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Geoconservation of Groundwater in the Getourism Area of Olele Village for the Development of the Tomini Bay Geopark

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Abstract: Geoconservation is an important effort in preserving geological diversity. Geoparks act as a link to encourage geoconservation. This research aims to evaluate the geology, geosite potential and groundwater availability in Olele Village, Gorontalo. This research aims to determine geological conditions, geosite potential, groundwater availability and groundwater conservation measures. The methods of literature survey, field survey, field data collection and ArcGis 10.8 data analysis were used. Stratigraphy shows the sequence of Reef Limestone (Ql), Pinogu Volcanic Rock (TQpv), Bone Diorite (Tmb), and Bilungala Volcanic Rock (Tmbv). Geomorphology includes reef terrace plains, alluvial plains, pyroclastic flow hills, and lava flows. Lithological contacts between reef limestone and pyroclastic breccia mark the Olele Geosite. Water quality is influenced by the level of rock passability and rainfall. Olele Village has good groundwater potential with a groundwater table depth of 1-8 meters. Groundwater conservation measures involve monitoring, public education, water use management, sustainable agriculture, wetland rehabilitation, development of alternative infrastructure, and mitigation of tourism impacts. Thus, this research emphasizes the need for sustainable strategies for the conservation of geological and groundwater resources in this area.

Keywords: Geoconservation; Groundwater; Groundwater conservation; Olele Geosite; Tomini Bay Geopark

Introduction

Tomini Bay Geopark, located in Gorontalo Province, Indonesia, is characterized by its unique geology and rich biodiversity (Arifin, 2022). Its development emphasizes the crucial need to prioritize the conservation and preservation of the surrounding environment (Mensah, 2019). This approach ensures that the natural beauty and distinct geological features of Tomini Bay remain intact for future generations (Eraku, 2022). Geotourism, a form of tourism that incorporates geological aspects, such as forms, processes, history, and related cultural and biodiversity factors (Rohaendi et al., 2023), is closely tied to the concept of conservation, which involves regular maintenance and protection to prevent damage and destruction (Setyadi, 2012). Geoconservation, on the other hand, is the deliberate effort to conserve and enhance geological and geomorphological features and processes (Burek et al., 2008; Dowling, 2014).

Geopark is a bridge for implementing geoconservation (Ríos et al., 2020). This is because one of the pillars (prerequisites) of a geopark is the conservation of the earth's diversity (geological heritage), biodiversity and cultural diversity (Dowling, 2011; Wu et al., 2021). Geopark Managed for the purposes of conservation, education, and community economic development in a sustainable manner with the active involvement of the community and local government, so that it can be used to foster public understanding and concern for the earth and the surrounding environment (Mihardja et al., 2020; Zuvara et al., 2022).

Groundwater is one of the water resources whose volume and existence are limited, and the damage can have wide-ranging impacts, and recovery efforts are

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difficult and expensive to carry out (Cosgrove et al., 2015; Gleeson, Wang-Erlandsson, et al., 2020). Groundwater is one of the elements in the hydrological cycle and serves as a buffer for life on planet earth (Gleeson, Cuthbert, et al., 2020; Wang et al., 2020). One way to ensure the sustainability of the potential of groundwater resources is through conservation efforts (Darwis, 2018). Therefore, it is important to conserve and manage groundwater resources wisely and sustainably. Thus, it is hoped that the availability of water can be maintained and can meet the needs of humans and ecosystems in the present and in the future (Soenyoto, 2013).

Groundwater conservation is an effort to maintain and increase available groundwater stocks in aquifers, by reducing water loss and increasing water availability (Tran et al., 2019). The main goal of groundwater conservation is to ensure sufficient water availability for current and future needs, as well as prevent environmental and economic damage caused by a significant decrease in groundwater stocks (Setiawan et al., 2020).

