



## Bulletin of Scientific Contribution GEOLOGY

Fakultas Teknik Geologi  
UNIVERSITAS PADJADJARAN

homepage: <http://jurnal.unpad.ac.id/bsc>  
p-ISSN: 1693-4873; e-ISSN: 2541-514X



Volume 24, No.01  
April 2026

### HYDROGEOLOGICAL CONDITIONS USING AN INTEGRATION OF AQUIFER GEOMETRY MODEL AND GROUNDWATER CHARACTERISTICS IN THE BANDUNG CITY AREA

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#### ABSTRACT

The rapid population and economic growth in Bandung City has driven increased groundwater use, necessitating an understanding of hydrogeological conditions to prevent negative consequences. This study aimed to identify the distribution of subsurface rocks, hydrostratigraphy, and groundwater characteristics in shallow aquifer systems through aquifer geometry modeling and ground-based observations. The model was developed by integrating regional geological data, 22 one-dimensional geophysical points, 7 well logging points, and previous research results, and analyzed using modeling software and GIS software. Resistivity interpretation reveals aquifer lithology consisting of coarse tuff, lapilli, and tuffaceous sandstone (21–103 Ohm.m), aquiclude lithology consisting of fine tuff, tuffaceous claystone (0–30 Ohm.m), and volcanic breccia (101–350 Ohm.m), and aquifug lithology in the form of lava (>350 Ohm.m). The model shows the dominance of tuff sandstone in the northwest, fine tuff in the northeast, and tuff claystone in the southeast. The model revealed two types of developed aquifers, unconfined aquifer at a depth of 0–34.08 m (shallow aquifer system) and confined aquifer at 41.75–68.5 m (deep aquifer system). The characteristics of groundwater in the shallow aquifer system are categorized as fresh groundwater with EC values of 183–897  $\mu\text{S/cm}$ , TDS 92–447 mg/l, and pH 5.4–6.86. Spatial distribution analysis of EC, TDS, and pH values is influenced by lithology, topography, and land cover. Vegetation in the upstream area preserves groundwater quality, while the dominance of built-up land and plantations increases EC, TDS, and pH to close to neutral levels. The results of this study emphasize the need for vegetation conservation in the upstream area, control of land use change, and urban spatial planning based on recharge to maintain the sustainability of groundwater resources in shallow aquifer system in the Bandung City area.

**Keywords:** Groundwater, Hydrostratigraphy, Model, Aquifer, Groundwater Characteristic

#### INTRODUCTION

Groundwater is one of the natural resources that must be maintained because it is an important aspect in fulfilling basic human needs (Lesmana et al., 2021). However, population growth and rapid economic development will have implications for increasing the amount of water needed by each individual and economic activities, which will eventually lead to excessive exploitation of groundwater (Water, 2022). The city of Bandung is an area where groundwater exploitation activities take place continuously (Agustin et al., 2023). This condition is an implication of the increasing demand for water for domestic and industrial activities. The correlation between the fulfillment of water resource needs and groundwater exploitation is a phenomenon that needs to be studied and monitored so as not to lead to more complex problems in the future in the

Bandung City area (Agustin et al., 2023; Azy et al., 2016; Delinom and Suriadarma, 2010). In addition, based on several previous studies (Agustin et al., 2023; Azy et al., 2016; Rahmatulloh et al., 2023) in the surrounding research area, there has been no research that integrates the aquifer geometry model with the groundwater characteristics in the aquifer layer. Therefore, an study is needed to determine the groundwater characteristics in the aquifer layer, especially in shallow aquifer systems, because they receive infiltration from rainwater, rivers, irrigation channels, and rice fields (Irawan, 2009), making them vulnerable to contamination. Hence, it is necessary to understand the hydrogeological conditions, including the types of rocks that lie beneath the surface, hydrostratigraphy units, and groundwater characteristics so that the impact of groundwater exploitation can be identified

and understood to enable effective groundwater resource management (Kinoti et al., 2024).

An attempt to understand the hydrogeological conditions in the Bandung City area were carried out using an aquifer geometry model approach that combined geological and geophysical data (rock resistivity values) and hydrogeological data in the form of the physical and chemical properties of groundwater. The aim was to provide comprehensive information on hydrogeological conditions, particularly in the shallow aquifer system in this area in order to be used as a reference in managing groundwater resources in Bandung City Area.

## LITERATURE REVIEW

### Geological Conditions

Bandung City is located in the central part of West Java Province and lies within the Bandung Basin. The Bandung Basin is an intermontane basin bounded by Quaternary volcanoes (Bemmelen, 1949). These Quaternary volcanoes are the Burangrang-Tangkubanperahu Mountain Complex to the north and the Wayang-Windu-Mandalawangi Mountain Complex to the south. This basin was composed of unconsolidated and undifferentiated Quaternary volcanic deposits and lake deposits that dried up approximately 16-20 thousand years ago (Delinom and Suriadarma, 2010).

