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Aquifer Potential Analysis Based On Hydrostratigraphy and Geological Lineament In Kokap Region, Kulon Progo, Yogyakarta, Indonesia

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Abstract

As a water-poor region, a study on the potential of water resources is urgently needed in the Kokap area, Kulon Progo. The purpose of this research is to carry out a hydrogeological survey to obtain an overview of water resources that can be approached from the groundwater aquifer potential. The method used is a hydrogeological survey in the field to determine the condition of morphology, rocks, geological structures, and hydrogeology; equipped with hydrostratigraphic analysis and geological lineament. The hydrostratigraphic analysis was made based on the interpretation of secondary data in the form of geoelectric, while the geological structure analysis was carried out based on the interpretation of DEM and Landsat imagery. The results showed that the Kokap area has hydrostratigraphy in the form of free aquifers 0 – 20 m thick and aquitards 0 – 8 m thick. Aquifug is at a depth of 4 - >20 m. With a lineament density of up to 808/km and supported by relatively intensive weathering, the Kokap area has the potential to have a fairly good groundwater aquifer configuration, with aquifer boundary types namely H1, H2, H4, H5 and V1, V2, V3.

Keywords: aquifer; configuration; groundwater; hydrostratigraphy; lineament

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INTRODUCTION

Kokap District is a fairly developed area, in line with the development of Kulon Progo Regency as the location for the establishment of a new airport and an increase in tourist destinations in the region. Kokap District is located in the western part of Kulon Progo Regency **(Figure 1)**, is part of the physiography of the Kulon Progo Hills with hilly morphology and less potential groundwater conditions. Hydrogeological research has been developed in various regions throughout Indonesia to assist communities in providing clean water, including in water-poor areas such as the Kokap area. The Kokap area and its surrounding groundwater basin have been studied in terms of hydrogeology (Listyani et al., 2018; Listyani et al., 2019; Listyani et al., 2020).

Water is a basic need in life, therefore water must be maintained in sufficient quantities and of good quality. All living things have the right to meet their water needs. This water resource can be obtained from surface water and groundwater. Groundwater is a water resource that is increasingly needed, shifting the position of surface water for the needs of everyday human life. Nowadays, surface water is sometimes polluted so groundwater is a better alternative to fulfill life's need for water. Therefore, the groundwater potential in an area needs to be studied so that we can provide water in sufficient quantities and of good quality.

Hydrogeological research through spatial analysis has been carried out to see water resources in the Kulon Progo Regency (Listyani et al., 2023). This spatial analysis needs to be supported by direct rock outcrop studies in the field to see the aquifer potential more accurately. By identifying aquifers, an interpretation of groundwater potential can be carried out. One of the potential studies of groundwater in an area can be done by knowing the hydrostratigraphy of the local area. In addition, the groundwater potential in an area needs to be supported by an understanding of the geological structure (lineament), which often indicates areas of discontinuity. By knowing the hydrostratigraphy and structural lineament characteristics we can interpret groundwater resources in an area. Hydrostratigraphy can be analyzed directly in the field or interpreted from the results of geoelectric surveys (Prastowo et al,. 2021; Devy and Sarongallo., 2018; Purwasatriya., 2013).

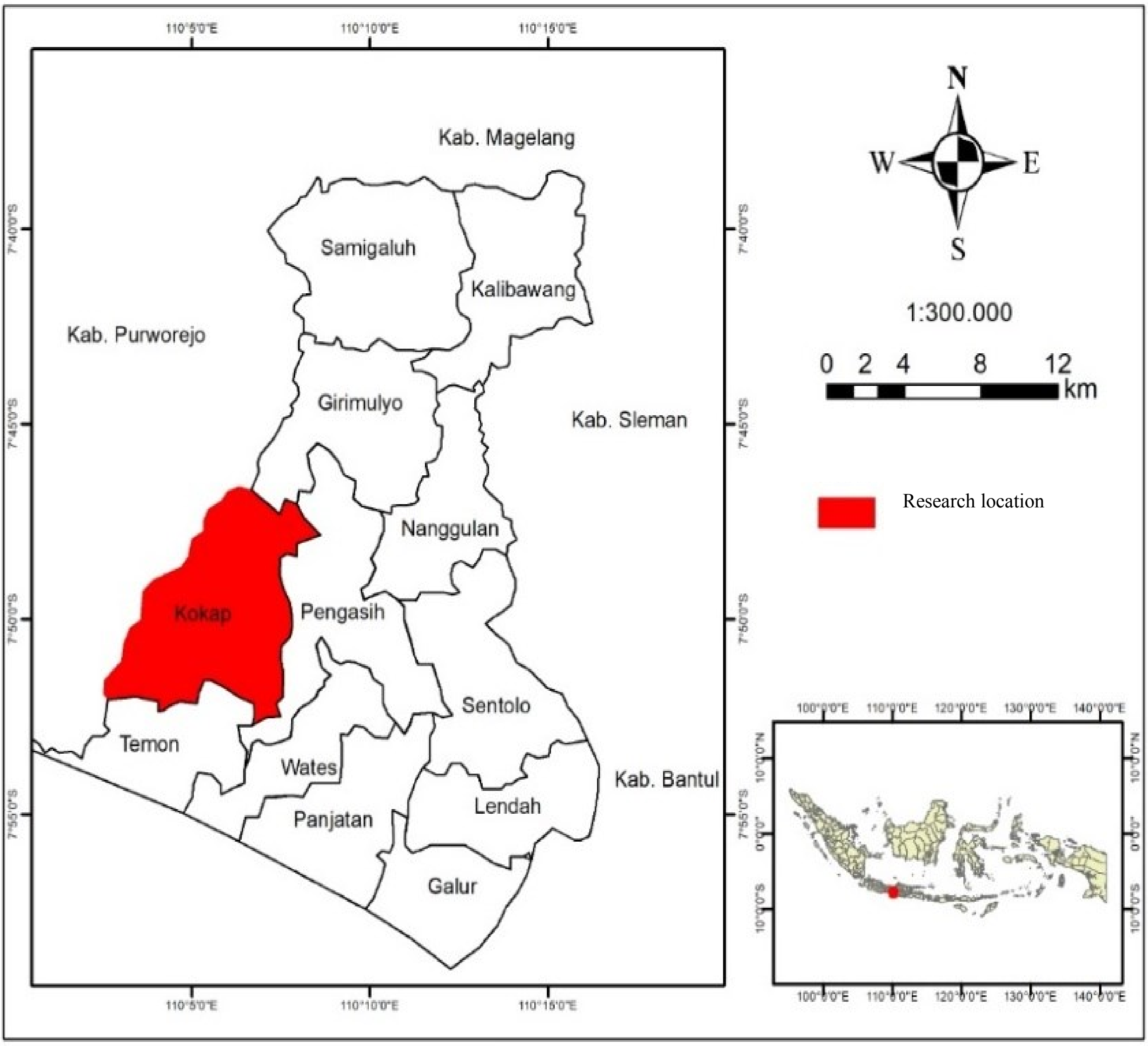

Figure 1. Research location (BPS Kab. Kulon Progo, 2021).

The results of hydrostratigraphic analysis and geological alignment of the Kokap area can be used to determine the potential of the aquifer, although the potential of groundwater is also very dependent on the supply of rainwater (precipitation). However, by knowing the configuration of aquifers in an area, groundwater resources can be better identified so that their potential can be developed more optimally.

