

Article

Hydrogeological Evaluation Based on Water Quality Parameters and Groundwater Level Conditions in Kolaka and Tangketada Basins, Southeast Sulawesi

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Abstract. This study aims to evaluate the hydrogeological conditions of Pomalaa through analysis of groundwater flow patterns, groundwater level fluctuations, and water quality parameters. The methods used include geological and hydrogeological mapping, groundwater level measurements, and delineation of groundwater basins based on regional topography and lithological data. Water quality analysis was conducted by measuring temperature, Total Dissolved Solids (TDS), electrical conductivity (EC), and pH parameters. The study area consists of five main rock units, with three types of aquifers based on lithological characteristics, namely intergranular and fractured aquifers, low-yield aquifers, and rare aquifers. The results of the study show that groundwater flow patterns follow natural hydraulic gradients, but fluctuate due to environmental changes and mining activities. Several points show significant water quality degradation, with pH, TDS, and EC values exceeding drinking water thresholds. The water quality index shows variations from very good (57), good (49), poor (23), very poor (22), to unfit for drinking (48). The solution offered by this study is the need for mitigation strategies and sustainable water resource management, which is of utmost urgency to maintain ecosystem balance and ensure the availability of clean water for the community and industry in the future.



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Email : mabdulrahmansalim99@gmail.com**1. Introduction**

Recent studies reveal that aquifer characteristics in the Pomalaa region are strongly influenced by nickel laterite lithology, resulting in striking differences in hydraulic conductivity and groundwater chemical composition [1]. The risk of pollution increases due to the proximity of mining sites to coastal areas, meaning that contaminants from mining activities have the potential to enter the marine water system and disrupt the balance of coastal ecosystems [2]. Based on hydrogeological studies, the study area is included in Sheet IX of the Sulawesi Island groundwater basin map [3].

Geographically, the study area is located in Kolaka Regency, Southeast Sulawesi Province, with coordinates 121°32'30"–121°42'30" BT and 4°20'–4°7'30" LS [4]. Kolaka Regency is located in the western part of Southeast Sulawesi Province, and Pomalaa Subdistrict is one of the largest subdistricts with a population of 28,656 and an area of 231.47 km² [5]. Administratively, the study area covers five subdistricts stretching from north to south, namely Wundulako, Baula, Pomalaa, Tanggetada, and Polinggona, as well as part of the Aere Subdistrict, which is included in East Kolaka Regency [4-5].

Groundwater quality assessment in various mining areas also commonly uses the Water Quality Index (WQI) approach, which has been proven effective in describing overall water quality conditions [6]. Based on Indonesia's hydrogeological map, the Pomalaa region is included in the laterite rock aquifer zone with low to moderate productivity [7]. The impact of mining activities on groundwater quality in this region is also in line with findings from similar studies in other mining areas [8].

Pressure on groundwater due to excessive exploitation has become an increasingly relevant global issue, with widespread socio-economic impacts and an urgent need for sustainable water resource management strategies [9]. The research location is in the Pomalaa area, Kolaka Regency, Southeast Sulawesi Province, as shown on Google Maps topography imagery [10]. Research in areas with anthropogenic activity, particularly mining areas, is very important because it can provide a comprehensive understanding of the influence of human activity on water quality and availability [11].

The National Sanitation Foundation Water Quality Index (NSF-WQI) approach, which is widely used in water quality assessment, refers to nine physical, chemical, and biological parameters of water as developed by Horton [12]. From a social perspective, mining activities in Pomalaa have had a real impact on people's lives, both in terms of the economy and access to clean water [13]. Based on national regulations, water quality must also meet environmental quality standards as stipulated by the Ministry of Health of the Republic of Indonesia [14]. The NSF-WQI approach used in this study has also been widely applied in studies of groundwater and surface water quality [15-16].

In addition, this study refers to various studies that apply water quality index methods in tropical [17-18] and non-tropical [19] regions. The presence of mineral deposits such as nickel and iron ore in the Pomalaa area has the potential to significantly affect the quality and availability of water resources [20]. In the study area, there are two main rivers that are included in two groundwater basins, namely the Huko-huko River in the Kolaka Groundwater Basin and the Oko-oko River in the Tangketada Groundwater Basin [20].

Hydrogeological studies play a crucial role in identifying groundwater flow patterns, potential pollution from industrial activities, and formulating conservation strategies to maintain ecosystem sustainability [21-23]. Water quality analysis based on the Water Quality Index (WQI) has also been widely applied to assess the condition of aquatic environments, including in tropical regions such as Indonesia [24-25].

Geologically, Pesouha Village and its surroundings, which are part of Pomalaa District, are composed of metamorphic, ultramafic, sedimentary, and alluvial deposits [26]. These geological characteristics influence groundwater distribution and water quality variations in the Pomalaa area [27]. Previous studies have shown that lithological conditions and rock structure greatly determine the level of heavy metal contamination in groundwater around mining areas [28].

In addition, natural factors such as hydrology, atmosphere, climate, topography, and lithology also have a significant influence on water quality [29]. Variations in rock porosity and permeability also play a role in determining the direction of groundwater movement and the degree of aquifer saturation [30]. Through a hydrogeological approach and water quality index analysis [31], this study aims to provide a more comprehensive understanding of the relationship between lithological conditions, water quality, and sustainable water resource management strategies in the Pomalaa area and its surroundings.

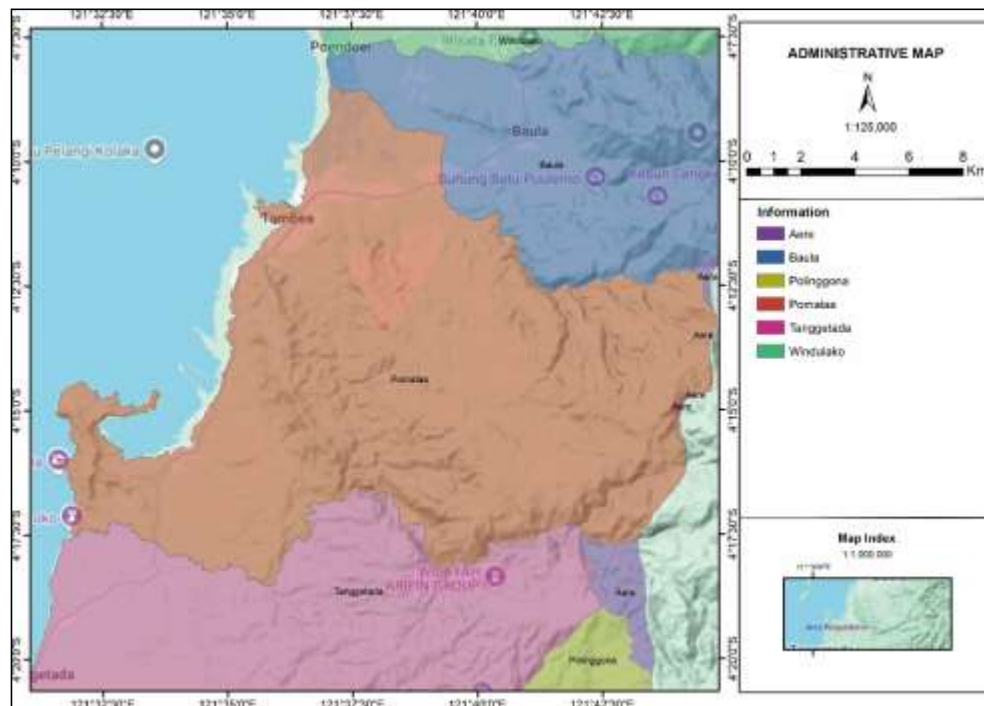


Figure 1. Administrative Map of The Study Area [4], [10]