Method

The research location is in Olele Village, Kabila Bone District, Bone Bolango Regency, Gorontalo Province. The research involves three stages: preparation, field survey, and data analysis. The preparatory stage includes an extensive literature review to understand the site's conditions and relevant research concepts. Additionally, various secondary data sources, such as the RBI Map of Bone Bolango Regency and Open Streets Map data, were utilized, along with geological, soil, and rainfall data.

Following this, the field survey phase focused on collecting in-depth data, including measurements of the shallow groundwater table and a comprehensive assessment of lithology and groundwater morphology. Finally, the data analysis stage utilized ArcGis 10.8 software to generate groundwater potential maps. The study also employed a parameter weighting and scoring approach based on the framework by (Danaryanto et al., 2007). This framework categorized parameters such as rainfall, soil cover, slope, and rock graduation, each assigned specific weight values to assess their influence on natural groundwater replenishment within the basin.

Table 1. Rock Pass Rating Value

Rock Graduation Grade (m/day)	Rating value	Information
> 10^3	5	very high
10^1 - 10^3	4	high
10^2 – 10^1	3	Enough
10^4 – 10^2	2	currently
< 10^4	1	low

Table 2. Rock Pass Rating Value (Danaryanto et al., 2007)

Rainfall (mm/year)	Rating value	Information
> 4,000	5	very high
3,000 – 4,000	4	high
2,000 – 3,000	3	Enough
1,000 – 2,000	2	currently
< 1,000	1	low

Table 3. Soil Cover Rating Value (Danaryanto et al., 2007)

Cover soil	Rating value	Information
Gravel	5	very high
Gravel sand	4	high
Sandy loam/silty silt	3	Enough
Clay silt	2	currently
Silt clay	1	low

Table 4. Slope Rating Value

Cover soil	Rating value	Information
> 40°	5	very high
20 - 40°	4	high
10 - 20°	3	Enough
5 - 40°	2	currently
< 5°	1	low

Result and Discussion

Geological Conditions in the Olele Region

According to Silver and Moore (Santoso et al., 2010), the Sangihe archipelago is an active volcanic arc that extends from Milano to the North Arm of Sulawesi. As a result, Gorontalo, which is located in the central part of this area, is in the volcanic-plutonic pathway of North Sulawesi which is dominated by Eocene-Pliocene volcanic rocks as well as intrusion rocks (Bachri, 2006). The Olele area in Bone Bolango Regency, Gorontalo Province has characteristics of Pliocene-Plistocene and Miocene volcanic rocks and the presence of Miocene breakthrough rocks (Apandi et al., 1997).

Volcanic activity is determined by magma chamber activity recorded in volcanic and plutonic rocks exposed in the field. In Olele Village, when viewed from a 1:25,000 scale map (Bahutala, 2016), variations in volcanic rocks include pyroclastic breccias (Pinogu Volcanic Rock Formation) as well as dacite and andesite lava rocks (Volcanic Rock Formation (Bilungala).

Based on the Regional Geological Map with a scale of 1: 250,000 Kotamobagu sheets, the stratigraphic order in this study area is sequential from young to old, namely Reef Limestone (Ql), Pinogu Volcano Rock (TQpv), Diorite Bone (Tmb), and Bilungala Volcano Rock (Tmbv). The geological structures that influence this area are a northwest-southeast trending strike-slip fault on the coast that intersects the Bilungala volcanic rock unit, a northwest-southeast trending strike-slip fault in the center of the map that intersects the diorite bone unit, as well as an estimated separator fault between the Bilungala volcanic rock units and the Tinombo formation in the southeastern part of the map (Nurahmah, 2021).