There are several versions of discussions related to the stratigraphy of Bandung City. Based on Regional Geological Map of Bandung, Java, Scale 1:100.000 (Silitonga, 1973), The Bandung city area is composed of several rock units, such as Qvu (Undifferentiated Old Volcanic Deposits; volcanic breccia, lava, and lava alternating), Qyu (Undifferentiated Young Volcanic Deposits; tuffaceous sand, lapilli, breccia, lava, agglomerate), Qyt (Pumice Tuff; tuff sand, lapilli, bombs, hollow lava, and angular fragments of dense andesite-basalt with many pumice chunks and fragments), Qyd (Sandy Tuff; very porous brown sand tuff, containing coarse hornblende crystals, reddish weathered lava, layers of lapilli and breccia), and Ql (Lake Deposits; tuffaceous clay, tuffaceous sandstone, tuffaceous gravel, and conglomerate). In addition, there is other literature discussed regarding stratigraphy in the Bandung City area (Koesoemadinata and Hartono, 1981). The literature proposes official names for rock units from previous studies (Silitonga, 1973). The official naming is Cikapundung Formation for Qvu Unit, Cibereum Formation for Qyt Unit, Cikidang

Formation for Qyt Unit, and Kosambi Formation for Ql Unit.

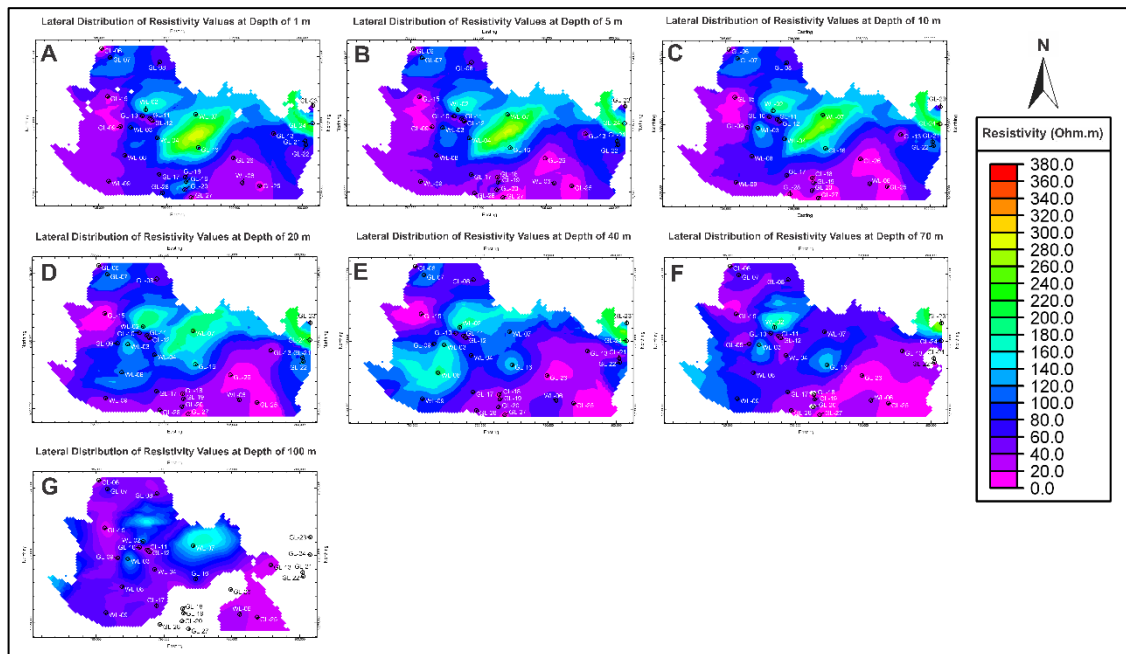
The geological structure near the city of Bandung is the Lembang fault. Morphologically, the Lembang Fault is manifested as a fault scarp with the cliff face facing north. This fault features lateral strike-slip movement. From east to west, the height of the fault scarp reflects the magnitude of the fault displacement (vertical displacement/dislocation), which varies from approximately 450 meters at the eastern end (Maribaya, Mt. Palasari) to 40 meters at the western end (Cisarua) and disappears at the northwestern end in Padalarang (Satriyo et al., 2024). Based on geomorphological analysis, this fault has a dominant sinistral movement direction with a movement rate of 1.95–3.45 mm/year (Daryono et al., 2019)

### Hydrogeological Conditions

Based on hydrogeological conditions, the Bandung basin consists of two aquifer systems based on their location, those are the shallow aquifer system (0–40 m) and the deep aquifer system (>40 m). The shallow aquifer system is the main aquifer layer used to fulfill the groundwater needs of most of the population in the Bandung Basin, although its productivity is generally low. Meanwhile, the deep aquifer system has medium to high productivity, with the main aquifer is from the Cibereum Formation (Soetrisno and Puradimaja, 1993).