2. Experimental Section

2.1. Materials

This study is based on the integration of multidisciplinary data covering geological mapping, hydrogeological mapping, and groundwater quality analysis. Geological mapping was carried out at 26 observation points spread across the study area, with the aim of identifying rock units, geological structures, and lithological characteristics that affect surface water systems. Meanwhile, hydrogeological mapping covered 244 observation points representing the spatial distribution of groundwater, flow direction, and local and regional aquifer potential.

Water quality analysis was conducted at 199 sampling points, covering physical and chemical parameters to evaluate the suitability of water against quality standards and its potential for use. Administratively and hydrogeologically, the study area is located in two groundwater basins, namely the Kolaka and Tangketada Groundwater Basins, as defined [3], each with different aquifer characteristics and groundwater flow dynamics [7] (Figure 2).

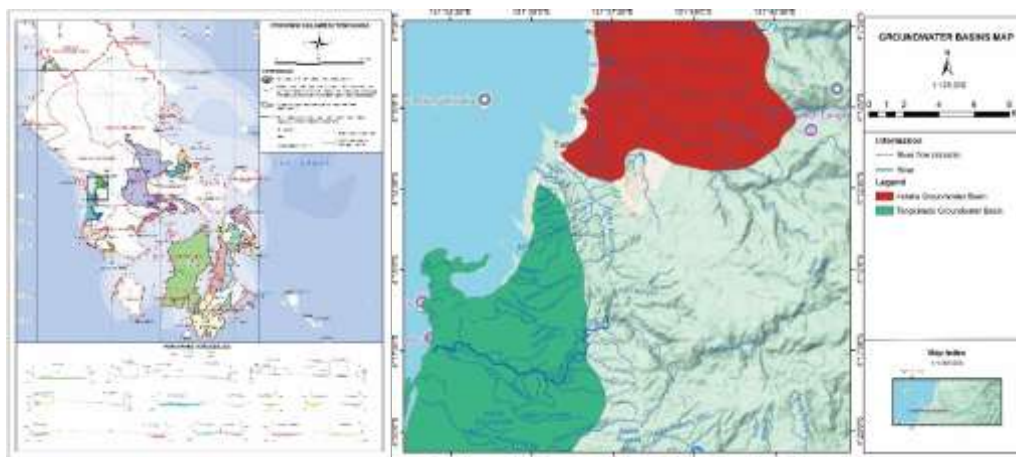


Figure 2. Groundwater basins map of the research location and modification of the groundwater basins [3], [7]

Field data collection in the form of geological mapping was carried out in June 2024, hydrogeological mapping was carried out in 2019 and June-July 2024, and water quality mapping was carried out in June-July 2024. Water quality data collection was carried out in June-July 2024, which means it was taken during the dry season. The dry season is characterized by low rainfall and predominantly hot temperatures. This will have a dominant effect on the quality of surface water in the study area. Samples were taken using random sampling methods. Water level data was collected in Pomalaa from the mapping results, yielding 244 observation locations (2 waterfalls, 43 bore wells, 67 digging wells, 5 artesian wells, 1 spring water, 121 rivers, 3 voids, and 2 swamps). Meanwhile, water quality data from the mapping results obtained 199 observation locations (2 waterfalls, 28 bore wells, 39 digging wells, 3 artesian wells, 1 spring water, 121 rivers, 3 voids, and 2 swamps). River data was collected along the Huko-huko and Oko-oko Rivers (Figure 2). Sample testing was conducted in situ in the field using available equipment, such as Electrometric (pH), Thermimetry (temperature), and Gravimetry (TDS and EC). Water quality sample testing in the field served to obtain actual water values in the field, thereby avoiding/minimizing potential contamination if testing was conducted in a laboratory.

Table 1. Types of Water Quality Parameters According to NSF-WQI

No	Parameter	Testing Method	Test Place
1	pH	Electrometric	Research sites
2	Temperature	Thermimetry	Research sites
3	TDS	Gravimetry	Research sites

Geologically, the study area is included in the Kolaka Sheet (Figure 3) [26]. This sheet covers rock units originating from the Pre-Tertiary to Quaternary periods, dominated by metamorphic and volcanic rocks that have undergone intensive tectonic deformation. The presence of geological structures, such as faults in this region, plays an important role in the formation and configuration of the water table, as well as influencing regional groundwater flow patterns. The integration of geological and hydrogeological data enables the identification of groundwater recharge and discharge zones, and supports accurate hydrogeological models for the conservation and sustainable management of groundwater resources in tropical regions affected by mining activities.