There are two volcanic rocks in the study area, namely TQpv (Pinogu Volcano Rock) and Tmbv (Bulungala Volcano Rock). The Pinogu Volcano Rock (TQpv) is a Pliocene unit that includes tuff, lapilli tuff, breccias, and lava. The tuffs and lapilli tuffs near the Bone River exhibit a tiered structure. The breccias found in the Bone Mountains are primarily composed of pyroxene andesite and dacite. The lava, which appears in shades ranging from light gray to dark gray, is dense, massive, and predominantly made up of pyroxene andesite. The Bilungala Volcano Rock (Tmbv) formation dates back to the Miocene period and comprises breccias, tuff, and lava composed of andesite, dacite, and rhyolite. Zeolite and calcite are frequently discovered within the fragments constituting the breccias. The tuff generally displays dacitic properties, appearing relatively compact with occasional poor layering. The lava, ranging in composition from andesitic to basaltic, exhibits a hypocrystalline to holocrystalline texture, appearing as a massive fine-grained structure that has undergone processes such as propylitization, chloritization, and epidotization.

Based on regional stratigraphy by Pholbud et al. (2012), the Bilungala Volcano rocks date back to the early Miocene, where this formation was formed simultaneously with the Dolokapa Formation to the middle Miocene and the Wobudu Breccia in the late Miocene. The Diorite Bone Formation is seen breaking through the Bilungala Volcano Rocks in the middle Miocene to late Miocene. While the Pinogu Volcano Formation appeared in the Pliocene.

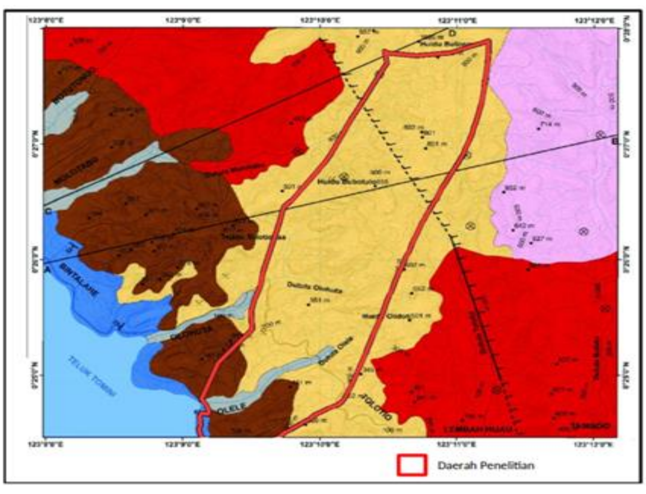

Figure 1. Geological map scale 1: 25,000 of the Olele area and its surroundings (Bahutala, 2016)

Bahutala (2016) classifies rock units in the Olele area and its surroundings on a 1:25,000 scale map into 6 units, namely the Alluvium unit (gray), the Reef Limestone unit (blue), the Pyroclastic Breccia unit (brown), the Diorite unit (Pink), Dasitan Lava units (yellow), and Andesite Lava units (red). The volcanic rock units taken in the study area based on the map are the Pyroclastic Breccia units which are products of Pinogu Volcanic Rocks (TQpv), as well as Andesite and Dacite Lava which are products of Bilungala Volcano Rocks.

Geomorphology, Structure and Lithology of Olele Village

The morphology of Olele Village includes oceans and mountains. This area has an altitude of 0-962.5 meters above sea level with the highest elevation being in the north. The slope of the slopes in this area is flat to very steep (van Zuidam 1985). Based on Twidale's classification (2004), the flow pattern in this area is dendritic. Geomorphology in Olele Village is divided into 4 terrain units, namely reef terrace plain units, alluvial plain units, pyroclastic flow hill units and lava flow units.

Reef Terrace Plain Unit

This unit consists of constituent lithology, namely reef limestone. This unit has an overall slope of 4° - 16° (sloping - rather steep) with a difference in height of about 0 - 50 meters above sea level and has relief in the form of plains forming a morphology of plains - low hills.