## RESEARCH METHOD

This study is designed to determine the hydrogeological conditions of the Bandung City area through an aquifer geometry model approach. This study was conducted using a quantitative-descriptive approach to determine hydrogeological conditions based on the aquifer geometry model that was created. The hydrogeological conditions in this regard consist of hydrostratigraphy units to identify aquifer and non-aquifer layers, and groundwater characteristics in shallow aquifer system. The aquifer geometry model was developed through the integration of regional geological maps, 22 1D geoelectric data, and 7 well-logging data, which were then correlated with previous research results. Before the modelling, an analysis of the lateral and vertical resistivity values was conducted to form lithological model blocks, which were then used in determining hydrostratigraphic units to identify the types, distribution, and aquifer systems in the aquifer geometry model.



**Figure 1.** Lateral Distribution of Resistivity Values at Several Depths; A (Depth 1 m), B (Depth 5 m), C (Depth 10 m), D (Depth 20 m), E (Depth 40 m), F (Depth 70 m), G (Depth 100 m)

The distribution of shallow aquifer system resulting from aquifer geometry model is used as the basis for determining the depth and location of observation wells (104 dug wells and 5 drilled wells) that represent shallow aquifer systems. Groundwater characteristics is taken from the observation wells, including Electrical Conductivity (EC), Total Dissolved Solids (TDS), and pH, were mapped using GIS interpolation methods, referring to groundwater classifications according to (Freeze and Cherry, 1979; Hem, 1985; Mandel and Shifan, 1981). Further analysis was conducted to assess the spatial relationship between ECS, TDS, and pH values and land cover in each sub-watershed so that the distribution of groundwater characteristics in shallow aquifer system could be comprehensively identified.

## RESULT AND DISCUSSION

### Distribution of Resistivity Values

The lateral spatial distribution of resistivity values is shown in map (Figure 1) form at depth intervals of 1 m, 5 m, 10 m, 20 m, 40 m, 70 m, and 100 m. The lateral distribution of resistivity values at depths of 1–20 m shows a range of 0–260 Ohm.m, with low values (0–80 Ohm.m) dominating in the west and southeast, and higher values (80–260 Ohm.m) in the center to north. The change in distribution at a depth of 5 m is relatively small, while at 10–20 m there is a decrease in resistivity (0–220 Ohm.m) with a dominance of low values in the south and medium to high values in the north and east.