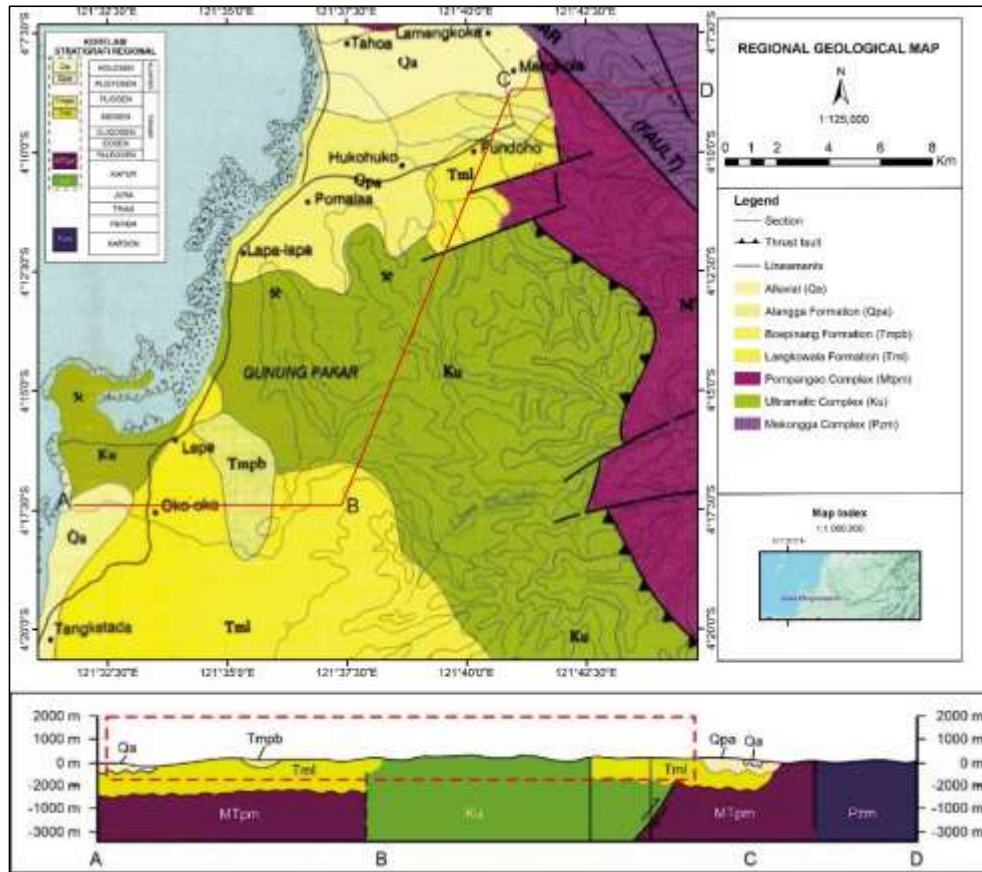


Figure 3. Regional Geological Map of the Research Area [26]

Hydrogeologically, the study area is included in Sheet IX based on the groundwater basin map of Sulawesi Island [3]. This sheet covers two groundwater basins in the study location, namely the Kolaka Groundwater Basin (north) and Tangketada (south). Based on the hydrogeological map of Indonesia, the study area is dominated by igneous/metamorphic rocks (very low water potential) and loose sediments (low water potential) (Figure 4) [7]. The boundaries of each basin indicate recharge areas and discharge areas. The upstream (eastern) area is a recharge area, while the downstream (western) area is a discharge area. This is used to identify the potential water quality in the upstream and downstream areas of the study area.



Figure 4. Hydrogeology Map of Indonesia [7]

2.2. Method

The research method was conducted based on existing problems in the field. The method was used for characterization, identification, and to assist in solving existing problems. In this case, the methods used included mapping (geology, hydrogeology, and water quality), literature review (geology and hydrogeology), and water quality index analysis (National Sanitation Foundation-Water Quality Index/NSF-WQI) (Figure 5).

The first stage of regional geological literature study and geological mapping is the initial stage to determine the distribution of lithology in the study area. This will be used to identify the constituent lithology in the study area. Lithology is thought to have a significant effect on the potential quality of surface water in the study area. Next, regional hydrogeological studies and hydrogeological mapping are conducted to determine the hydrogeological conditions in the study area. This is used to identify the conditions of the groundwater basin (CAT), groundwater table, and groundwater flow patterns.

The second stage of the Water Quality Index (WQI) method is based on comparing nine water quality parameters with regulatory standards according to their designation, then assigning a single value to determine water quality [6]. WQI was first created by Horton (1965), and other ideas were used as the basis for developing the initial method. The Water Quality Index (WQI) value is calculated based on the water quality level (q_i) and weight factor (w_i) [12]. The second stage of the Water Quality Index (WQI) analysis is used to analyze water quality. The water quality index does not depend on a single indicator or parameter, which is a very effective and useful approach for disseminating comprehensive information about water quality [25].

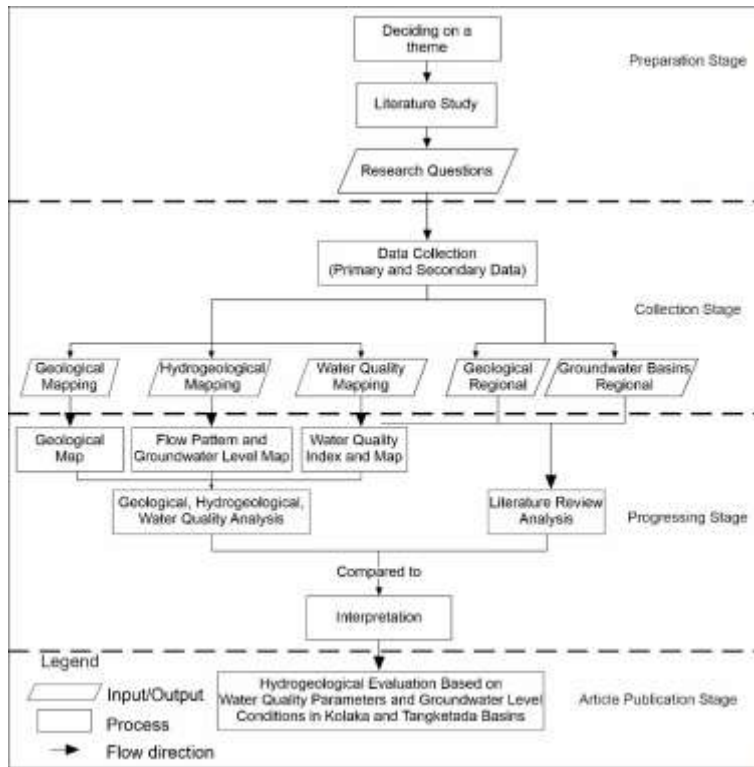


Figure 5. Schematic/Flowchart of research

The analysis was conducted using the Water Quality Index method, which is the result of the development of the Weighted Arithmetic Water Quality Index. The Water Quality Index method has the advantage of analyzing whether surface water and groundwater are suitable or not, as well as water quality based on its purity level using several variables. The calculation steps for the Water Quality Index method according to Kusuma and Pradesh (2015) [16] are:

(1) Calculating the WQI (Water Quality Index)

$$WQI = Antilog (\sum_{n=1}^n W_n \log q_n)$$

WQI = Water quality index

W_n = Weigh age factor

q_n = Quality rating

(2) Classification of WQI values

Table 2. Classification of WQI values [16]

Water Quality Index (%)	Description
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very poor
>100	Unfir for drinking

3. Results and Discussion

3.1. Geological Mapping

In this study, geological mapping was conducted covering various aspects, such as lithological characteristics and geological structures in the study area. From the mapping results, 26 observation locations were identified as research points to obtain more comprehensive data on local geological conditions. The following is the data obtained from the mapping results (Table 3).

Table 3. Geological Mapping Data

Kode STA	Coordinates		Colour	Degree of Weathering	Structure	Particle Shape	Spacing	Lithology
	X	Y						
ST1	345775	9526646	Red	Residual soil	Non structure (fine)	Clay	None	Soil
SB2	347186	9526941	Grey	Slightly weathered	Massive	Angular, flat, smooth	0.1-0.25 mm	Peridotite
SB3	337910	9526343	Greenish Grey	Slightly weathered to moderately weathered	Massive	Angular, flat, rough	0.1-0.25 mm	Low serpentinised peridotite
SB4	359484	9523518	Greenish Grey	Highly weathered	Massive	Angular, flat, rough	0.1-0.25 mm	Low serpentinised peridotite
SB5	358498	9523297	Brownish Grey	Moderately weathered	Massive	Sub rounded	None	Conglomerate

Lithological characteristics greatly determine aquifer potential and groundwater quality. Metamorphic and peridotite rocks, which are dominant in the eastern part of the study area, have low permeability, thus functioning as recharge areas with high groundwater levels. In contrast, alluvial deposits in the western part have high permeability and function as discharge areas, but are vulnerable to pollution. Based on previous research, laterite nickel is known to contribute to an increase in dissolved metal content and affect the electrical conductivity of groundwater, which is consistent with the conditions found at the research site [1].

