River Floodplains, Alluvial Fan of Lake Sediment, Structural

Hills of Reef Limestone Faults, Structural Hills of Pinogu Volcano Faults, and Diorite Bone Intrusive Hills. The different approaches consider the significant morphological differences in Gorontalo City, namely the structural and volcanic hilly areas in the south and the alluvial plains in the northern part of Gorontalo City. The difference between this study and previous studies is the unit of analysis, namely the landform. Previous studies have not analyzed groundwater availability in terms of landform units. The use of two different methods is expected to be a comparison and find the advantages and disadvantages of the methods used as recommendations for further research for researchers and readers. The results of this research are expected to be the basis for decision-making processes by parties related to Gorontalo City's groundwater maintenance and use policies. The need to know the availability of groundwater and the urgency of novelty in research conducted in Gorontalo City, this study aims to know the potential of groundwater in unconfined aquifers in Gorontalo City based on a landform approach.

2. METHOD

Research on calculating groundwater potential using a landform approach was carried out in Gorontalo City. The landform units in Gorontalo City are interpreted as the unit of analysis in this study. The landform units are interpreted by looking at the morphology, structure, processes, and rocks in the formation of the landform units (Santosa & Adji, 2014). Landform delineation was carried out using DEMNAS imagery, Landsat 8 OLI TIRS composite 432, and the Geological Map of the Kotamobagu Sheet and the Tilamuta Sheet. The relief pattern is identified using slope data processed from DEMNAS data. The results of the delineation of the Gorontalo City landform can be seen in Table 1.

The landform unit above is divided into two analytical methods: the meteorological and dynamic approaches. The meteorological approach was carried out in areas with hilly morphology, such as Diorite Bone Intrusive Hills, Pinogu Volcano Fault Structural Hills, and Reef Limestone Fault Hills. The dynamic approach is carried out in areas with flat morphology, such as Alluvial Plains of Lake Sediment, Flood Plains of River Sediment, and Alluvial Fan of Lake Sediment (Figure 1).

2.1. Groundwater Potential Meteorological Approach

A dynamic and meteorological approach is used to calculate the unconfined groundwater potential. The meteorological approach calculates water availability in the southern hilly areas, which are indicated as not having an aquifer system or where the aquifer is non-homogeneous and anisotropic. The meteorological approach explains that part of the rainwater becomes surface runoff, and the rest seeps into the ground (infiltration) and becomes groundwater reserve through percolation. The meteorological approach is carried out by looking at the research location's recharge. Karmadi (2019) researched to determine the groundwater recharge coefficient in the Cisadane Sub-watershed using the recharge equation. The amount of recharge produced can be used to determine the permissible withdrawal of groundwater in that area. The amount of recharge needs to be considered in researching the potential of subsurface water. The volume of infiltrated rainwater determines the balance of groundwater conditions (Igboekwe & Ruth, 2011; Karmadi, 2019). Simmers (1987) explains the meaning of groundwater recharge as the process of water

Table 1. Landform of Gorontalo City

No	Genetics	Geology	Landform units	Symbol
1	Breakthrough Volcano	Diorite bone	Diorite bone intrusive hill	V.Tmb
2	Fluvial/Lake	Lake sediment	Alluvial plains of lake sediment	F1.Qpl
3	Fluvial/Lake-River	River sediment	River sediment flood plains	F2.Qps
4	Fluvial/Lake	Lake sediment	Lake sediment alluvial fan	F3.Qpl
5	Structural/Fault	Pinogu volcano rocks	Pinogu volcano fault structural hills	S2.TQpv
6	Structural/Fault	Reef limestone	Reef limestone fault structural hills	S2.Ql

Source: Analysis result, (2022)