METHOD

The general description of the hydrogeological conditions of the research area must be studied first through secondary data in the form of relevant scientific writings from previous researchers. This needs to be done so that researchers do not work without regional geological knowledge. This literature study will also be a good direction for future researchers. A literature study was carried out as a preparation to determine the hydrogeological condition of the research area.

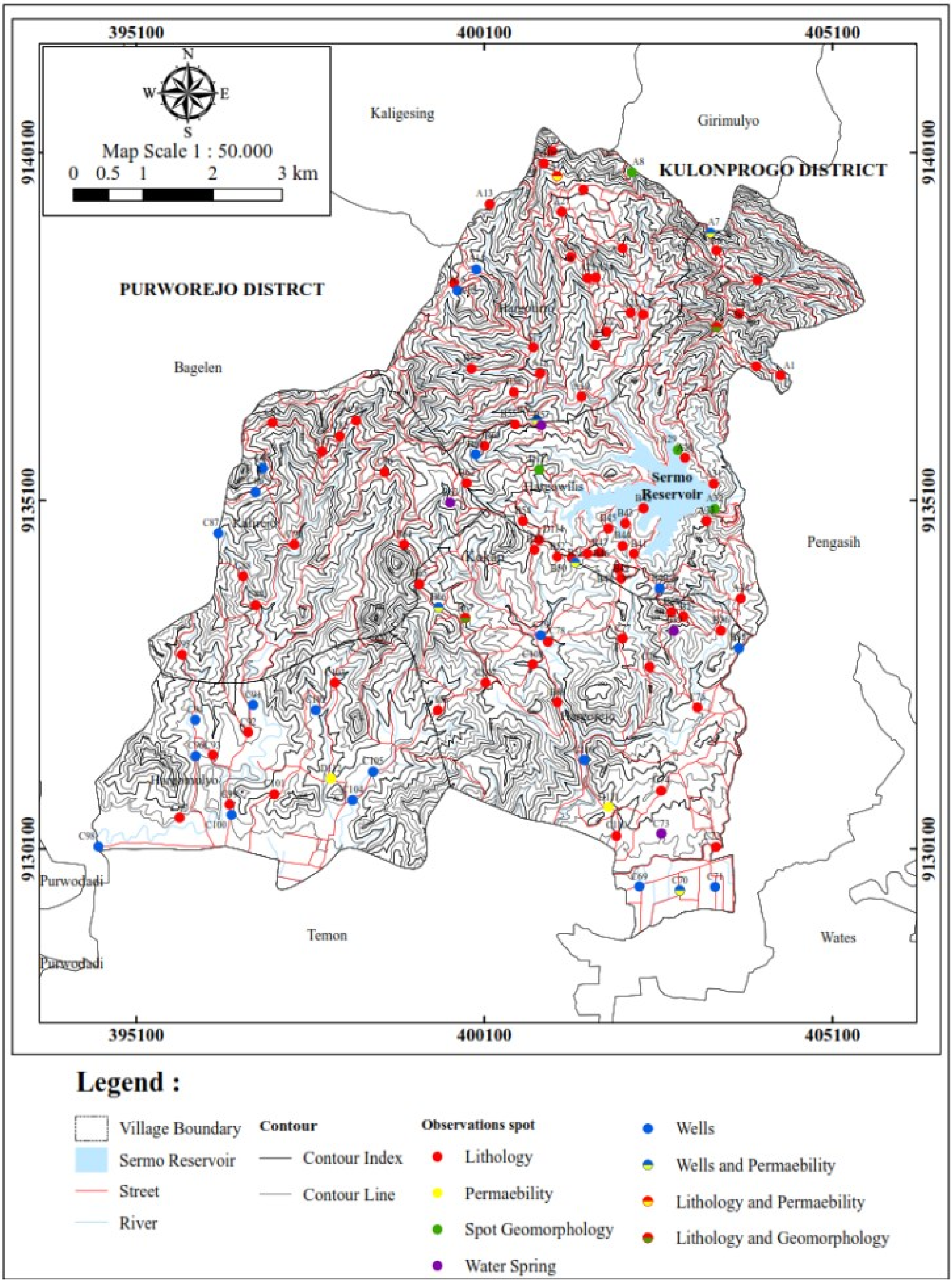

Figure 2. Map of the research area observation locations.

Furthermore, field geological surveys were carried out to obtain morphological data, rock outcrops, geological structures and wells/springs **(Figure 2)**. This fieldwork emphasizes the hydrogeological aspect, including determining stratigraphy and geological structure, to determine the characteristics of rocks that have the potential to act as aquifers.

Secondary data analysis carried out included:

1. Interpretation of geoelectric data to determine the hydrostratigraphic sequences. The hydrostratigraphic analysis is useful for viewing aquifer zones. Hydrostratigraphy will be analyzed based on geoelectrical data obtained from several published journal articles, including:
    a) Purwasatriya (2018) uses geoelectricity to determine the potential for andesite resources in the Kokap area.
    b) Prastowo et al. (2021), who has analyzed ground motions in the Kalirejo area, Kokap based on the geoelectric method.
2. Alignment data analysis (Budiadi., 2008) and assisted with DEM (Digital Elevation Model) image analysis. This DEM map was obtained from the Shuttle Radar Topography Mission (SRTM) imagery in 2000. Interpretation of the pattern and lineament density of geological structures to determine the type of aquifer.

Furthermore, the results of field surveys and secondary data analysis were compiled to determine the aquifer potential, especially the configuration/type of aquifer boundaries in groundwater basins. Interpretation of this type of aquifer boundary will be very useful for understanding the groundwater potential of the research area.

RESULTS AND DISCUSSION

Geology of the Kokap Region

Bappeda DIY has conducted landform mapping throughout the Province of the Special Region of Yogyakarta. According to the map, the study area is included four landforms, namely andesitic denudational mountains, andesitic denudational hills, colluvial foot slopes, and alluvial plains. Field observation results show that the study area can be divided into four geomorphologies referring to the Van Zuidam (1983) classification, including strong wavy morphology – denudational hills (D2); denudational hills (D3); Fluvial Plain (F1), and Reservoir (F2). Of the four units, denudational hills are the dominant landscape in the Kokap area **(Figure 3)**.

Andesitic intrusive rocks are the main constituent of the Kokap area. These rocks are widely distributed (65%) from north to south. In addition, dacite intrusions were also found in a narrow area (4%) in the central and northwest **(Figure 4)**. Tertiary sedimentary rocks that compose the Kokap area include Old Andesite Formation (OAF) andesite breccias (12%), Jonggrangan carbonate sandstone (1.5%), Sentolo limestone (6.5%), and Nanggulan sandstone (4%). These sedimentary rocks are scattered in several places, in the north, east, and south. The alluvial deposits have a distribution of 7% and extend in the southern part of the study area.

Figure 3. The hilly landscape that makes up most of the Kokap area (photographed from Hargowilis) (Loc. 113).