3.2. Hydrogeological Mapping

In this study, hydrogeological mapping was conducted to identify the characteristics and potential of groundwater resources in the study area. From the mapping results, 244 observation locations were obtained, spread across various parts of the study area. The following is the data obtained from the mapping results (Table 4).

Table 4. Hydrogeological Mapping Data

Kode STA	X	Y	Water Bodies	Elevation (mdpl)	Water Table (m)
AT1	359458	9523666	Waterfall	519	0
AT2	352699	9523991	Waterfall	333	0
SB1	340913	9528699	Bore well	3	0
SB2	340744	9528350	Bore well	10	0
SB3	340196	9526188	Bore well	28	0

This flow pattern indicates an aquifer system influenced by geological structure and topography. The highest groundwater level was found in metamorphic rocks (average 455.5 m), while the lowest was found in alluvial deposits (average 21.5 m). This supports the theory that the recharge zone is located in high areas with impermeable lithology, while the discharge zone is located in low areas with permeable lithology. Previous studies have confirmed that hydraulic gradients and lithology are the main factors controlling groundwater flow in tropical aquifer systems [22].

3.3. Water Quality Index

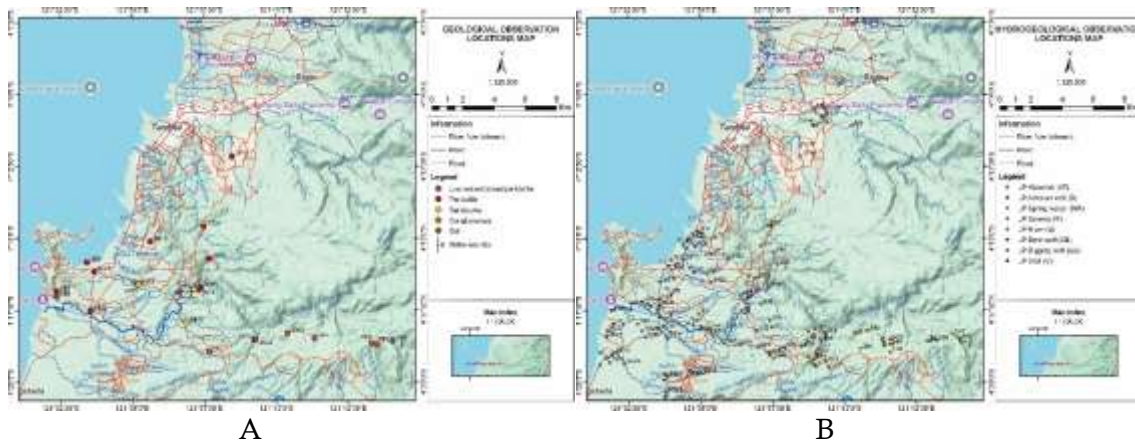
In this study, water quality mapping was conducted to understand the physical characteristics of water resources in the study area. As a result of the mapping, 199 observation points were obtained, each representing different hydrogeological conditions in the study area. At each observation point, water quality parameters including temperature, total dissolved solids (TDS), electrical conductivity (EC), and pH were analyzed. The following data were obtained from the mapping results (Table 5).

Table 5. Water Quality Mapping Data

Kode STA	X	Y	Water Bodies	Temperature (°C)	TDS (ppm)	EC (μS/cm)	pH
AT1	359458	9523666	Waterfall	25.2	108	140	7.2
AT2	352699	9523991	Waterfall	25.4	170	490	7.1
SB1	340913	9528699	Bore well	32.1	25	50	3.8
SB2	340744	9528350	Bore well	31.8	24	50	4.4
SB3	340196	9526188	Bore well	33.7	156	370	7.4

pH values <5 were found in several boreholes (e.g., SB1 and SB2), indicating acidic conditions that are unsuitable for consumption. According to Indonesian Minister of Health Regulation No. 2 of 2023, the pH threshold for drinking water is 6.5–8.5. High TDS and EC values in downstream areas indicate potential contamination from mining activities. Points SB1 and SB2 exceed these limits, indicating that the water is not suitable for consumption without treatment.

The coastal areas of Sulawesi shows a similar pattern, where nickel mining activities cause an increase in dissolved metal ions and a decline in water quality [21]. This reinforces the finding that the discharge area in Pomalaa is vulnerable to anthropogenic pollution.