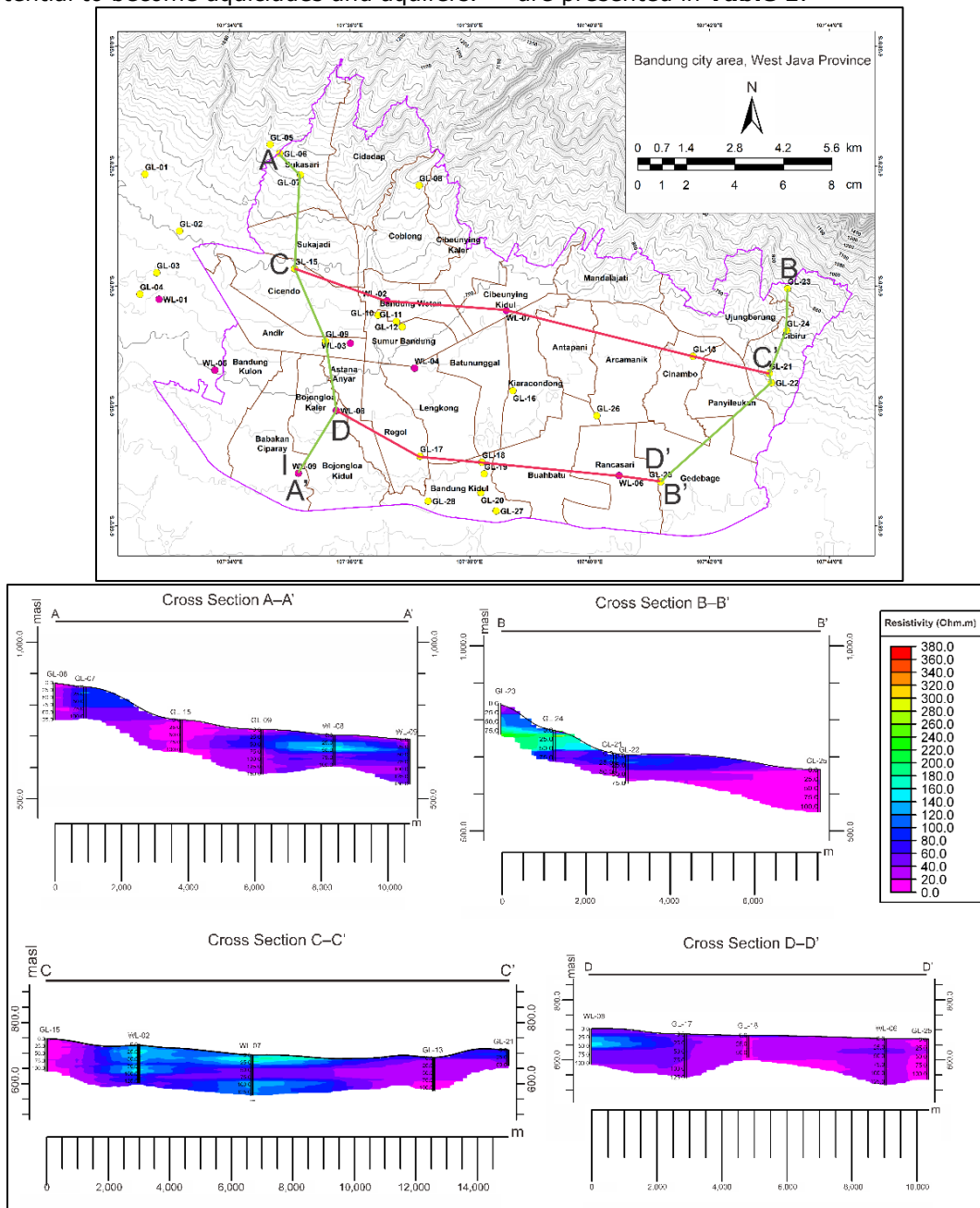
At depths of 40–100 m, resistivity ranges from 0–240 Ohm.m. Zones with low values (0–80 Ohm.m) continue to dominate the southern part, while medium–high values (80–240 Ohm.m) appear in the north and northeast. At a depth of 100 m, some areas are not measured due to the inconsistency of the measurement depth, but the remaining resistivity values (0–150 Ohm.m) show dominance in the center to southwest of the study area.

The vertical distribution of resistivity values is made into two north-south oriented cross sections (A–A' and B–B') and two west-east oriented cross sections (C–C' and D–D'). The distribution of these cross sections can be seen in Figure 2. These four sections were used to analyze vertical variations in resistivity values, which were then correlated with lithological types and hydrostratigraphic unit determination. The four cross-sections are shown in Figure 3. The resistivity values across the entire cross-section range from 0–220 Ohm.m and show variations that reflect differences in rock characteristics at each measurement point. In section A–A', layers with low to moderate resistivity (0–60 Ohm.m) dominate points GL-06 and GL-09, while layers with moderate to high resistivity (60–160 Ohm.m) are found at GL-07 and WL-08 with a lateral spread of  $\pm 3$  km. Section B–B' shows a combination of low resistivity layers (20–40 Ohm.m) at the top and medium to high resistivity layers (100–200 Ohm.m) at the bottom, revealing a repetition of lithology with different potentials as

aquiclude and aquifer layers. On section C–C', resistivity values of 60–140 Ohm.m to 220 Ohm.m dominate points WL-02 and WL-07, while low values (20–40 Ohm.m) are seen at GL-13 and GL-15 to a depth of 75 m, indicating clear vertical variation between layers. Section D–D' shows a dominance of medium resistivity values (40–100 Ohm.m) flanked by low resistivity layers (20–40 Ohm.m), with the highest values (120–160 Ohm.m) appearing at a depth of 25–50 m at WL-08. In general, the four cross-sections show patterns of low, medium, and high resistivity, indicating diversity in subsurface lithology and differences in the physical properties between layers that have the potential to become aquicludes and aquifers.

**Correlation Of Resistivity Values With Lithology And Hydrostratigraphy Unit**

The correlation between resistivity values and lithology types is carried out by correlating geoelectric and well-logging measurement points according to the location of the measurement points in each regional geological unit in the study area. In addition, Lithology types were also correlated with the hydrostratigraphic unit distribution in the study area. Both correlations were performed with reference to previous literature and research (Bachtiar et al., 2022; Fauzan, 2024; Mohammad et al., 2016; Soetrisno and Puradimaja, 1993; Telford et al., 1990; Todd and Mays, 2005) and the correlation results are presented in **Table 1**.