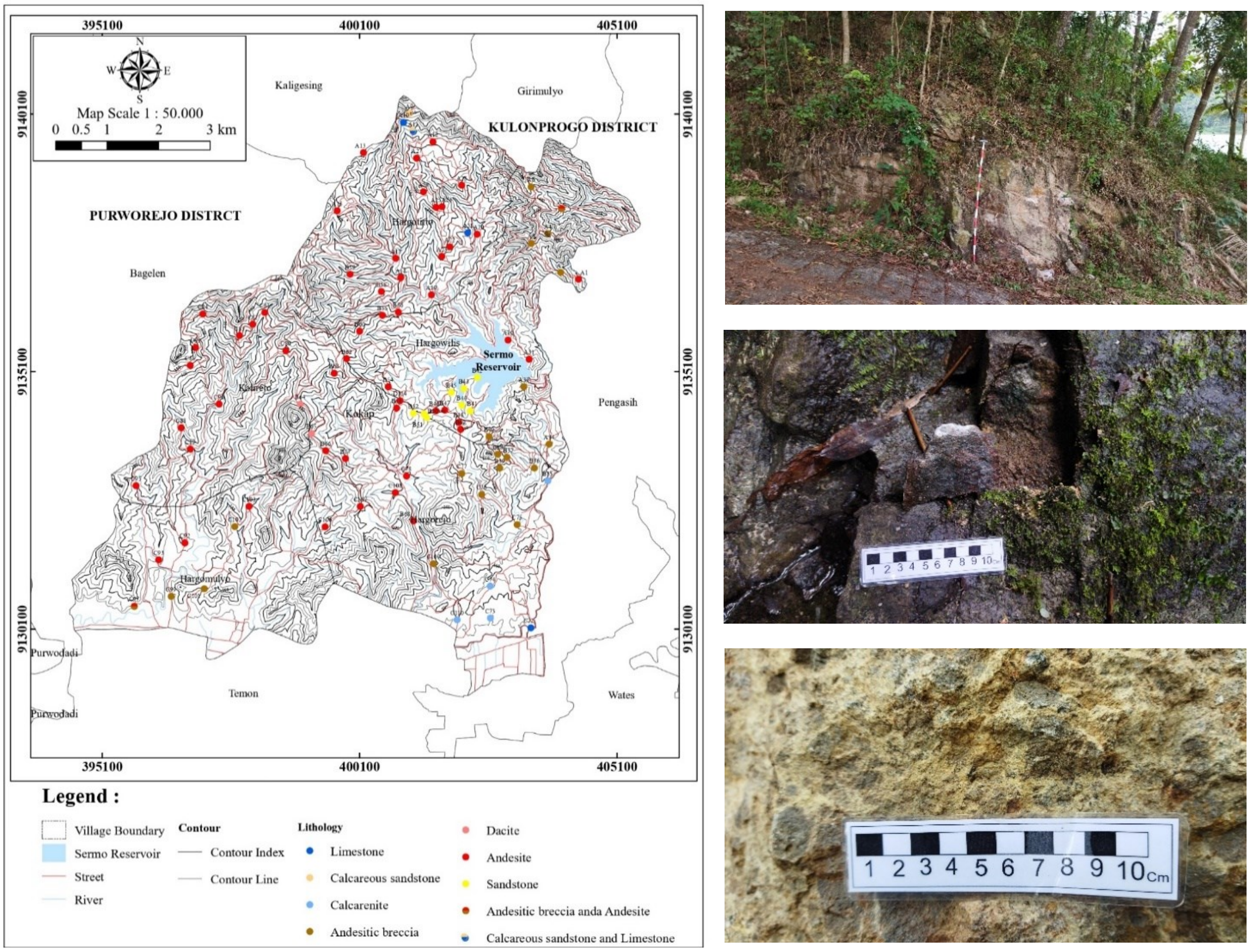

Figure 4. Location map of the distribution of lithology in the Kokap area; **a.** Layered sandstone outcrops (Loc. 42); **b.** andesite intrusion, fractured (Loc. 12); and **c.** andesitic breccia Old Andesite Formation (Loc. 99).

Due to their relatively old age, the rocks of the Kokap area have been tectonic many times since the Eocene period to the present. This tectonic activity produces many geological structures which are reflected in the morphological lineaments and geological structures.

Hydrostratigraphy

Rocks that have the potential to become groundwater aquifers in the Kokap area are dominated by massive Tertiary sedimentary rocks of the Old Andesite Formation and intrusive igneous rocks. Both of these rock formations can function as aquifers if conditions begin to weather or are intensively fractured. In addition, colluvial deposits resulting from the breakdown of Tertiary rocks can also be good aquifers, but in general, they are only thin and are found locally in river valleys or between hills. Other sedimentary rocks such as carbonate sandstones and carbonate limestones of the Jonggrangan Formation can also act as fairly good aquifers. Meanwhile, the sandstones and claystone of the Nanggulan and Sentolo Formations have less potential as aquifers due to their poor permeability.

DPUP ESDM DIY & CV. CPK (2016) states that the study area has aquifers that can be classified into the colluvium aquifer group which is a Quaternary deposit. This aquifer group is formed from material resulting from weathering or breakdown of the Tertiary formation so that its thickness depends on the level of local weathering (up to 30 m in some places). The transmissivity value of this aquifer group ranges from 1 – 100 m^2/day. This colluvium aquifer group is a free aquifer.

The aquifer system in the study area is based on bedrock (aquifer basement/basin basement) composed of Tertiary rocks from the Sentolo Formation, Old Andesite, and Nanggulan. These rocks function as non-aquifer rocks because of their physical and hydraulic characteristics in terms of K, T, and S values (DPUP ESDM DIY & CV. CPK., 2016).

The rocks in the study area are dominated by andesitic igneous rocks and volcanic breccias, apart from the sedimentary rocks of the Nanggulan, Sentolo, and Jonggrangan Formations which only make up a small part of the study area. Therefore, the discussion of hydrostratigraphy is more focused on intrusive andesite and andesite breccias. The carbonate sandstone and Jonggrangan limestone can function as aquifers, while the Sentolo and Nanggulan claystone can only act as aquitards or aquicludes.

Intrusive rock can function as an aquifer if the rock has experienced weathering or alteration, supported by many cracks due to the geological structure. The presence of joints and faults that are often found in the study area will support the occurrence of cracks or fissure-type aquifers. From the intensive lithology and geological structure, this rift aquifer can be grouped into hydrostratigraphic units **(Figures 5 - 9)**. This hydrostratigraphic analysis was made based on the interpretation of secondary data in the form of a geoelectric cross-section in the Kalirejo area, Kokap (Prastowo et al., 2021).

From **Figures 5 – 9**, it is known that the hydrostratigraphy of the Kokap area has the following variations:

a. Aquifer thicknesses of 6 – 20 m, 2 – 17 m, 0 - 12 m, 6 – 12 m, and 0 – 4 m respectively on lines 1 to 5, are free aquifers.
b. Aquitars are generally found under aquifers with thicknesses of 0 – 8 m, 2 – 7 m, 1 – 8 m, 2 – 10 m, and 2 – 8 m, respectively on lines 1 – 5.
c. Aquifugs were not visible in line 1, but in lines 2 to 5, they were seen at depths of 7 - >20 m, 11 - > 20 m, 10 - >20 m, and 4 - >12 m.

Other secondary data mentions the presence of lava and intrusion which is interpreted from geoelectric (Purwasatriya., 2013). The author said that the igneous rocks that are in the shallow horizon of Hargowilis Village are thin lava. In the field, igneous rocks which are interpreted as lava are often found in a state of cracks, moderate to advanced weathering. The condition of these rocks provides opportunities for aquitards or even aquifers that can provide water during the rainy season.