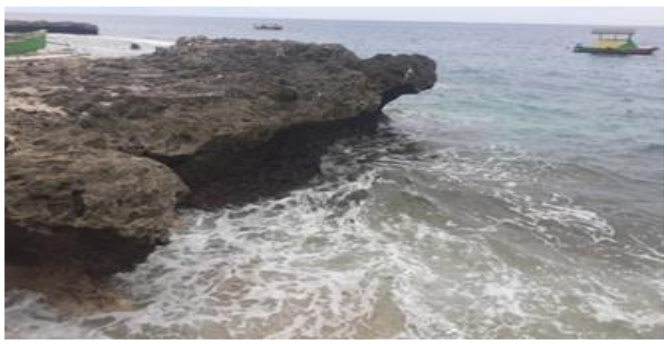

Figure 2. Reef terrace plain unit

Alluvial Plain Unit

This unit consists of a constituent lithology which is in the form of alluvial along with loose material of fine sand-crustal size. This unit has an overall slope of 0° - 8° (flat – oblique) with a height difference of about 0 – 25 meters above sea level and has relief in the form of plains forming a lowland morphology.

Pyroclastic Flow Hill Unit

This unit consists of pyroclastic breccia lithology which is a product of volcanic activity. This unit has an overall slope of 16° - 55° (steep – very steep) with a height difference of around 50 - 207 meters above sea level. The relief of hills with steep to steep slopes and elongated morphological patterns in this unit express the results of a seaward flow.

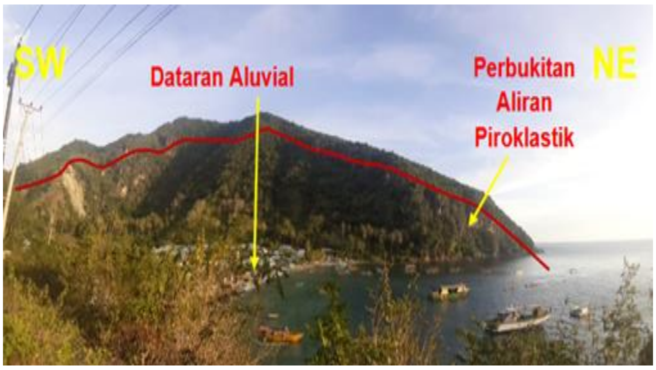

Figure 3. Alluvial plains & pyroclastic flow hills

Lava Flow Unit

This unit consists of porphyritic dacite lithology which dominates most of the lithology in Olele Village. This unit has an overall slope of 8° - 55° (rather steep – very steep) with a height difference of around 75 - 845 meters above sea level. The relief of the hills has steep to steep slopes and elongated morphological patterns in this unit express volcanic rocks with a higher degree of resistance.

Figure 4. Lava flow

Rock Description

Based on the results of the mapping carried out, that the Olele area has four rock units. Here's the explanation:

Dasit Unit

This unit is the oldest unit of all rock units found in Olele Village. Based on its characteristics, this dacite unit has a fresh color (light to dark gray), weathered (yellowish-brown), faneritic-porphyritic, euhedral, inequigranular, holocrystalline. Main mineral composition (plagioclase), additional minerals (quartz, hornblen, and pyroxene).

Figure 5. Dasit

Tuff Unit

This tuff unit is a pyroclastic rock resulting from volcanic eruptions. Tuff is characterized by weathered (yellow-brown) fresh (white-gray) color, has a texture with fine-coarse ash size, angular tough-rounded grain shape, open packaging.

Figure 6. Tuff

Breksi Piroklastik Unit

This unit is a breccia with white-brown characteristics, grain size of gravel fragments, angular fragments, poor selection, open packing, good compactness, matrix supported, poor porosity, polymic fragments in the form of andesite rock. The matrix is in the form of fine-coarse sand tuff with gray-white color.

Figure 7. Breksi Piroklastik

Reef Limestone Unit

This unit is a white carbonate rock, hollow, non-clastic texture, and there are remnants of coral reefs and coral. Formed in shallow marine environments.

Figure 8. Reef Limestone

Alluvial Unit

This unit is loose material consisting of igneous rock, pebble-sized andesite-dacite. These materials originate from the headwaters of the river which are carried to form this unit. The coastal sedimentation process makes this unit a fine sand-clay sized material.