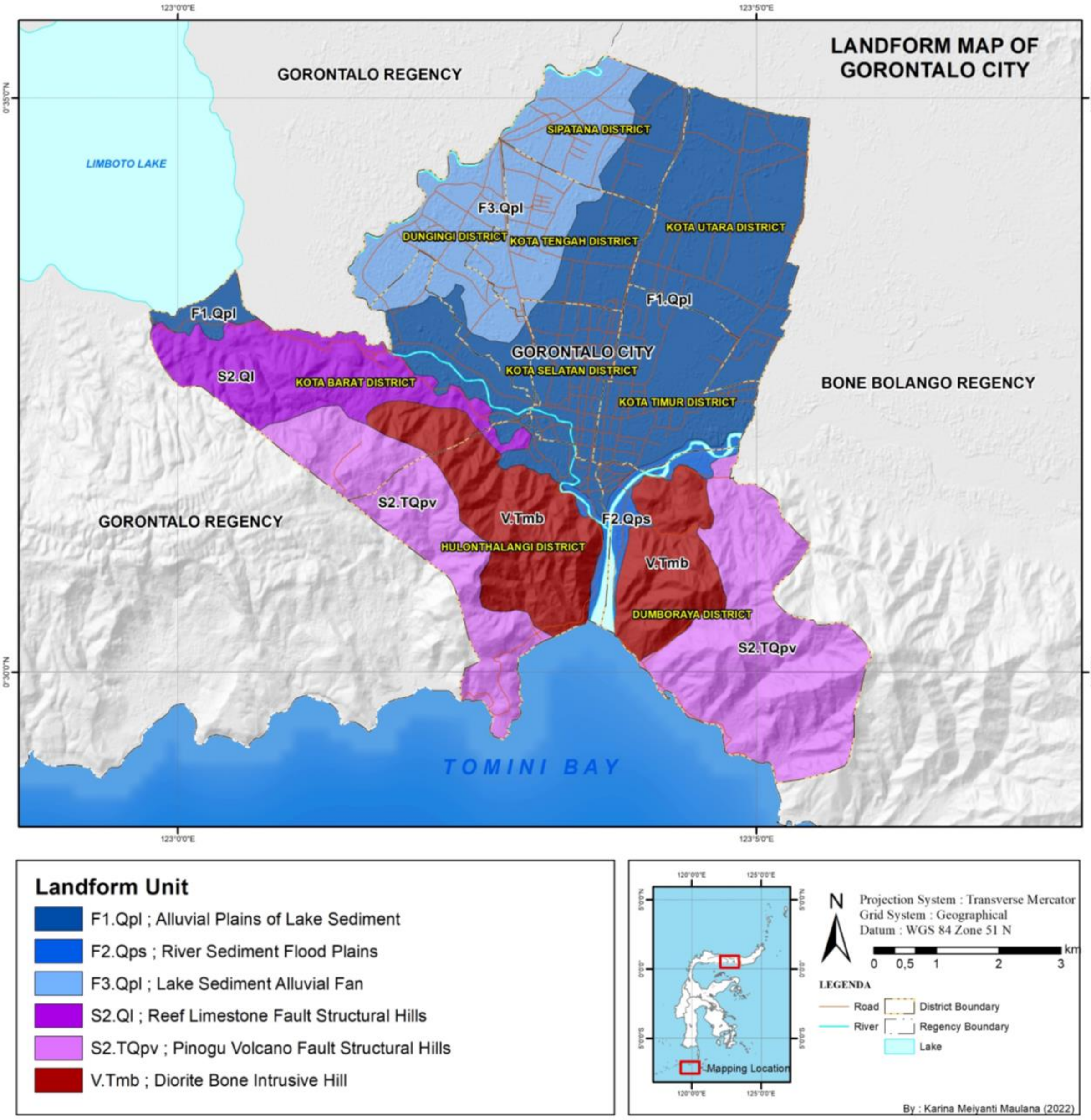

Figure 1. Landform map of research location.

entering the saturated zone in the soil, which is influenced by gravity and hydraulic conditions (Karmadi, 2019). Calculation of the initial estimate of recharge is calculated by the percentage of annual average rainfall (Rf) based on the condition of the rocks aquifer. The groundwater recharge rate is controlled by geological conditions, soil, land cover or use, and slope. The amount of rainwater recharge according to SNI 19-6728.1-2002 can be calculated with the following formulation.

$$RC = P \times A \times Rf(\%) \tag{1}$$

where: RC is the amount of recharge (m^3/year); P is the annual average rainfall; A is the rainfed area (m2); and Rf is the percentage of recharge based on geological conditions, which can be seen in Table 2.