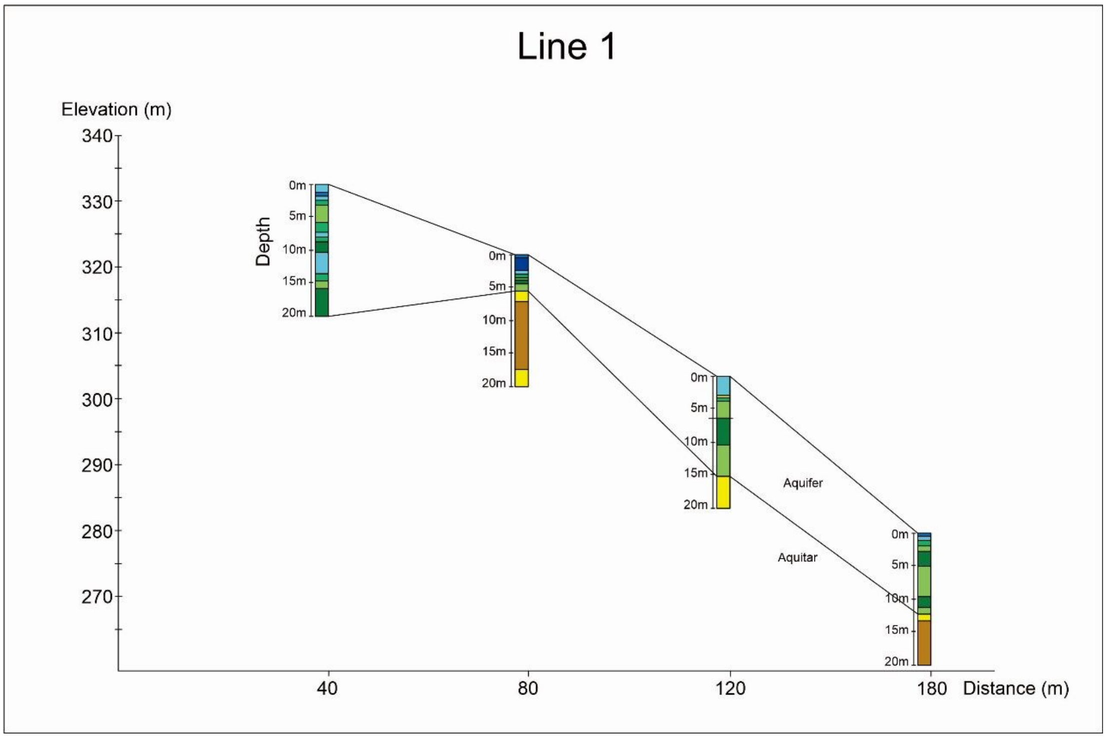

Figure 5. Hydrostratigraphy of the Kalirejo area as a result of geoelectrical interpretation from Prastowo et al (2021) on line 1.

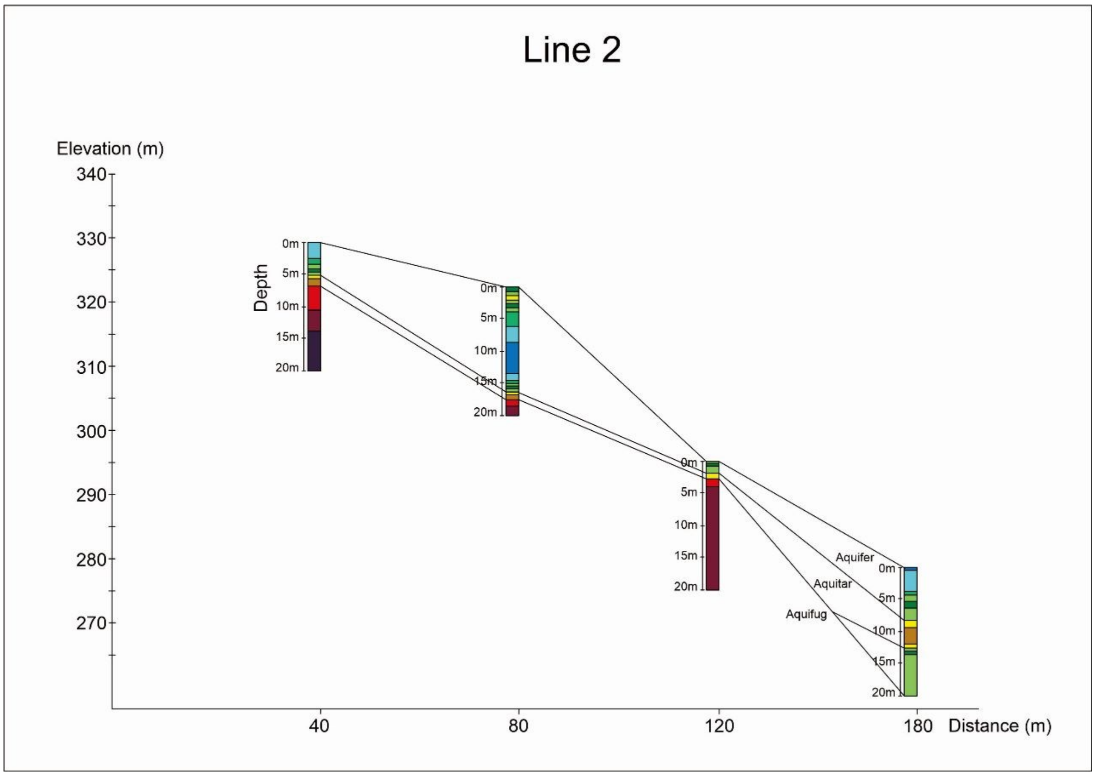

Figure 6. Hydrostratigraphy of the Kalirejo area as a result of geoelectrical interpretation from Prastowo et al (2021) on line 2.

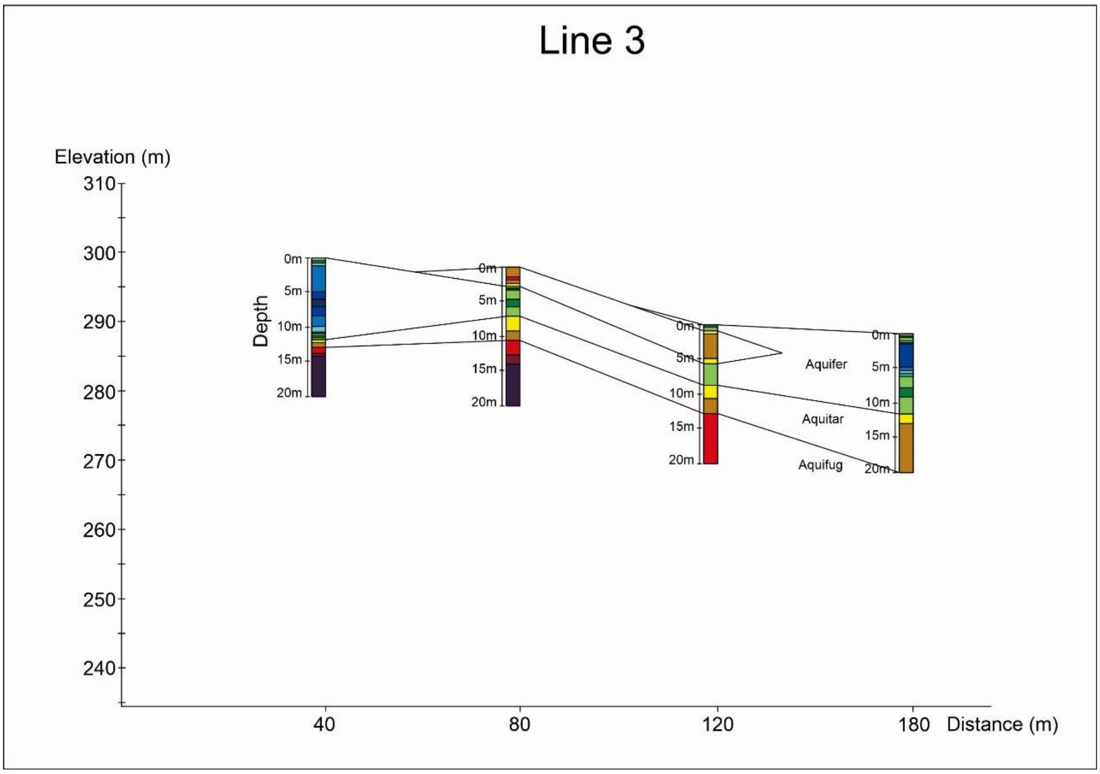

Figure 7. Hydrostratigraphy of the Kalirejo area as a result of geoelectrical interpretation from Prastowo et al (2021) on line 3.