Figure 9. Alluvial

Olele Village Geosite Potential

Geosite and Geomorphosite are landscapes that have potential as tourism sites and have value from the point of view of human judgment. This analysis is intended to provide an assessment of certain parameters such as the value of a scientific approach, educational value, economic value, conservation value and added value (beauty, culture, geological factors) in certain areas (Kubalíková, 2013).

The existence of a Geosite in Olele Village has the potential to become an edu Geotourism. Lithological contact between reef limestone and pyroclastic breccias is a geological characteristic of the Olele Geosite. This contact is interpreted as a fault contact or as a result of tectonic control as indicated by the presence of slickenside on the surface of limestone and volcanic breccias. The Olele limestone geosite is located to the north of the Olele waters and the Olele Beach plain.

Ground Water Potential

Referring to the weight value of the water absorption parameter, it is known that the parameters that greatly influence the infiltration ability to add groundwater naturally in the groundwater basin area of Olele Village from very high to moderate are the pass rate of rock, rainfall, soil cover and slope. Parameter rating is distinguished based on the value of water absorption capacity listed in table 1 to table 4.

Table 5. Water Absorption Parameter Weight Value (Danaryanto et al., 2007)

Parameter	weight value	Information
Rock Graduation	5	very high
Rainfall	4	high
Cover Land	3	Enough
Slope	2	currently

The lithology of Olele Village has units of reef limestone which are good water-carrying layers. Healing or replenishment of water in the soil takes place due to rainfall, which partially seeps into the soil, depending on the type of soil and rock that underlies an area where rainfall seeps into the earth in large or small amounts, there are rare earths and there are impermeable soils. Graduation of soil or rock is a measure of the ease with which water can pass through the material.

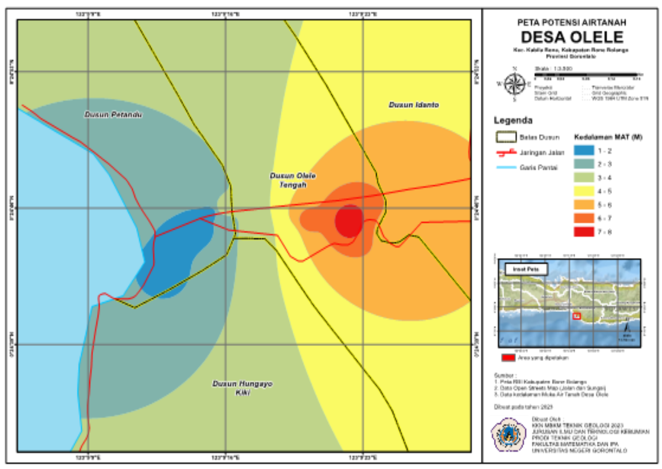

Figure 10. Map of the groundwater potential of Olele village

Based on the groundwater potential map of Olele Village, it is known that the depth of the groundwater table (MAT) is 1-8 meters. Areas that tend to have high groundwater potential are areas along the coast shown in dark blue and light blue on the map. If based on a 1:17,000 scale geological map of the study area, the area with high groundwater potential is occupied by the olele reef limestone type. Where in the outcrops found in the field it was found that the limestone of the reef has a fairly good level of porosity. Very suitable as a groundwater aquifer.