The amount of effective rainfall is calculated by subtracting the average annual rainfall by the product of the ETP (potential evapotranspiration) and Kc (plant coefficient) values assessed for each land cover. ETP calculation is done by the Thornthwaite method. The RC value or the amount of recharge is calculated in the hilly areas of the southern part of Gorontalo City, which are indicated to have no aquifers. The recharge value is assumed to be the amount of rainwater that

Table 2. Percentage recharge and average annual rainfall based on geological conditions

No.	Conditions or geological formations	Recharge Rf (%)
1.	Young Volcanic	30 – 150
2.	Old volcanic – sedimentary – a mixture of young sediments	15 – 25
3.	Marl sediments and *indurated rock*	5
4.	Limestone	30 – 50

Source: SNI 19-6728.1-2002

will become the number of groundwater reserves, regardless of the evapotranspiration value. The annual average rainfall is obtained from BMKG Tilongkabila data, Gorontalo. The analysis was carried out using landform units to calculate the area based on the landform area. The method of calculating groundwater potential using a meteorological or recharge approach is carried out due to a lack of supporting data, such as drill and geoelectric data on the structural and volcanic landforms of the southern hills of Gorontalo City.

2.2. Groundwater Potential Dynamic Approach

Research on the potential of groundwater with a dynamic approach, especially based on the principles of Darcy's law, has been widely carried out. Pangestu & Waspodo (2019) researched predicting the potential for groundwater reserves using the Darcy equation in Bogor Regency. In addition, Hendrayana et al. (2020) also researched groundwater balance calculations in the Menoreh and Wates groundwater Basins, Kulon Progo Yogyakarta using Darcy's law principles. In this study, groundwater potential using dynamic methods was carried out for the plains of Gorontalo City, namely the alluvial plains of lake sediment, flood plains of river sediment, and alluvial fans of lake sediment. Santosa & Adji (2014) explained the method of dynamically calculating water availability, which means that dynamic means groundwater in an aquifer flows at a certain speed. The amount of groundwater flow in the aquifer largely determines groundwater availability. Calculation of dynamic groundwater availability is calculated based on the principles of Darcy's law. The formula for calculating the availability of groundwater using the dynamic method can be seen in the following equation.

$$Q = K \times I \times A \qquad (2)$$

where: Q is groundwater discharge (m^3/day); K is hydraulic conductivity (m/day); I is the difference in slope of the groundwater contour head; and A is the cross-sectional area of the aquifer (m^2).

The value of hydraulic conductivity is obtained from log interpretation of geoelectric results at each sounding point on the landform and is heterogeneous. Each material is multiplied by its thickness, and the overall K value for each material is added and divided by the overall layer thickness (Purnama et al., 2020). The range of K values for several materials can be seen in Table 3. The different values of the slope of the groundwater contour head are obtained from the following equation (Purnama et al., 2020).

$$I = \frac{Ci}{B} \qquad (3)$$

where: I is the difference in the slope of the groundwater contour head; Ci is the contour interval (m); and B is the average distance of the two contours of the groundwater level (m) obtained from the quotient between the surface area of the aquifer and the average length of the two contours. The value of the aquifer cross-sectional area is obtained from the following equation (Purnama et al., 2020).

$$A = d \times AB \qquad (4)$$

where: A is the cross-sectional area of the aquifer (m^2); d is the thickness of the aquifer obtained from the resistivity interpretation of rock layers at the study site (m); AB is the length of the contour at the highest groundwater level or the length of the top contour of each landform (m).