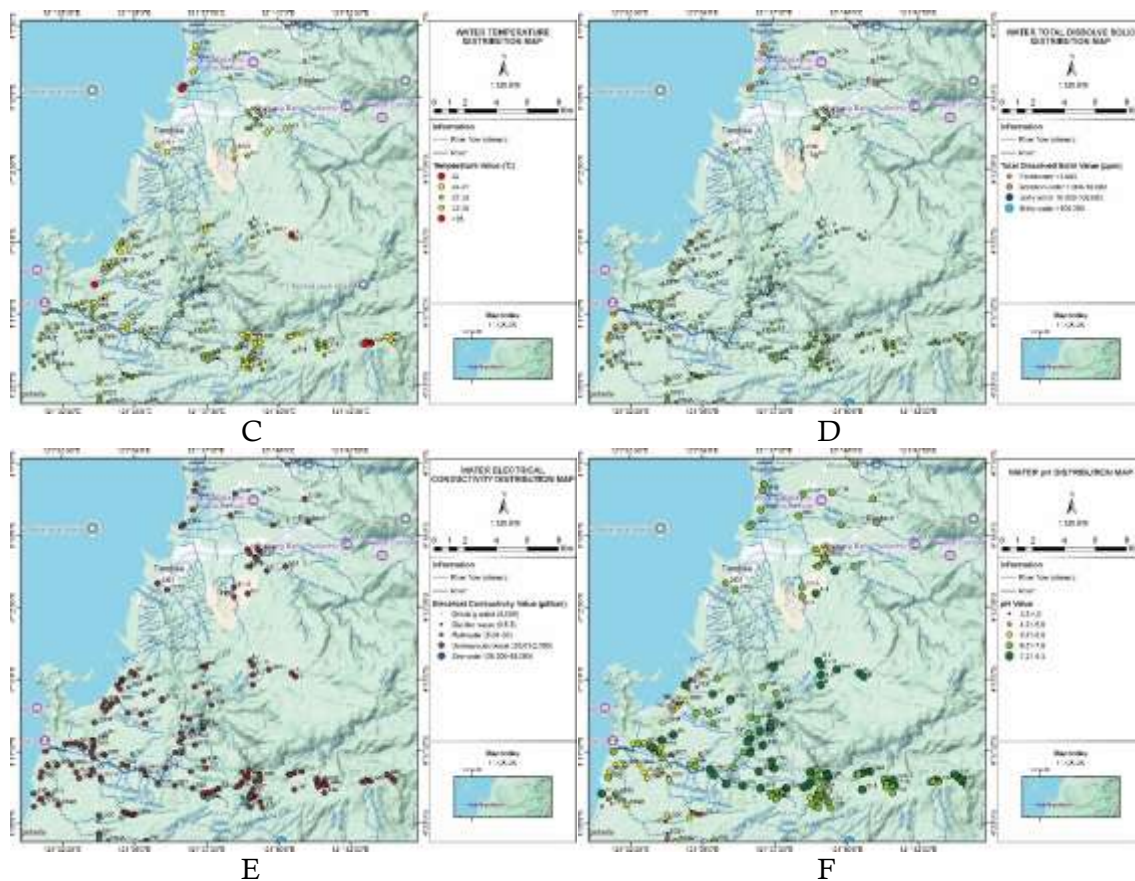


Figure 6. Distribution Locations Map of Water Quality. A) Geological Observations, B) Hydrogeological Observations, C) Water Temperature, D) Water Total Dissolve Solid, E) Water Electrical Conductivity, and F) Water pH [4], [10]

3.4. Geological Setting

Nickel laterite in Pomalaa is known to have varying hydraulic conductivity and the potential to increase dissolved metal content [1]. Based on the Kolaka Geological Map [26] and field mapping results, the stratigraphy of the study area consists of five main rock units arranged stratigraphically from oldest to youngest. The Pompangeo Complex Metamorphic Rock Unit (MT_{pn}) is the oldest unit, consisting of mica schist, glaucophane schist, amphibolite schist, chlorite schist, rijang, marble, and meta limestone [26].

These rocks are crystalline, compact, and have low permeability, thus functioning as a recharge area with a relatively high water table. Above this unit is the Pomalaa Peridotite Unit (Ku), which consists of peridotite, basalt, and serpentinite. These ultramafic rocks have low porosity and tend to be impermeable, but weathering processes can form nickel laterite, which increases the potential for heavy metal leaching into groundwater. Metamorphic rocks with foliation structures are known to influence the direction of groundwater flow through microfracture zones [29].

The unit above the ultramafic rock is the Langkowala Conglomerate Unit (Tml), which consists of conglomerate, is clastic in nature with moderate to high permeability. The Langkowala Sandstone Unit (Tml) is composed of sandstone, mudstone, claystone, and siltstone, showing significant variations in permeability. Sandstone has the potential to be a productive aquifer, while claystone and siltstone tend to function as aquitards. The youngest unit is the Alluvial Deposit (Qa), which consists of clay, silt, and sand, located in low-lying areas and functioning as a discharge area. Due to its

permeable nature and proximity to the surface, this unit is highly susceptible to anthropogenic pollution. Alluvial deposits in coastal areas are known to exhibit high water quality fluctuations due to waste infiltration and industrial activities [30].

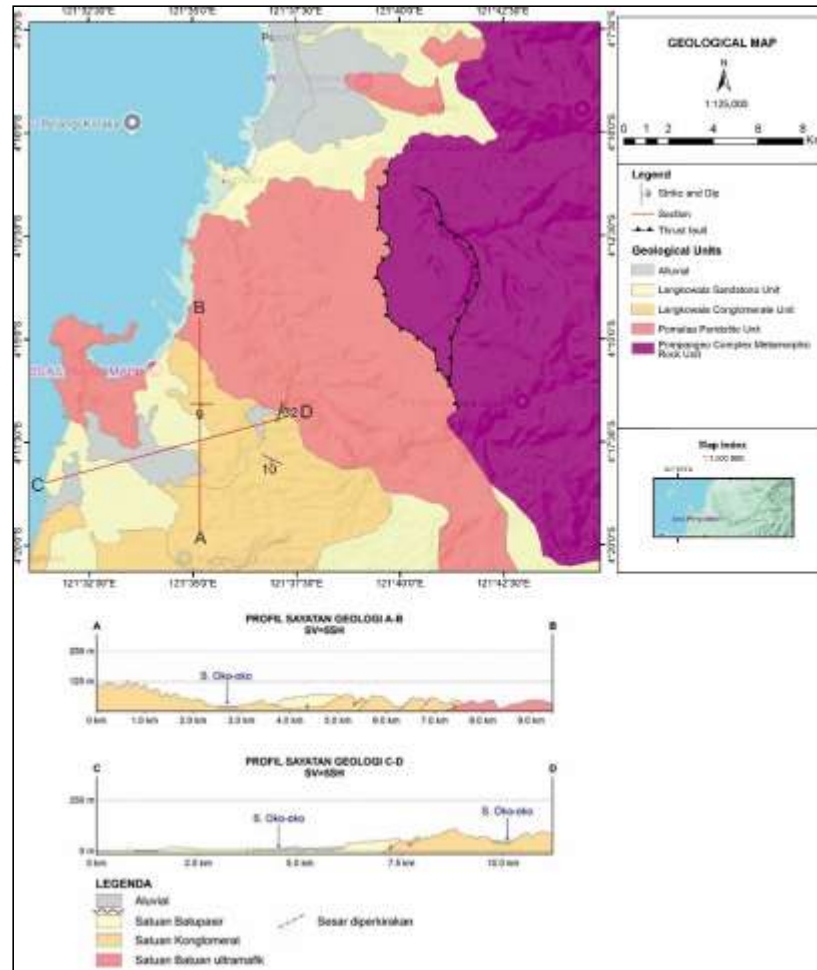


Figure 7. Geological Map [4], [10]

3.5. Analysis of Flow Pattern and Groundwater Level

The groundwater flow pattern map provides an overview of the dynamics of the hydrogeological system in the study area. Based on this map, it is known that groundwater flow patterns are influenced by local topography and geological conditions. Primary groundwater sources tend to follow hydraulic gradients and ground surface elevation, which play a role in determining the direction of water flow.

Analysis of flow patterns shows that groundwater in the study area flows from higher elevation areas with elevations of approximately 400 to 750 meters above sea level (east of the study area/mountains) to lower elevation areas with elevations of approximately <50 meters above sea level (west of the study area/sea), following the natural hydraulic gradient (Figure 8). The presence of groundwater contour values provides information about aquifer depth and potential recharge areas that allow rainwater infiltration into the aquifer system. Identification of the groundwater surface also assists in land use planning and water resource conservation. In the context of industrial development, understanding these flow patterns is crucial to avoid overexploitation that can lead to a decline in the groundwater table and other negative impacts such as seawater intrusion and local drought.