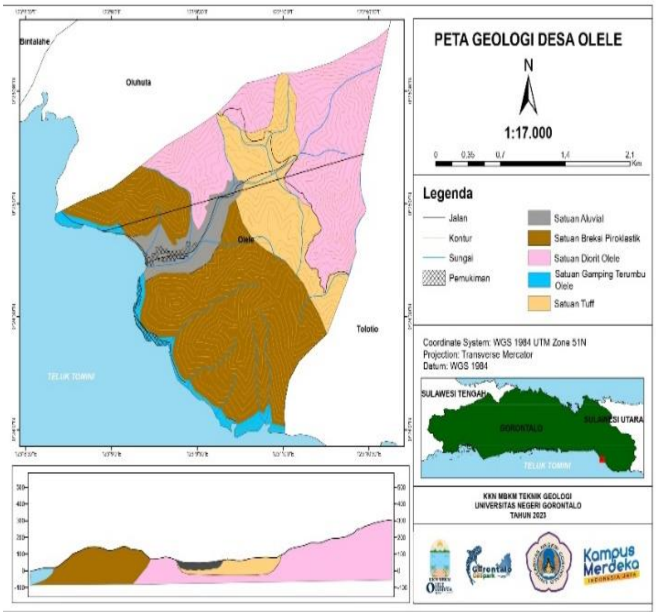

Figure 11. Geological map of the Olele region

Groundwater Conservation Plan

Following are the detailed steps for a groundwater conservation plan to support the development of the Tomini Bay Geopark:

Step 1: Groundwater Monitoring

Determine strategic locations for the installation of groundwater monitoring wells throughout the Geopark area. Install sensors and monitoring equipment in the wells to measure groundwater level, temperature, and water quality on a regular basis. Collect and analyze monitoring data to identify trends in groundwater change and impacts of human and natural activities.

Step 2: Community Education

Develop educational materials about the importance of groundwater, the benefits of conservation, and threats to water resources. Organize seminars and workshops for local residents, farmers, students, and relevant stakeholders. Use social media, brochures and information campaigns to reach a wider audience.

Step 3: Management of Water Use

Establish a special team consisting of environmental experts, scientists, and community representatives to formulate policies for managing water use. Develop regulations that limit groundwater extraction and encourage the use of water-efficient technologies. Develop incentives for environmentally friendly agricultural and industrial practices related to water use.

Step 4: Sustainable Farming Practices

Identify smallholders interested in implementing sustainable farming techniques. Conduct training on crop rotation, use of organic fertilizers, water-saving irrigation, and other sustainable practices. Provide technical support and monitoring to smallholders applying these techniques.

Step 5: Wetland Rehabilitation

Assess and map the wetlands that need rehabilitation around the Geopark. Develop a restoration plan, including planting suitable vegetation and restoring natural habitats. Invite local communities to participate in wetland rehabilitation activities.

Step 6: Development of Alternative Infrastructure

Conduct feasibility studies for rainwater collection and storage, seawater desalination, and treated wastewater utilization. Choose the technology that best suits the geographic conditions and needs of the Geopark. Implement alternative infrastructure gradually and monitor its effectiveness.

Step 7: Collaboration and Mitigation of Tourist Impacts

Collaborate with the tourism industry to identify and mitigate the impacts of tourists on groundwater. Implement good waste management practices in tourist areas, including environmentally friendly sanitation facilities. Regulate the number of tourists to match the natural capacity of the Geopark to prevent degradation of water resources.

Conclusion

Olele area's stratigraphy progresses from the youngest Reef Limestone (Ql) to the oldest Bilungala Volcano rock (Tmbv), while its notable geological structure is the northwest-southeast-trending strike-slip fault. The region's rock units include Alluvium, Reef Limestone, Pyroclastic Breccia, Diorite, Dasitan Lava, and Andesite Lava, contributing to diverse geomorphological features. The geosite potential lies in the distinctive contact lithology of reef limestones and pyroclastic breccias, enhancing the village's groundwater prospects. With a shallow groundwater table depth (MAT) of 1-8 meters, the village exhibits a robust water-carrying capacity, supported by a comprehensive groundwater conservation plan encompassing monitoring, education, water management, sustainable agriculture, wetland rehabilitation, infrastructure development, and tourist impact mitigation.

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Author Contributions
Investigation, N. N and A. P. A.; data analysis and map creation, Y. I. A.; investigation, N. N and A. P. A.; resources, Y. I. A and N. N; data curation, A. P. A.: writing—original draft preparation, Y. I. A and N. N; writing—review and editing, A. P. A.: visualization, Y. I. A, and N. N; supervision, Y. I. A.; project administration, N. N; funding acquisition, A. P. A and Y. I. A. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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