In most of the study area, aquifer systems are formed by weathered/altered rocks, andesite, and volcanic breccias with thicknesses ranging from 0 – 20 m. In some places, aquifers do not develop because fresh, massive bedrock appears on the surface. Igneous rocks that are subject to intensive weathering can form soil layers up to 5 m thick and can develop into part of the aquifer zone, joining the slightly weathered fractured rock. Weathering processes in the rocks in the study area are caused by physical and chemical changes (exogenic processes), supported by many areas of discontinuity (joints/faults). This discontinuity area is a weak area which is the medium for groundwater flow in the aquifer.

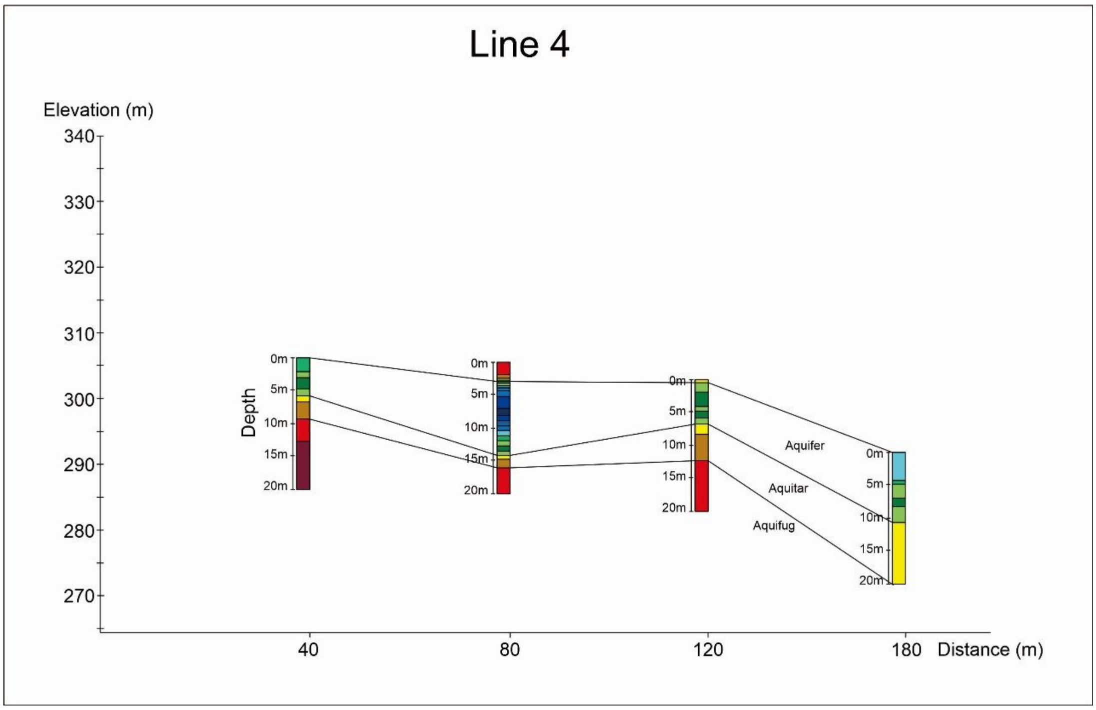

Figure 8. Hydrostratigraphy of the Kalirejo area as a result of geoelectrical interpretation from Prastowo et al (2021) on line 4.

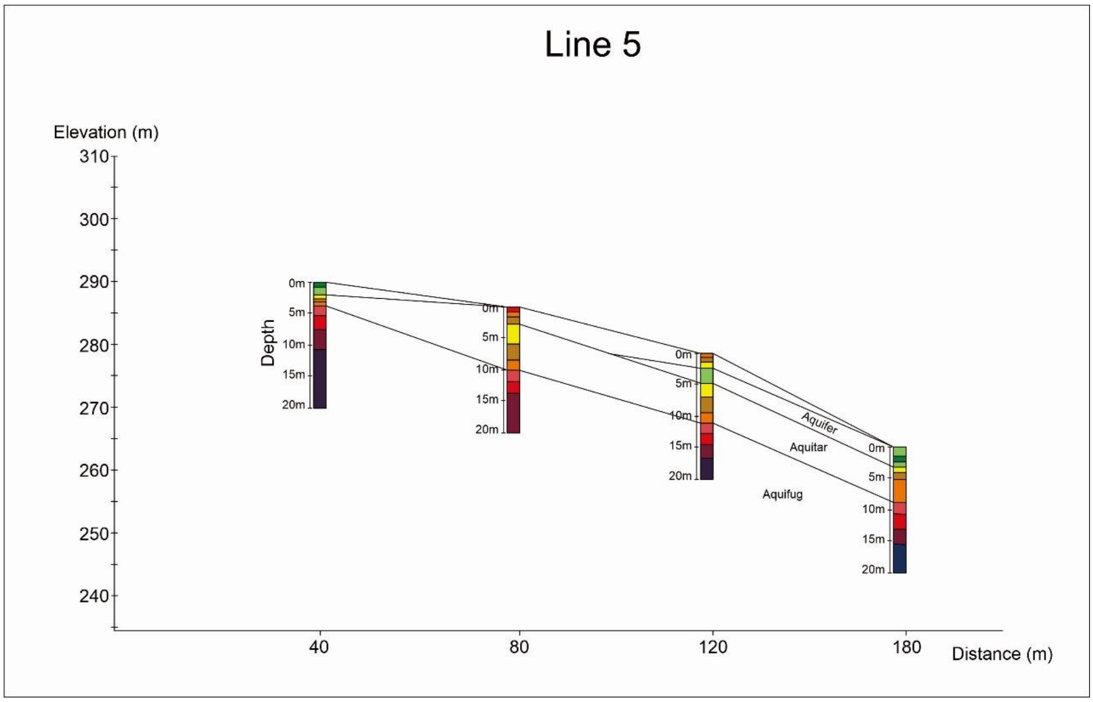

Figure 9. Hydrostratigraphy of the Kalirejo area as a result of geoelectrical interpretation from Prastowo et al (2021) on line 5.

The joints and faults that appear on the surface can continue to great depths. This weak field is more intense in the shallow zone, and results in potential aquifers in the vadose zone if supported by sufficiently high rainfall.

The rocks forming the aquifer system in the study area are intrusive and volcanic rocks, which are supported by weak areas in the form of fractures, joints, and faults. Volcanic and intrusive rocks, which usually have low porosity and permeability, can turn into aquifers by the presence of interconnected cracks, as well as increased porosity due to weathering conditions. Rainwater infiltration to the lower surface is supported by light to heavily weathered rocks and many areas of discontinuity. This discontinuity area can affect changes in groundwater level at close range.