**Figure 2.** Distribution Map of Cross Section

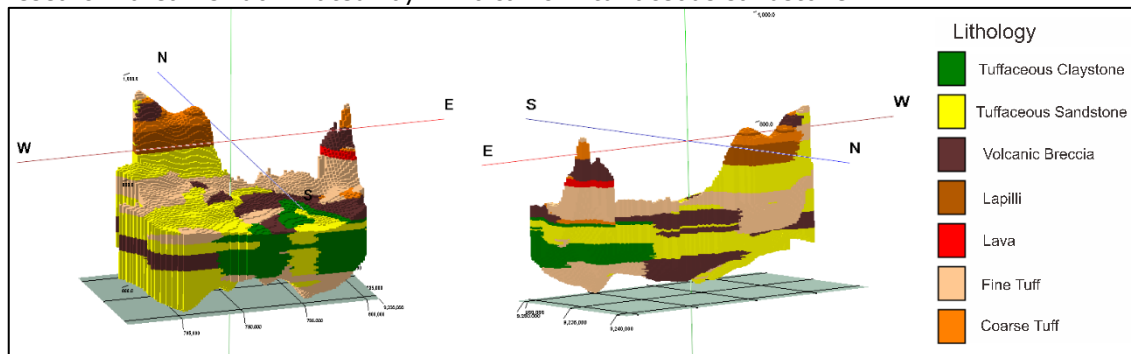
**Table 1.** Correlation Of Resistivity Values With Lithology Types And Hydrostratigraphy Unit

Geological Unit	Resistivity Range (Ohm.m)	Resistivity Class	Lithology	Hydrostratigraphy Unit
Ql	0 – 20	Low	Tuffaceous Claystone	Aquiclude
	21 – 91	Medium	Tuffaceous Sandstone	Aquifer
	92 – 300	High	Volcanic Breccia	Aquiclude
Qyd	0 – 54.8	Low	Coarse Tuff	Aquifer
	55.8 – 103	Medium	Lapilli	Aquifer
	>103	High	Volcanic Breccia	Aquiclude
Qyt	0 – 20	Low	Fine Tuff	Aquiclude
	21 – 100	Medium	Tuffaceous Sandstone	Aquifer
	101 – 225	High	Volcanic Breccia	Aquiclude
	>225	Very High	Lava	Aquifuge
Qyu	0 – 30	Low	Fine Tuff	Aquiclude
	31 – 100	Medium	Coarse Tuff	Aquifer
	101 – 350	High	Volcanic Breccia	Aquiclude
	>350	Very High	Lava	Aquifuge

**Lithology and Geometry Aquifer Blok Model**

The lithology model blocks that have been made by referring to the correlation of resistivity values with lithology types (**Table 1**), it can be seen (**Figure 4**) that the research area is dominated by volcanic

deposits, in the form of volcanic breccia, lapilli, coarse tuff, fine tuff, and tuffaceous sandstone. In addition, it can also be seen that in the south to southeast of the study area there is lake sediment material consisting of tuffaceous claystone and tuffaceous sandstone.



**Figure 3.** Lithology Block Model of Bandung City

Based on the identification of lithology types, it is found that the hydrostratigraphy units (**Table 1**) in the study area can be divided into aquifers, aquicludes, and aquifuges. Lithology that act as aquifers in the study area are rocks with resistivity values of 21–103 Ohm.m in general. The resistivity value consists of several types of lithology, such as coarse tuff, lapilli, and tuffaceous sandstone. The aquifer is divided into unconfined aquifer, confined aquifer. Lithology that act as aquicludes in the research area are rocks with resistivity values of 0–30 Ohm.m and 101–350 Ohm.m that consists of several types of lithology, such as fine tuff, tuffaceous claystone, and volcanic breccia. Lithology

that act as aquifuges are rocks with a resistivity value of > 350 Ohm.m in the form of lava rocks. The aquifer layer in the study area is divided into two types, namely unconfined aquifers at a depth of 0–34.08 m (identified as shallow aquifer system) and confined aquifers at a depth of 41.75–68.5 m (identified as deep aquifer system) based on identification of geometry aquifer block model (**Figure 5**). Based on the aquifer geometry block model unconfined aquifers are scattered in the central to northwestern parts of the study area, with a small portion found in the southeastern part of the study area. The depth boundary of shallow aquifer system refers to previous research (Soetrisno and

Puradimaja, 1993), located at a depth of up to 40 m.

**Groundwater Characteristic in Shallow Aquifer System**

Identification of groundwater characteristics in shallow aquifer systems was carried out in each sub-watershed area included in the Bandung City area, considering the results of physical and chemical testing of dug wells and bore wells with a depth of  $\leq 40$  m (assumed to be shallow aquifer system tapping wells), as well as land cover distribution. The distribution of these physical and chemical properties is presented in the form of a distribution map using the interpolation method in geographic information system software with a data distribution of 104 dug wells and 5 drilled wells.