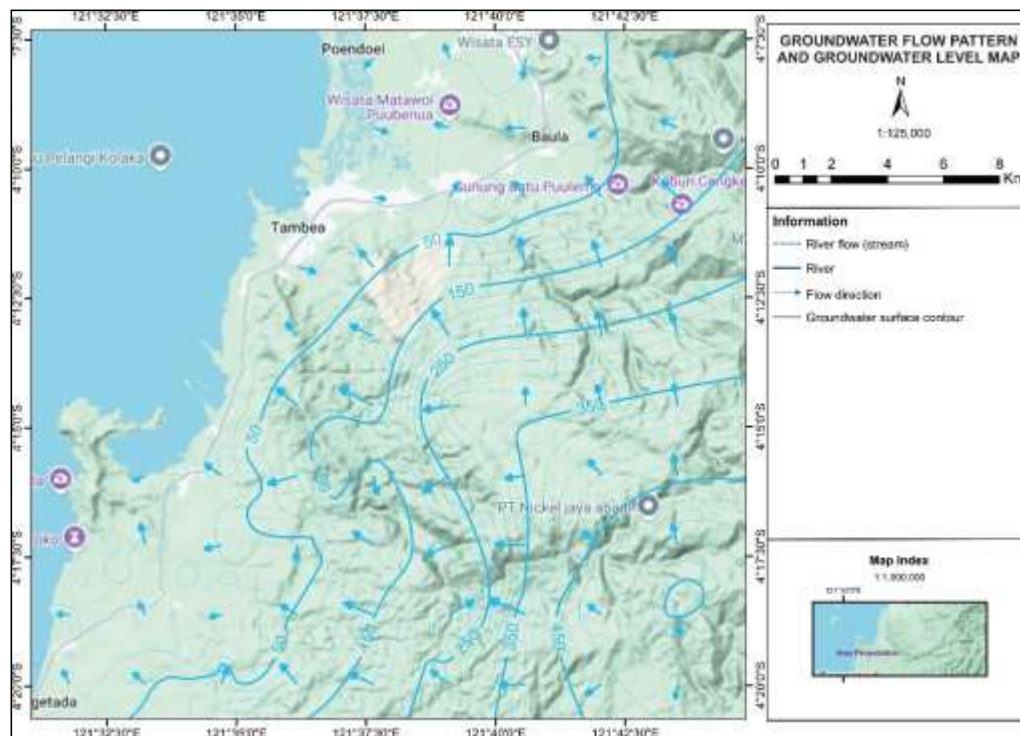


Figure 8. Map of Flow Pattern and Groundwater Level [4], [10]

Observations from 236 points show that the distribution of the water table varies based on lithological units. The Pompangeo Complex Metamorphic unit has the highest average groundwater level (455.5 m), while the Alluvial Deposits show the lowest value (21.5 m) (Table 6). This pattern indicates that lithology and topographic elevation synergistically control the hydraulic gradient and direction of groundwater flow.

3.6. Discharge Zone

Alluvial deposits and sandstone located in lowland areas function as disposal zones. This lithology has high porosity and permeability, allowing groundwater accumulation but also increasing vulnerability to contamination. Shallow aquifers located in disposal zones are known to be highly susceptible to contaminant infiltration from the surface, particularly in mining areas [29].

3.7. Recharge Zone

Metamorphic and peridotite rock units located in mountainous areas function as groundwater recharge zones. These rocks are massive and have low permeability, but local fractures and weathering allow rainwater infiltration. Metamorphic rocks with foliation structures are known to become groundwater flow pathways through secondary fractures [30].

3.8. Statistical Analysis, Visualization, and Relevance to Standards and Regulations

The stratigraphic box diagram (Figure 9) reinforces these findings by showing the wide distribution of groundwater levels in peridotite and conglomerate units, and the narrow distribution in sand and alluvial units. This reflects the heterogeneity of aquifers and the potential for local variation due to geological structures and anthropogenic activities. Significant declines in groundwater levels in alluvial and sandstone units need to be monitored as they can lead to seawater intrusion and water

quality degradation. Groundwater management in Indonesia needs to consider conservation and exploitation zones based on groundwater recharge and discharge potential [14]. Therefore, mapping groundwater levels based on lithology is considered an important tool in water resource conservation planning.

Table 6. Variations in Groundwater Level in Stratigraphy

Stratigraphy	Total	Average (m)	Standard Deviation (m)	Minimum (m)	Q1 (m)	Median (m)	Q3 (m)	Maximum (m)
Metamorf	10	455.5	153.862	42	406.225	522	547.5	572
Peridotite	63	161.743	174.182	-2	18.1	86	337.3	495
Conglomerate	77	117.436	84.496	0	43	92	193	278
Sandstone	56	15.538	12.543	-7	3.875	13.6	25.250	52
Aluvium	30	21.532	21.064	0.64	7	16.85	20.703	86.5
Total	236							

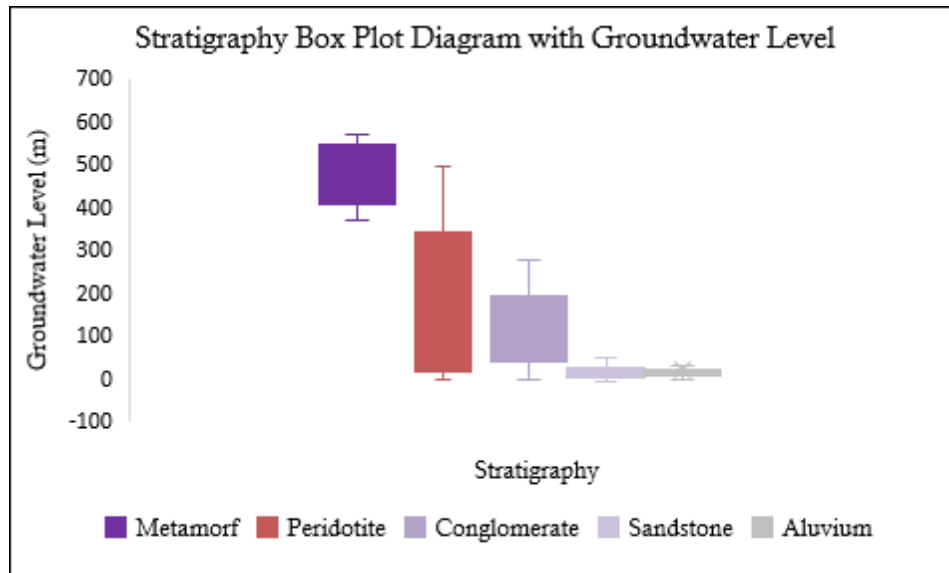


Figure 9. Stratigraphy Box Plot Diagram with Groundwater Level

3.9. Water Quality

Water quality in the study area was observed through direct measurements of surface water, well water, and groundwater. Based on the parameters of temperature, total dissolved solids (TDS), electrical conductivity (EC), and pH, water quality showed temperature values ranging from 23,2-36,4 °C, with an average of 29,34 °C. TDS values ranged from 7 to 8.760 ppm, with an average of 364,774 ppm. DHL values ranged from 10 to 10.050 $\mu\text{S}/\text{cm}$, with an average of 523,768 $\mu\text{S}/\text{cm}$. pH values ranged from 3,4 to 9,72, with an average of 6,38. There are river water bodies and empty water bodies with DHL values $>1500 \mu\text{S}/\text{cm}$ and EC $>1000 \text{ ppm}$ found in estuarine areas and nickel mining areas in the southwest and northwest.