Geological Lineaments

The geological structure can be estimated from the number of lineaments interpreted from Landsat images (Budiadi., 2008). Based on this interpretation, it appears that in the Kokap area, there are many geological structure lineaments with varying directions, including southwest-northeast; North-South; as well as some west-east relatives. The lineaments are quite tight and intersect **(Figure 10)**.

In the study area, there are many symptoms of deformation such as fractures, joints, and faults. In the central to the western part of the study area, there are several shear faults with a southeast-northwest direction and normal faults with a west-east and north-south direction in both andesite and dacite intrusive rocks (Widagdo et al., 2017).

In the eastern part of the study area, around the Sermo Reservoir, there are minor reverse faults and minor normal faults. The geological structure is found in the contact of Nanggulan claystone and andesite intrusion. In addition, there is also a fault trending northwest-southeast to the south of the Sermo Reservoir, which is interpreted as a dextral strike-slip fault (Yulaikhah et al., 2021).

Shear and tension joints are often found in the field **(Figure 11)**. A large number of joints indicates that the rock at Kokap has undergone further deformation, resulting in many discontinuities. This discontinuity area will produce rock porosity and permeability so that the fractured rock can function as an aquitard or even become an aquifer.

Faults and joints that are relatively dense have the potential to make rocks more porous and permeable. The fractured rock can be a fissure-type aquifer or a rift aquifer that allows groundwater to flow through the rock. The dominant aquifer system in the study area was built by intrusive igneous rocks which can be classified as fractured aquifers. Kusumayudha (2010) said that the aquifer in Tertiary volcanic rock in Kulon Progo has low permeability and the porosity of the fissure system which in several places gives rise to springs with small discharges (2 - 10 L/sec). The aquifer system in this area is a free aquifer.

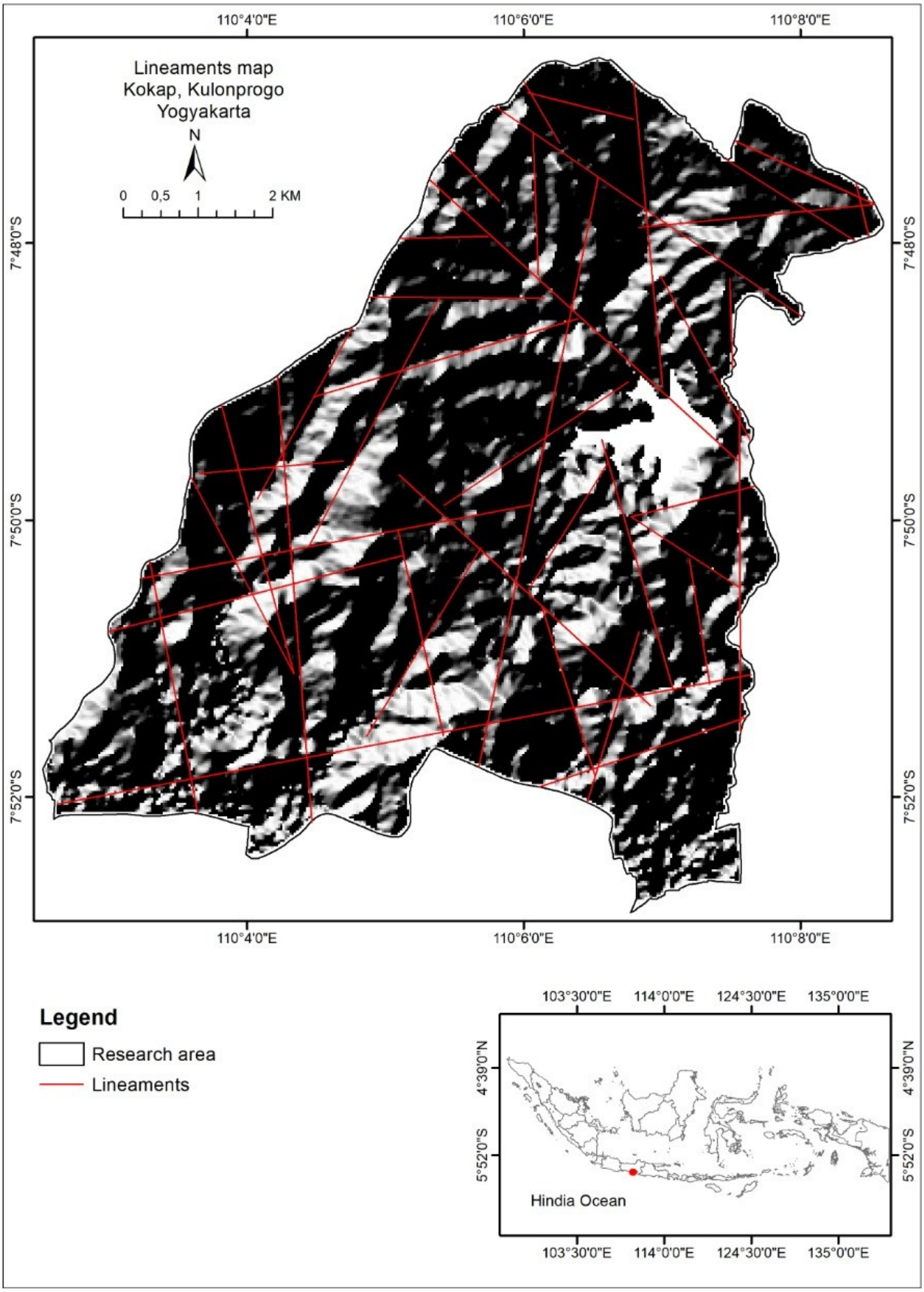

Figure 10. The lineament of the geological structure results from the interpretation of Landsat imagery (Budiadi., 2008).

Figure 11. Joints appearance (from left to right) at Loc 41, 50, and 95.

Remote sensing results show that the Kokap area has many geological lineaments. This geological structure lineament concerns all the Tertiary rock formations that make up this area.

Lineament density maps are made based on length of lineaments. The lineament for each km^2 area is shown in **Figure 12**. From the figure, it appears that the lineament for the study area ranges from 0 – 808 km/km^2 or 0 – 808 /km. A high lineament is found in the southwestern part of Kokap, covering the Kalirejo and Hargomulyo areas. Dusun Sangon is an area that has a high lineament, which is highly correlated with the abundance of alteration rocks related to the potential for epithermal gold.