The following map (Figure 6) shows the distribution of land cover in the city of Bandung. Based on the analysis of 2024 raster data using GIS software, there are

seven types of land cover, such as water bodies, vegetation, swamps, agricultural land, built-up land, vacant land, and shrubs. In the GIS software, calculations are also carried out on the area of each type of land cover spread across the Bandung City area. The results of these area calculations are presented in Table 2. Land cover in the type of built-up land dominates almost the entire area of Bandung City with an area of 156.3 km<sup>2</sup> or 93.7% of the total area of Bandung City. These conditions influence the characteristics of groundwater in shallow aquifer systems in the Bandung City area, which is generally covered by developed land. Shallow aquifer systems in this area are dominated by unconfined aquifers that are highly vulnerable to contamination due to the unavailability of impermeable rock layers, allowing surface water to penetrate directly into the aquifer.

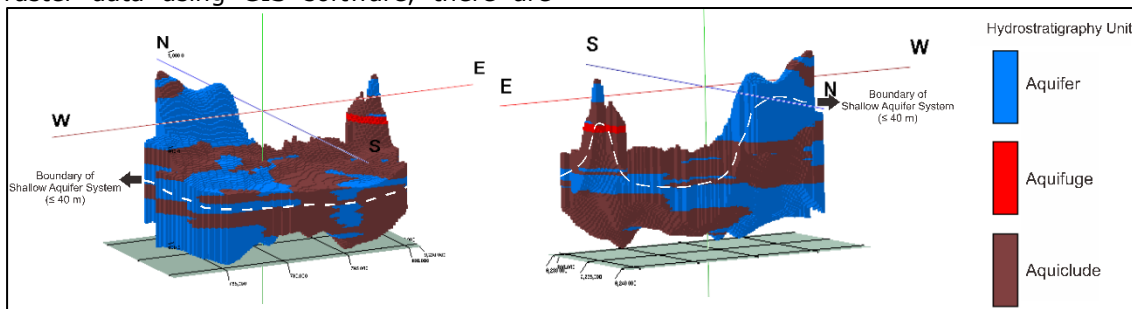


Figure 4. Aquifer Geometry Block Model of Bandung City

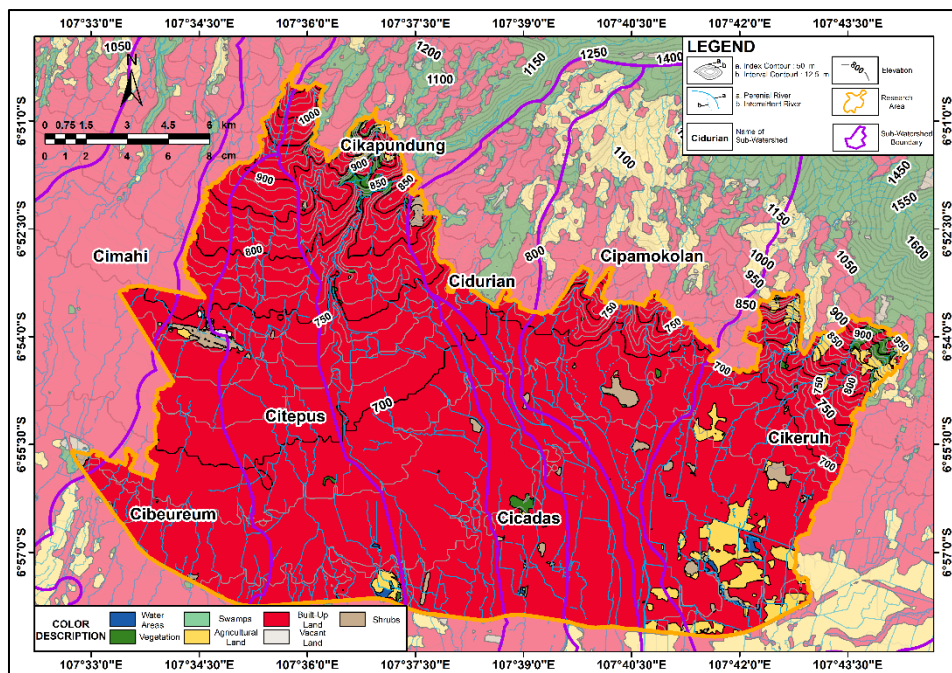


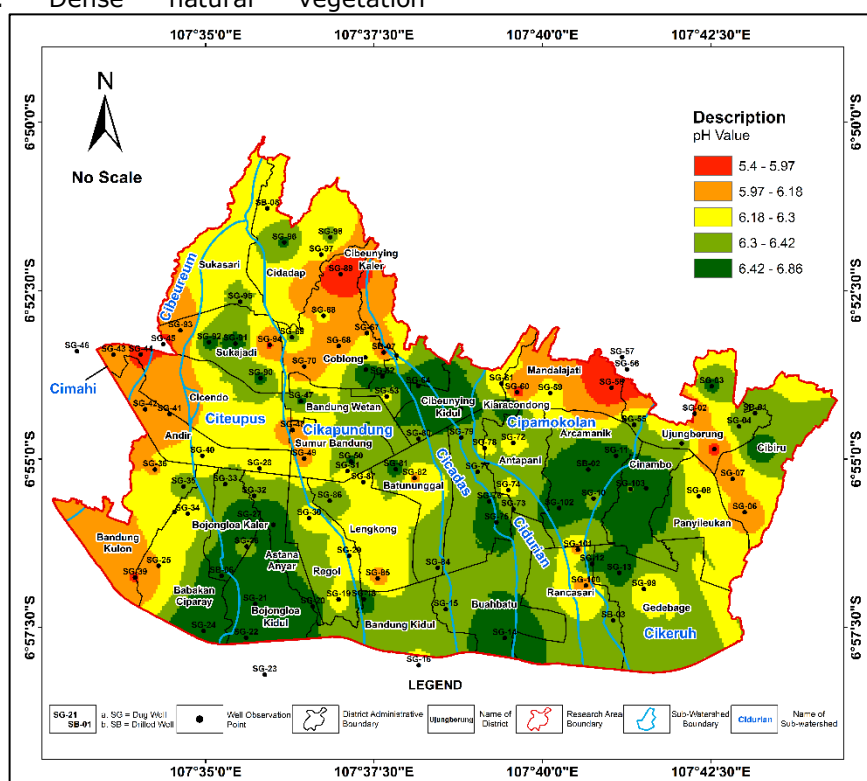
Figure 5. Land Cover Distribution Map of Bandung City

**Table 2.** Recapitulation of Land Cover Area Calculations

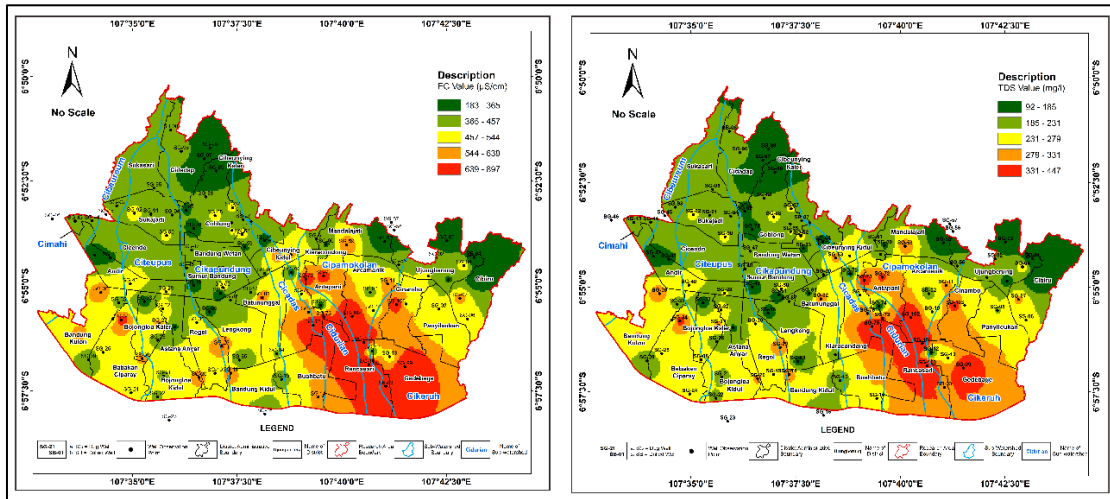
Land Cover Type	Area (km <sup>2</sup> )	Percentage (%)
Water Area	0.3	0.17
Natural Land Cover	2.1	1.25
Swamps	0.0139	0.0083
Agricultural Land	5.72	3.42
Built-up Land	156.3	93.7
Vacant Land	0.0931	0.055
Shrubs	2.26	1.35