Classification of groundwater potential criteria classes based on quantity by Decree of the Minister of Energy and Mineral Resources Number 1451K/10/MEM/2000 is divided into three

Table 3. Rock-type hydraulic conductivity value, according to Morris and Johnson

Material	Hydraulic conductivity (m/day)	Material	Hydraulic conductivity (m/day)
Coarse gravel	150	Medium limestone	3,1
Medium gravel	270	Limestone	0,94
Fine gravel	450	Peat	5,7
Rough sands	45	Schist	0,2
Medium sands	12	Slate	0,00008
Fine sands	2,5	Tuff	0,2
Dust	0,08	Basalt	0,01
Clay	0,0002	Weathered gabbro	0,2
Fine sandstone	0,2	Weathered granite	0,4

Source: Todd & Mays (1980)

classes, namely: (a) large, if the optimum discharge for each well is more than 10 liters/second; (b) moderate if the o optimum discharge for each well is between 2.0 – 10 liters/second; (c) small if the optimum discharge for each well is less than 2.0 liters/second. The groundwater flow direction and contour maps were prepared using primary data, namely groundwater height from the results of a survey of dug wells in Gorontalo City using a sampling technique with a grid measuring 0.5 km x 0.5 km with a total of 41 sample points.

3. RESULTS AND DISCUSSION

3.1. Groundwater Potential Meteorological Approach

Some rainwater flows into surface water, and some infiltrate into the ground to become groundwater reserves. The ability of rocks or soil to absorb water varies, depending on the type and geological conditions of the area. The calculation of the recharge value or coefficient of groundwater recharge was carried out by Karmadi (2019) to produce the overall value of the recharge coefficient at his research location, namely the Cisadane Sub-watershed. From the coefficient value, the amount of recharge in a rock formation is obtained in units of m^3/year. The analysis was carried out in two-time units during the rainy and dry seasons. This recharge coefficient method ignores the evapotranspiration factor and only considers the water factor that enters the rock during the infiltration process, which is stored as groundwater reserves. Of course, this method should calculate the value of evapotranspiration so the results obtained from the calculations can be optimal. Meteorological groundwater availability calculations in Gorontalo City are carried out in areas with diverse geological conditions, with hilly morphology, especially in the southern part of Gorontalo City. Calculation of meteorological groundwater availability is carried out using the average rainfall data of the study area, the calculated landform unit area, and the recharge or infiltration value based on geological conditions (Table 4).

The calculation result of meteorological groundwater availability above are obtained from the landform unit area obtained from the results of the landform mapping, described in hectare units (ha) and square meter units (m^2). The annual average rainfall value is obtained from daily data from the Bone Bolango Climatology Station and Gorontalo City in Figures 2022, with a total annual rainfall value of 2,633.1 mm/year, converted to 2.6331 m/year. The amount of annual rainfall was then calculated with the amount of evapotranspiration and crop coefficient. The result of effective rainfall in Gorontalo City was 259,19 mm/year, or 0,259 m/year. The potential rain value is obtained from the product of the landform unit area (m^2) and the annual average rainfall value (m/year), resulting in 247.085,74 m^3/year of potential rain on the Diorite Bone Intrusive Hill landform, 3.996.584,43 m^3/year in the Structural Hillsforms of the Pinogu Volcano Fault, and 1.405.205,59 m^3/year in the structural limestone fault hills forms, with a total of 7.888.875,77 m^3/year of potential rainfall.

Each landform unit's infiltration value or recharge calculation must be multiplied by the Rf value or rock's ability to absorb rainwater based on geological conditions or formations. Based on the geological framework of Gorontalo by the Geological Agency and the geological map of the Kotamobagu sheet (Apandi & Bachri, 1997; Bachri et al., 1993), Bone diorite is around the late

Table 4. Meteorological groundwater potential in Gorontalo City

No	Landform Unit	Area		Effective Rainfall		Potential Rain	Recharge	
		(Ha)	(m^2)	(mm/year)	(m/year)	(m^3/year)	Rf	(m^3/year)
1	Diorite bone intrusive hill	960,26	9.602.647,67	259,19	0,259	247.085,74	Old volcanic = 0,15	373.062,86
2	Pinogu volcano fault structural hills	1.543,08	15.430.827,93	259,19	0,259	3.996.584,43	Young volcanic = 0,3	1.198.975,33
3	Reef limestone fault structural hills	542,55	5.425.504,23	259,19	0,259	1.405.205,59	Limestone = 0,3	421.561.67
Total		3.045,89	30.458.979,8			7.888.875.77	-	1.993.599,87