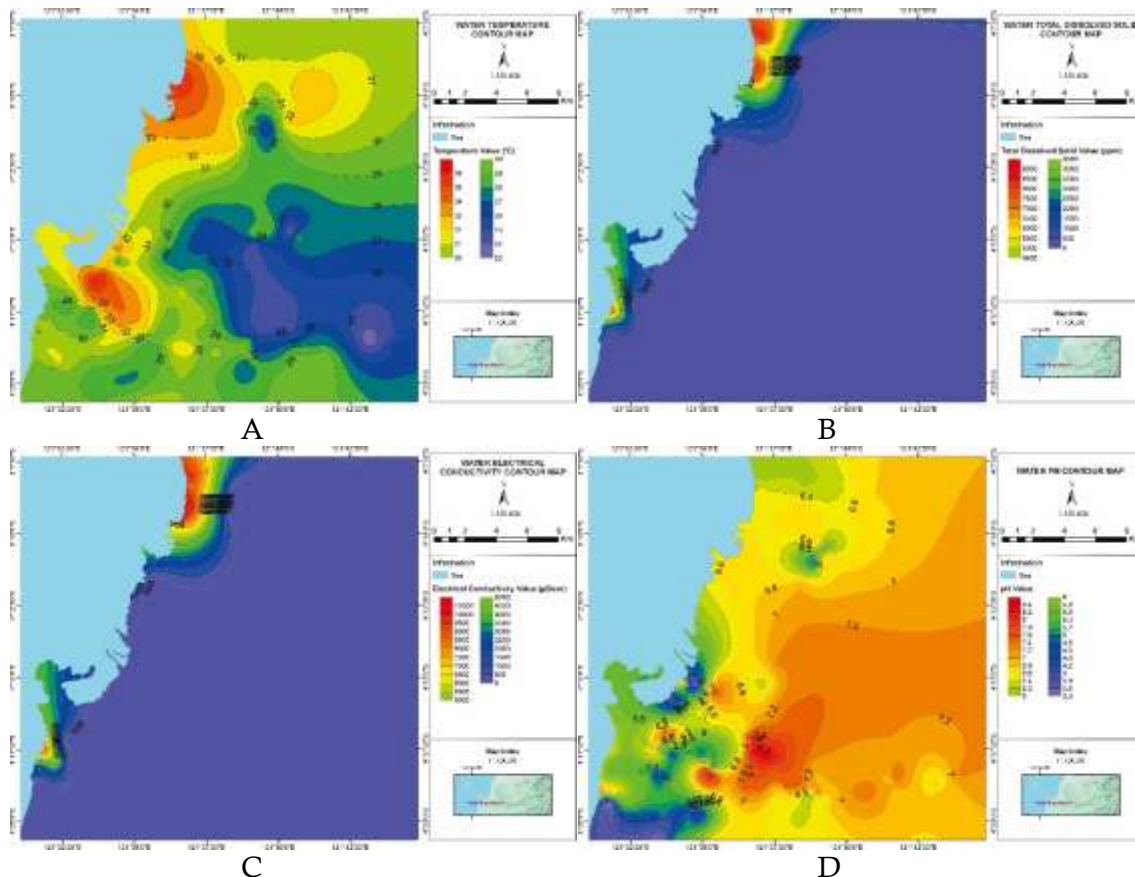


Figure 10. Distribution Contour Map of Water Quality. A) Water Temperature, B) Water Total Dissolved Solid, C) Water Electrical Conductivity, and D) Water pH [4], [10]

3.10. Water Quality Index

After collecting data in situ in the field, data on temperature, TDS, and pH were obtained for water quality index analysis. The sample parameters, consisting of surface water, well water, and groundwater, are known (Table 7), so the water quality index values will be calculated to determine the quality of shallow and deep groundwater at the research location, namely Pomalaa Regency and its surroundings, using the Water Quality Index [16] AT1 points, with the following calculation example:

(1) Calculating the WQI (Water Quality Index)

$$\begin{aligned}
 WQI &= \text{Antilog} \left(\sum_{n=1}^n W_n \log q_n \right) \\
 &= \text{Antilog} \left((W_{Suhu} \times \log q_{Suhu}) + (W_{TDS} \times \log q_{TDS}) + (W_{pH} \times \log q_{pH}) \right) \\
 &= \text{Antilog} \left((W_{0,227} \log q_{90}) + (W_{0,021} \log q_{36}) + (W_{0,750} \log q_{13,33}) \right) \\
 &= \text{Antilog} (1,323) = 21,0441
 \end{aligned}$$

(2) Classification of WQI values

The water quality at point AT1 was included in the water quality calculation using the Water Quality Index method and applying water quality standards for determining raw water for drinking water. The results showed that point AT1 was classified as excellent.

Table 7. Water Quality Index Value Results

Kode STA	X	Y	Water Bodies	Water Quality Index	Description
AT1	359458	9523666	Waterfall	21,0442	Excellent
AT2	352699	9523991	Waterfall	12,6500	Excellent
SB1	340913	9528699	Bore well	172,8336	Unfit for drinking
SB2	340744	9528350	Bore well	147,4404	Unfit for drinking
SB3	340196	9526188	Bore well	38,1342	Good

3.11. Distribution of Water Quality Index and Its Implications for Groundwater Management

Based on the Water Quality Index (WQI) calculations from 199 observation points, the following classifications were obtained: 57 points were classified as excellent (0–25%), 49 points as good (26–50%), 23 points as poor (51–75%), 22 points as very poor (76–100%), and 48 points as unfit for consumption (>100%). The spatial distribution of WQI values is shown in map Figure 11, which shows a pattern of water quality degradation from upstream to downstream of the main rivers, namely the Huko-huko River and the Oko-oko River.

3.12. Western Region

In the western part, especially downstream of the Huko-huko and Oko-oko Rivers, the WQI value increased dramatically to >100%, indicating that the water was unfit for consumption. This area is dominated by permeable sandstone and alluvial units located in the discharge zone. Intensive nickel mining activities around this zone contribute to increased TDS, EC, and decreased pH. Nickel laterite and mining waste in the Pomalaa region are known to cause heavy metal leaching and a decline in groundwater quality [1-2].

3.13. Eastern Region

Points in the eastern part of the study area, which are dominated by metamorphic and peridotite rock units, show WQI values <50%, indicating good to very good water quality. This is in line with the crystalline and massive lithological characteristics, as well as the high elevation recharge zone. Recharge zones are known to have more stable water quality and low levels of contamination [12].