The following map (**Figure 7**) is the result of interpolation of the Electrical Conductivity (EC) and Total Dissolved Solids (TDS) values of groundwater at observation points in wells located in the city of Bandung. Based on field observations, the EC values of water samples from the observed wells ranged from 183 to 897  $\mu\text{S}/\text{cm}$  and are classified as fresh groundwater (Mandel and Shiftan, 1981). The TDS values of water from the observed wells ranged from 92 to 447 mg/l and are classified as fresh water (Freeze and Cherry, 1979). The spatial distribution of EC and TDS values shows a clear correlation with land cover conditions in each sub-watershed. The Cimahi and Cikapundung sub-watersheds, which are still dominated by natural vegetation cover in their upstream mountainous areas, exhibit relatively low EC and TDS values. This condition is closely related to the presence of forest and mountain vegetation, which play an important role in regulating hydrological processes. Dense natural vegetation

enhances infiltration and groundwater recharge, while also reducing surface runoff and limiting the transport of dissolved ions from the surface into the subsurface system. In addition, soil-plant interactions in vegetated areas can promote ion uptake and natural filtration, thereby maintaining lower concentrations of dissolved solids. In contrast, the Cibeureum, Citepus, Cicadas, Cidurian, Cipamokolan, and Cikeruh sub-watersheds, which are generally dominated by built-up and agricultural land, show higher and more variable EC and TDS values. The reduced presence of natural vegetation in these areas decreases infiltration capacity and increases surface runoff, which facilitates the accumulation and mobilization of dissolved ions from anthropogenic sources such as domestic waste, agricultural inputs, and urban activities. Consequently, groundwater in these sub-watersheds tends to have higher EC and TDS values.



**Figure 6.** Distribution Map of pH Values in Bandung City



**Figure 7.** Distribution Map of Electric Conductivity (Left) and Total Dissolve Solid (Right) Values in Bandung City

From 5.4 to 6.86 and was classified as acidic groundwater because the pH value is <7. This indicates that the aquifer in the Bandung city area is the result of volcanic deposits that tend to be acidic (Hem, 1985). Relatively low pH values are found in the Cimahi and Cibereum sub-watersheds, which are dominated by developed land with limited vegetation and influenced by acidic volcanic rocks in the upper reaches. In contrast, the Citepus, Cicadas, and Cidurian sub-watersheds showed higher pH values (6.18–6.86) and are near neutral, which is thought to be influenced by the dominance of built-up land and the contribution of anthropogenic activities that cause dilution of soil acidity. The Cikapundung, Cipamokolan, and Cikeruh sub-watersheds have varying pH ranges (5.4–6.86), with an acidic tendency in the upstream area due to acidic volcanic rocks and increasing towards the downstream area along with the increase in built-up land and the presence of plantations and vegetation that still allow infiltration into the aquifer layer.

In general, the physical and chemical characteristics of groundwater in the study area indicate that variations in EC, TDS, and pH values are greatly influenced by a combination of lithology, topography, and land cover types, which together control the characteristics of groundwater in the shallow aquifer system of Bandung City.

**CONCLUSION**

The results of the study show that the subsurface lithology in the study area is composed of volcanic sedimentary rocks in the form of tuffaceous sandstone, lapilli, fine tuff, coarse tuff, volcanic breccia, and lava rocks up to ±150 m depth, as well as lake sedimentary rocks in the form of tuffaceous

sandstone, tuffaceous claystone, and volcanic breccia up to ±80 m depth spread across the south-southeast part of the study area. Based on the results of hydrostratigraphy identification, rock types can be classified into aquifers (coarse tuff, lapilli, tuffaceous sandstone), aquicludes (tuffaceous claystone, fine tuff, volcanic breccia), and aquifuges (lava rocks). The types of aquifers that have developed consist of unconfined aquifers at a depth of 0–34.08 m (as a shallow aquifer system) and confined aquifers at a depth of 41.75–68.5 m (as a deep aquifer system). The characteristics of groundwater in the shallow aquifer system show spatial variations in physical and chemical properties influenced by lithological conditions, topography, and land cover. Electrical Conductivity (183–897 µS/cm) and Total Dissolved Solids (92–447 mg/l) are classified as fresh groundwater, with lower values in areas dominated by vegetation (Cimahi and Cikapundung sub-watersheds) and higher values in areas affected by built-up land and agricultural plantations (Cibereum, Citepus, Cicadas, Cidurian, Cipamokolan, and Cikeruh sub-watersheds). The pH value of groundwater (5.4–6.86) indicates slightly acidic to near-neutral conditions, where low pH is generally found in areas dominated by volcanic rocks and limited infiltration, while near-neutral values are found in areas influenced by anthropogenic activities. In general, vegetation serves an important function in reducing dissolved ion concentrations and maintaining groundwater pH stability, while the dominance of built-up land tends to increase EC, TDS, and pH values in shallow aquifer systems in the Bandung City area.

## ACKNOWLEDGEMENT

The author sincerely expresses his gratitude for the academic guidance and support provided by his supervisor during the research and preparation of this paper. Gratitude is also extended to the Environmental Geology and Hydrogeology Laboratory of Padjadjaran University for providing the equipment for field activities.

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