Source: Analysis Result (2022)

Miocene, namely in the early magmatism-volcanism period (volcanic activity) so that it is included in the old volcanic category with an additional value of 15% or 0.15. The formation of the Pinogu volcanic unit is thought to be around the Pliocene-Plistocene age and entered the late magmatism-volcanism period (volcanic activity), so it is included in the young volcanic category with an added value of 30% or 0.3. Many reef limestone units are found along the south coast of Gorontalo, considered around the Holocene age, formed as a result of quaternary tectonic processes so that they are included in the limestone category with an added value of 30% or 0.3. The potential rain value multiplied by the Rf value or the addition produces a large potential rain infiltration. The Diorite Bone Intrusive Hill landform unit with an Rf value of 0.15 has an infiltration size of 373.062,86 m^3/year. The Pinogu Volcano Fault Structural Hills landform unit with an Rf value of 0.3 has an infiltration size of 1.198.975,33 m^3/year. The hill landform unit, Structural Fault Limestone Reef, with an Rf value of 0.3, has large groundwater storage of 421.561,67 m^3/year, with a total of all three landform units of 1.993.599,87 m^3/year.

The high value of groundwater recharge or potential in structural and volcanic landforms and methods is due to the large Rf value or the ability of rocks to absorb rainwater based on geological conditions. A landform with a 30% recharge represents the amount of infiltrated rainwater, which is 30% of the total potential rainfall. The results will be very much different from the dynamic approach because of the different magnitudes of recharge, types of geological formations and materials, as well as the factors of land use in urban areas, which will reduce the amount of rainwater infiltration because the land surface is mostly covered with buildings (Syahruddin, 2012).

3.2. Groundwater Potential Dynamic Approach

Water, by its nature, flows from high areas to lower areas. Surface water groundwater also moves from higher to lower areas, although it cannot be directly observed. The movement of groundwater occurs due to differences in groundwater levels in different places and is called dynamic. Calculating groundwater availability estimation dynamically is based on the principles of Darcy's law, namely the equation that defines the relationship of fluid flow flowing in a porous media (Santosa & Adji, 2014). Pangestu and Waspodo (2018), in their research on predicting potential groundwater reserves using the Darcy equation, also use a dynamic approach in estimating groundwater potential. The results of Pangestu and Waspodo's research (2018) are the thickness of unconfined and confined aquifers and the amount of groundwater flow in Dramaga District, Bogor Regency. With a dynamic approach, this method is considered more effective in determining potential groundwater reserves because it considers the value of hydraulic conductivity, the difference in groundwater level, and the cross-sectional area of the aquifer. Todd & Mays (1980), natural groundwater is considered to move in aquifers (aquifers are considered as natural porous media) due to the hydraulic principle that occurs (liquid will flow from high places to low places). In calculating the availability of dynamic groundwater, it is necessary to look at the hydraulic conductivity