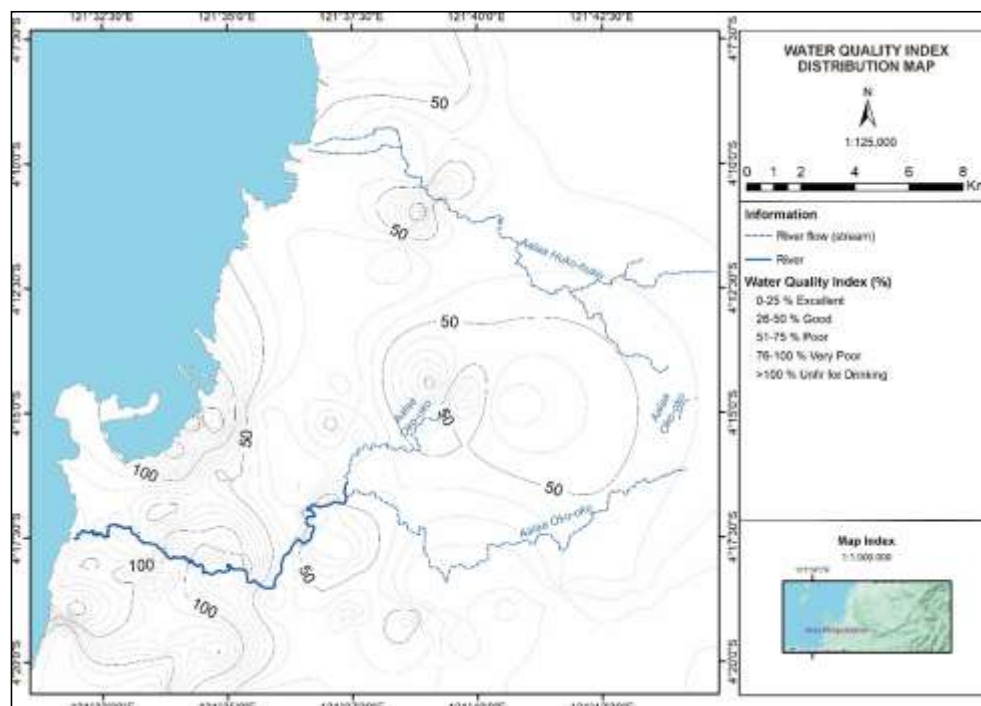


Figure 11. Countur Map of Water Quality Index [4], [10]

The pH parameter shows variations depending on the content of reactive minerals in the lithology. Carbonate rocks or those containing basic minerals tend to increase the pH of groundwater, while silicate rocks or those undergoing acid weathering can decrease the pH. For example, conglomerate and sandstone units undergoing intensive weathering show lower pH values than metamorphic units that are more chemically inert.

Table 8. Variations in Lihology Data on Water Quality

Stratigraphy	Total	Min Temperature (°C)	Min TDS (ppm)	Min pH	Max Temperature (°C)	Max TDS (ppm)	Max pH
Metamorf	11	23	12	6.6	32.2	443	8.2
Peridotite	51	24.3	22	4.5	33.7	496	8.73
Conglomerate	78	24.9	11	3	34.1	274	8.3
Sandstone	38	27.4	7	3.8	36.4	7870	7.5
Aluvium	21	28	16	4.5	35.6	8760	9.72
Total	199						

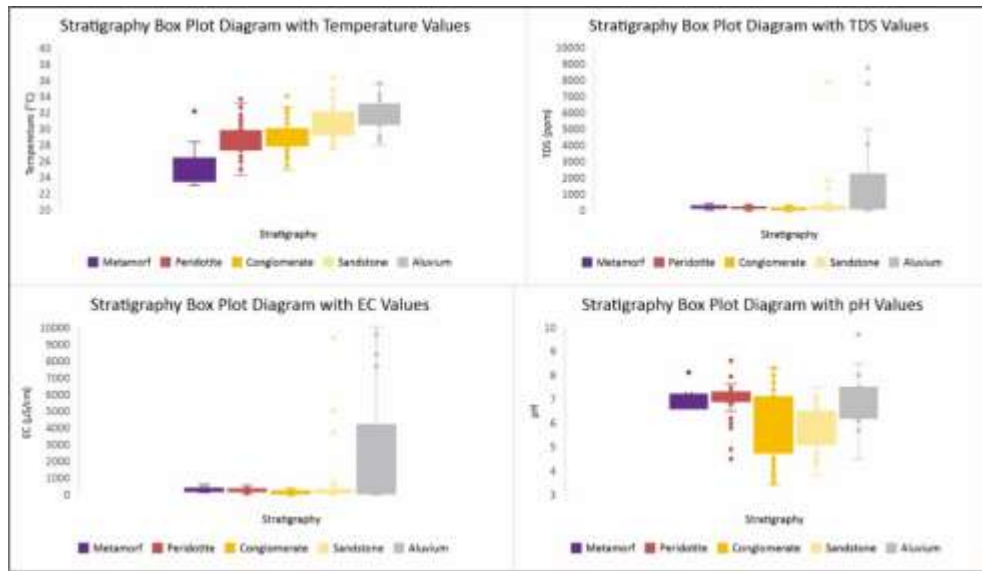


Figure 12. Stratigraphy Box Plot Diagram with Water Quality Parameters

In general, the relationship between lithology and water quality is such that clastic and permeable lithological units, such as sandstone and alluvium, tend to show higher TDS values due to the intensity of mineral dissolution and the contribution of dissolved materials from the infiltration process. This also correlates with a decrease in electrical resistivity, given the high content of dissolved ions that increase the conductivity of water-saturated media. Conversely, crystalline and massive lithologies, such as metamorphic and peridotite, generally show higher resistivity and lower TDS values, reflecting limited mineral dissolution and low groundwater storage and flow capacity. Groundwater temperature values are also influenced by weather and rock thermal conductivity, where shallow lithologies, such as alluvium, show greater temperature fluctuations than more thermally stable bedrock (Figure 12).

4. Conclusion

The study area consists of five main lithological units, namely the Pompangeo Complex Metamorphic Rock Unit, the Pomalaa Peridotite Unit, the Langkowala Conglomerate Unit, the Langkowala Sandstone Unit, and the Alluvial Deposit Unit. Regional hydrogeological studies have identified two groundwater basins (CAT), namely the Kokaka and Tangketada Groundwater Basins. Groundwater movement patterns tend to follow the natural hydraulic gradient from high to low elevation areas.

Groundwater quality analysis shows a significant decline at several observation points due to increased heavy metal concentrations and changes in water chemistry characteristics, which are suspected to originate from mining activities. Massive mining activities occur downstream at the study site, which is close to the sea. This is evidence that the water quality index values downstream of the Huko-huko River (>50%) and Oko-oko River (70 to >100%) are poor. Water quality parameters such as temperature, Total Dissolved Solids (TDS), and pH at several locations were recorded as exceeding the threshold, indicating potential pollution. An evaluation of the Water Quality Index (WQI) at observation points needs to be carried out to reduce the more severe impact on water quality. This impact will be more severe if polluted water enters the sea through rivers, which will have a negative impact on coastal/marine areas and disrupt shallow water ecosystems

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