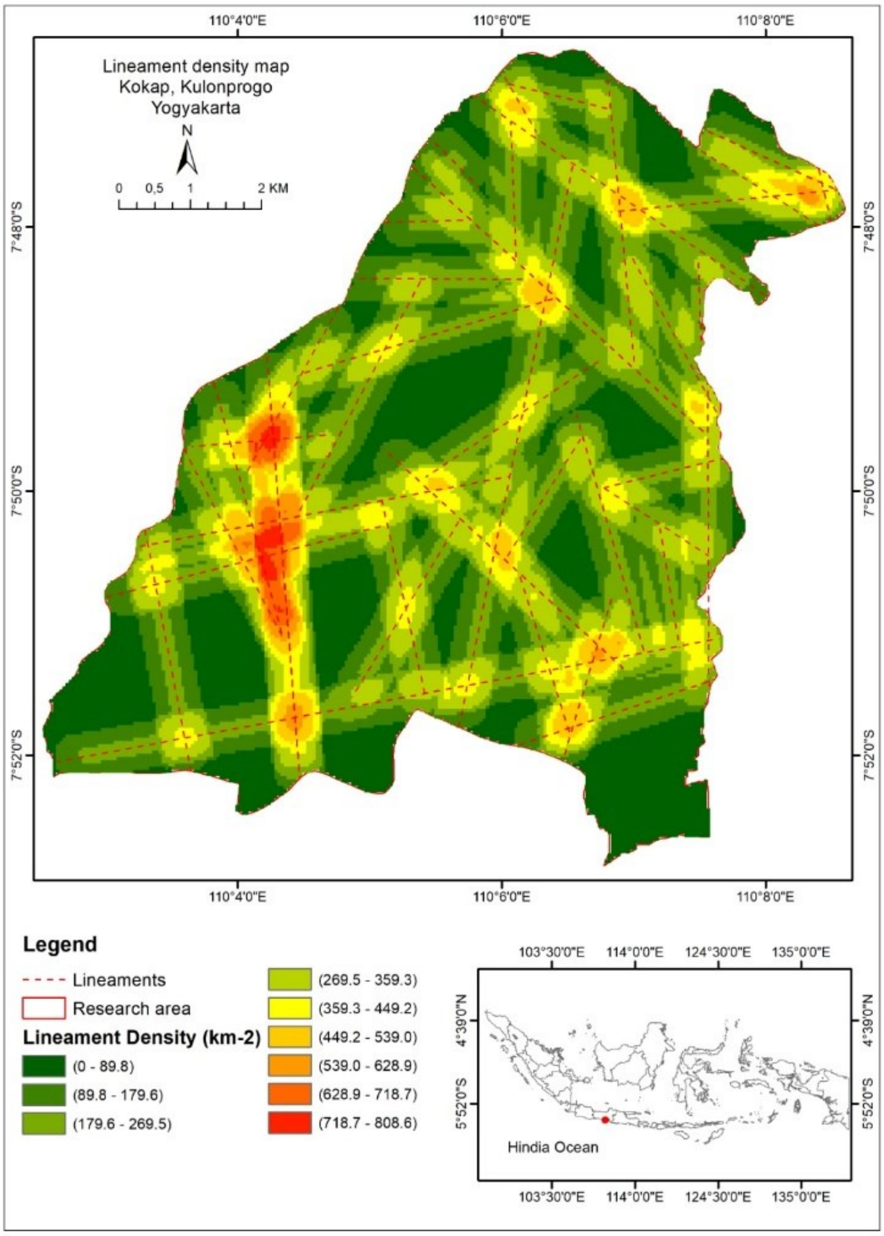

Figure 12. Map of the lineament density of the Kokap area.

Listyani et al (2018) stated that the azimuth and density of the lineament in the Kokap area and the area to the north indicate that springs occur through lineaments or fractures. The lineament trait that most influence the appearance of springs is its distance, with a correlation coefficient of 84% (very strong correlation). Meanwhile, the lineament density has a moderate to strong correlation.

Not only springs but the potential for groundwater in the aquifers in the Kokap area is also supported by the many geological structures that are reflected in the lineaments. High lineament density indicates the number of weak zones that produce adequate porosity and permeability as a condition for the formation of groundwater aquifers.

Aquifer Configuration

The results of hydrostratigraphic analysis and geological lineament interpretation support the potential for aquifers in the Kokap area which is reflected in their configuration. This research area is included in the non-Grounwater Basin (GB) or not potentially GB (Geological Agency., 2011) east side. This area is part of the Menoreh GB proposed by the DPUP ESDM DIY & CV. CPK, 2016. The hydrostratigraphy that makes up this area includes:

1. **Colluvial aquifer subsystem**

This subsystem is composed of material resulting from the breakdown of Tertiary rocks, forming deposits of varying thickness, generally <1 m, and formed in hill valleys or around river channels.

2. **Fractured aquifer sub-system**

This system was formed by compact and hard Tertiary rock but has experienced moderate to advanced weathering symptoms, supported by intensive rock fractures. This fissure sub-system forms the dominant aquifer system in Kokap. The thickness of this aquifer varies, depending on the level of weathering or rock alteration. In the eastern and southern parts of the study area, Jonggrangan limestones and sandstones also have the potential to form this aquifer system.

3. **Aquifer bottom (non-aquifer group)**

The base of the aquifer is intrusive rock and volcanic rock of the massive Old Andesite Formation, as well as a fine sedimentary rock from the Nanggulan and Sentolo Formations, where several outcrops can still be found in the northern part of the study area.

The aquifer configuration in the study area has several types of horizontal and vertical hydraulic boundaries. The horizontal boundary of this aquifer zone according to Boonstra & De Ridder (1981) can be classified into several types as follows **(Figure 13)**.

- H2 (Groundwater divide): this happens in the northern and western parts of the study area, separating the study area on the hilltops.
- H4 (Inflow boundary): is the boundary between the Kulon Progo Dome and Wates GB, in the southern part of the study area.
- H5 (Outflow boundary), as well as H4, where groundwater flows out or enters the Wates GB area.

The vertical boundaries of groundwater basins in the study area include:

- V1 (Free-surface boundary): this boundary is located in the study area locally, with a shallow groundwater table.
- V2 (Internal head controlled boundary): occurs in the stream of children of Serang River.
- V3 (Internal zero-flow boundary): separates the aquifer subsystem from non-aquifer rock.

An understanding of groundwater resources is necessary for fulfilling water resources in the Kokap area, as well as in Kulon Progo Regency in general. The potential of the catchment zone also needs to be studied, including what has been done in the southeastern part of Kulon Progo (Listyani & Prabowo., 2022). The general description of the aquifer configuration in Kokap can also be applied to several areas in Kulon Progo Regency. With these varying types of boundaries, groundwater potential can be expected from several inputs, including external and internal basins. The aquifer potential in the Kokap area is proven to be obtained from rocks with fairly intensive lineament, or weathered rocks. However, groundwater potential is also very dependent on surface water supply and especially from rainwater. This condition is also strongly influenced by the season. Seasonal changes will be followed by changes in groundwater potential in this area (Listyani et al., 2018; Listyani et al., 2021). Thus, fluctuations will occur with the change from the dry season to the rainy season and vice versa.