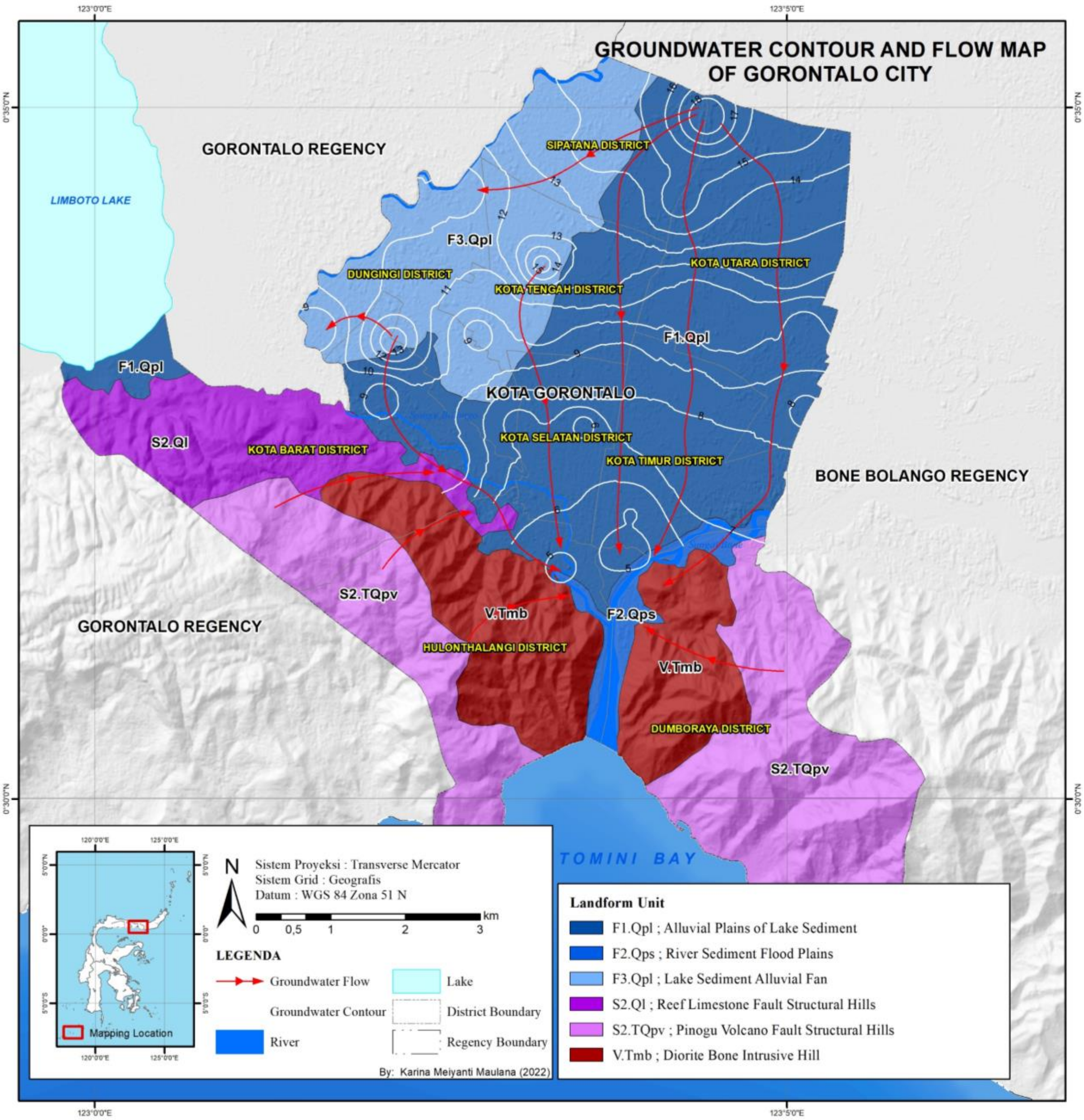

Figure 2. Contour map and groundwater flow of Gorontalo City.

value of the rock, the difference in slope of the head contour from the flow net map and the flow direction, as well as data on the cross-sectional area of the aquifer which in this research is a landform unit.

The characteristics of its main pores influence the rock's hydraulic conductivity. The stability of the pores is affected by the stability of the aggregates from the soil/rock. The more stable the soil aggregate, the faster the water movement in the pores in the soil, whereas if the soil aggregate is unstable, it will close the pores for water movement due to the destruction of the soil aggregate (Masria et al., 2018). The hydraulic conductivity value can be obtained from a pump test or a deductive method that is carried out by considering the rock's nature, type, and main texture, which is obtained from various references or previous studies.