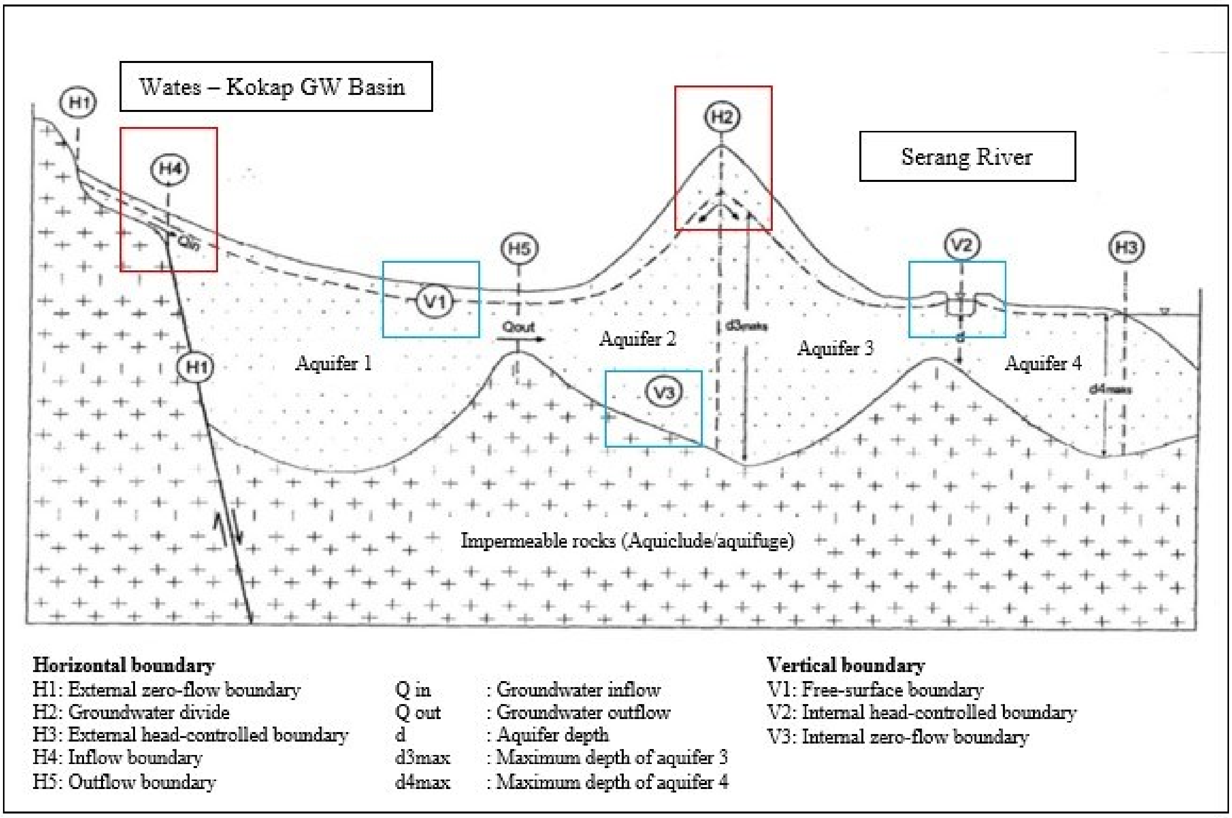

Figure 13. Types of aquifer boundaries in the study area.

CONCLUSION

The Kokap area is part of the Kulon Progo Dome, dominated by denudational hill morphological landscapes, and composed of intrusive igneous rocks and Tertiary sedimentary rocks of the Nanggulan, Sentolo, and Jonggrangan Formations which have undergone intensive tectonics. The hydrostratigraphy of this area shows that the rocks capable of becoming aquifers are sediments and weathered/altered rocks at shallow depths. From the results of the geoelectrical interpretation obtained, it is known that the Kokap area has aquifers with a thickness of 0 – 20 m, while aquitards have a thickness of 0 – 8 m. The aquifer as the basis of the aquifer is found at a depth of 4 to > 20 m below the soil surface. The morphological lineament and the many geological structures in the form of joints and faults are reflected in the intensive lineaments. The lineament density at Kokap is calculated as 0 – 808 /km. This geological lineament supports the potential of rocks as groundwater aquifers, especially those of the fissure type. The hydrogeology of this area is supported by colluvial deposit subsystem aquifer groups and cracked and weathered volcanic rocks, with aquifer bases in the form of massive volcanic and intrusive rocks, with aquifer boundary types H2, H4, H5, and V1, V2, V3.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

REFERENCES

Badan Pusat Statistik Kabupaten Kulon Progo. (2021). *Kabupaten Kulon Progo dalam Angka 2021.*

Boonstra, J., De Ridder, N.A. (1981). *Numerical modeling of groundwater basins.* International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands. pp. 226.

Budiadi, Ev. (2008). *The role of tectonics in controlling the geomorphology of the Kulon Progo mountainous region, Yogyakarta.* (Doctoral Dissertation) Post Graduate Program, Padjadjaran University, Bandung.

Devy, S.D. and Sarongallo, C. (2018). Groundwater aquifer study on coal mining area: a case of North Samarinda, Indonesia. *J. Degraded. Min. Land Manage.*, *6*(1): 1483-1493, DOI: 10.15243/jdmlm.2018.061.1483.

DPUP ESDM DIY – CV. Cita Prima Consultant (CPK). (2016). *Preparation of groundwater basin geometry maps and groundwater conservation zone maps in Kab. Kulon Progo*. Final Report.

Geological Agency. (2011). *Atlas of Indonesian Groundwater Basins.* Ministry of Energy and Mineral Resources, Bandung, ISSN 987-602-9105-09-4.

Kusumayudha, S.B. (2010). Kulon Progo Dome hydrogeological conceptual model based on fractal geometry mapping and analysis. *Proc. of The 39th IAGI Annual Convention and Exhibition*, Lombok.

Listyani R.A.T., Isnawan, D., Prabowo, I.A. (2020). Hydrogeology potential of Hargorejo area Kokap Subdistrict West Progo Regency. *Angkasa, Jurnal Ilmiah Bidang Teknologi, 12*(2), 175-184, DOI: https://doi.org/10.28989/angkasa.v12i2.772.

Listyani R.A.T. and Prabowo, IA (2022). Recharge zone of shallow groundwater at southeastern part of Kulon Progo District area based on groundwater facies. *Int. J. Econ. Environment. Geol.*, *13* (4), 10-15. http://www.econ-environ-geol.org/index.php/ojs/article/view/754/439.

Listyani, R.A.T., Prabowo, I.A., Suparta, W. (2023). Determination of groundwater recharge–discharge zone to support water resources in Galur–Lendah area, Indonesia. *Journal of Water and Land Development*, *56* (1), 203–214, DOI: https://doi.org/10.24425/jwld.2023.143761.

Listyani, R.A.T., Sulaksana, N., Alam, B.Y.C.S.S.S., Sudradjat, A., Haryanto, A.D. (2018). Lineament control on spring characteristics at central West Progo Hills, Indonesia. *International Journal of GEOMATE, 14*(46), 177-184, DOI: https://doi.org/10.21660/2018.46.70127.

Listyani, R.A.T., Sulaksana, N., Alam, B.Y.C.S.S.S., Sudradjat, A. (2019). Topographic control on groundwater flow in the central of hard water area, West Progo Hills, Indonesia. *International Journal of GEOMATE, 17*(60), 83-89, DOI: https://doi.org/10.21660/2019.60.8104.

Listyani, R.A.T., Sulaksana, N., Alam, B.Y.C.S.S.S., Sudradjat, A. (2021). Groundwater flow model in the center of West Progo Dome based on hydrochemical and isotopic characteristics. *Bulletin of the Geological Society of Malaysia, 71*(1), 227-241, Geological Society of Malaysia, DOI: https://doi.org/10.7186/bgsm71202118.

Prastowo, R., Helmi, H., Trianda, O. and Umam R. (2021). Identification of slip surfaces using the geoelectric imaging method in the Kalirejo area, Kokap District, Yogyakarta, Indonesia. *J. Theory and Application of Physics,* *6*(3), 2477-8451, DOI: https://doi.org/10.26737/jipf.v6i3.2072.

Van Zuidam, R.A. (1983). *Guide to geomorphologic aerial photographic interpretation & mapping, section of geology and geomorphology*. ITC, Enschede, The Netherlands.

Widagdo, A., Pramumijoyo, S., Harijoko, A. (2017). Reconstruction of the geological structure of Mount Ijo in the Kulon Progo Mountains, Yogyakarta based on the distribution of joints, faults and quartz veins. *Proceedings of the 10th Seminar Nasional Kebumian*, Yogyakarta.

Yulaikhah, Pramumijoyo, S., Widjajanti, N., Widagdo, A. (2021). Optimal design of the Sermo Fault deformation monitoring network using sensitivity criteria based on geological information. *Arabian Journal of Geosciences, 14*(20), 1-9. DOI: https://doi.org/10.1007/s12517-021-08411-6.