The I value or the slope difference of the groundwater contour head is obtained from the difference in the highest contour value minus the lowest contour value in each landform divided by the distance of the highest and lowest contours. This slope difference is an important determinant of the amount of water discharge obtained in the final result. The groundwater contour is obtained by interpolating the groundwater height from the results of field calculations in the wells at the study site. The direction of groundwater flow is analyzed based on the highest to lowest contour with the application of Darcy's law. Contour maps and groundwater flow directions in the study area are presented in Figure 2.

Interpretation of hydraulic conductivity data based on the type of lithology of the study site and the difference in slope of the highest and lowest groundwater contours, as well as the cross-sectional area of the aquifer, is obtained from the results of geoelectrical estimation, which can be used to calculate the groundwater potential dynamically. More detail is the calculation of unconfined groundwater discharge using a dynamic approach (Table 5).

The value of groundwater discharge in the Alluvial Plain of Lake Sediment (F1.Qpl) is included in the large groundwater discharge category because the value is > 10 liters/second, which is 49,26 liters/second or 4.256.921,62 liters/day. The sedimentary flood plains (F2.Qps) have a large groundwater discharge of 17,19 liters/second or 1.486.031,66 liters/day. The Alluvial Fan Landform of Lake Sediment (F3.Qpl) has a large groundwater discharge of 16,65 liters/second or 1.439.334,89 liters/day. The other landform units have been calculated using a static and meteorological approach because they are not expected to have homogeneous and isotropic aquifers. The value of groundwater discharge in units of m^3/day is then converted to units of m^3/year to determine the estimated total availability of groundwater for one year—the groundwater availability for the F1.Qpl landform unit is 1,553,776.39 m^3/year, the F2.Qps landform unit is 542,401.56 m^3/year, and the F3.Qpl is 525.357,24 m^3/year. Overall, the total dynamic water availability in Gorontalo City in 2021 is 2.621.535,19 m^3/year.

The value of groundwater discharge using the dynamic method is greater than the meteorological approach. This difference was because plains areas have a higher potential for storing groundwater. Besides that, the plains area was mostly covered by clay, gravel, and sand, which greatly percolated the rainfall.

4. CONCLUSION

Groundwater potential in Gorontalo City is calculated using two approaches: groundwater potential using a meteorological approach and groundwater potential using a dynamic approach. Both use different methods and are carried out at different locations in Gorontalo City. Groundwater potential with a meteorological approach is carried out to estimate the amount of groundwater stored in structural and volcanic landforms in the hills of the southern part of Gorontalo City by using a recharge approach as seen from the type of lithology, evapotranspiration, crop coefficient, and runoff surface in the study area. The total meteorological groundwater potential of Gorontalo City is 1.993.599,87 m^3/year. Meteorological water availability in the southern hills of Gorontalo City has not been used optimally. Dynamic availability is carried out on the plains of Gorontalo City by following the principles of Darcy's law. The availability of water is dynamic. That is, groundwater is considered to be in a state of movement and flowing from high to low places. The

Table 5. Groundwater potential dynamically

No	Geomorphology unit	Aquifer characteristics						
		K (m/day)	Groundwater contour slope	Aquifer cross-sectional area (m^2)	Aquifer surface area (m^2)	Landform area (m^2)	Groundwater availability (m^3/day)	Groundwater discharge class
1	Alluvial plains lake sediment	2,91	0,0033	141.930	7.692.835	24.027.077,00	1.553.776,39	Large
2	River sediment flood plains	7,51	0,0025	19.075	413.932,27	1.717.563,71	542.401,56	Large
3	Alluvial fan lake sediment	6,65	0,0022	36.580	3.740.215	10.059.361,02	525.357,24	Large

Source: Analysis Result (2022)

total dynamic water availability of Gorontalo City is 2.621.535,19 m^3/year or has a discharge of 49.26 lt/s (discharge > 10 lt/s = large) in the Alluvial Plains of Lake Sediments, has a discharge of 17.19 lt/s sec (large discharge) on the Floodplain Sedimentary River landform, and has a discharge of 16,65 lt/s (large discharge) on the Alluvial Fan Deposition Lake landform.

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