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Review on the Impacts of the Samalas Eruption (1257 CE) to the Hydrogeological Conditions of Mataram, Lombok, Indonesia

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Abstract - This paper examines the local impacts of the 1257 CE Samalas eruption in the Mataram plain in relation to the hydrogeological conditions. Data from several previous studies in the Mataram plain is summarized and then reinterpreted. Data collected from new fieldwork is also presented. This review summarizes hydrogeological conditions into several categories, *i.e.* stratigraphy, aquifer formation, groundwater quality, and evolution. Two coring data were evaluated, which showed that Mataram plain has a relatively thick alluvial layer with a dominant material of sand mixed with pumice from the reworked deposit of the 1257 CE Samalas eruption. The sediment from this eruption formed a freshwater aquifer layer up to ~18 m deep. Using resistivity data, the aquifer layers in the studied area were characterized as unconfined aquifer, aquitard, and semi-unconfined aquifer. Seven water samples show that the groundwater in the studied area is in good condition, which indicates the bicarbonate water type. The results of the analysis show that the impact of the 1257 CE Samalas eruption on the hydrogeology of Mataram is considered a positive impact, *i.e.* forming an unconfined aquifer containing freshwater that is good for domestic uses.

Keywords: groundwater, hydrogeology, Samalas eruption, volcanic impacts, Lombok

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Introduction

Volcanic eruption is one of the factors that can lead to the disruption of natural and societal conditions (Newhall *et al.*, 2018). A major eruption with a volcanic explosivity index (VEI) > 4 may induce global, regional, and local impacts (Malawani *et al.*, 2021). The eruption of the Samalas Volcano on Lombok in 1257 CE is included on the list of the largest eruptions in Indonesian history (Lavigne *et al.*, 2013; Rachmat *et al.*, 2016; De Maisonneuve and Bergal-Kuvikas, 2020). This eruption produced voluminous pyroclastic density currents (PDCs), which were distributed over Lombok with various thicknesses (Figure 1). The thickest deposits are ~40 m on the foot slopes of the Samalas-Rinjani Complex (Vidal *et al.*, 2015; Mutaqin *et al.*, 2019). A study on the local impact of this event has yet to be conducted on a wide area of Lombok. According to the map

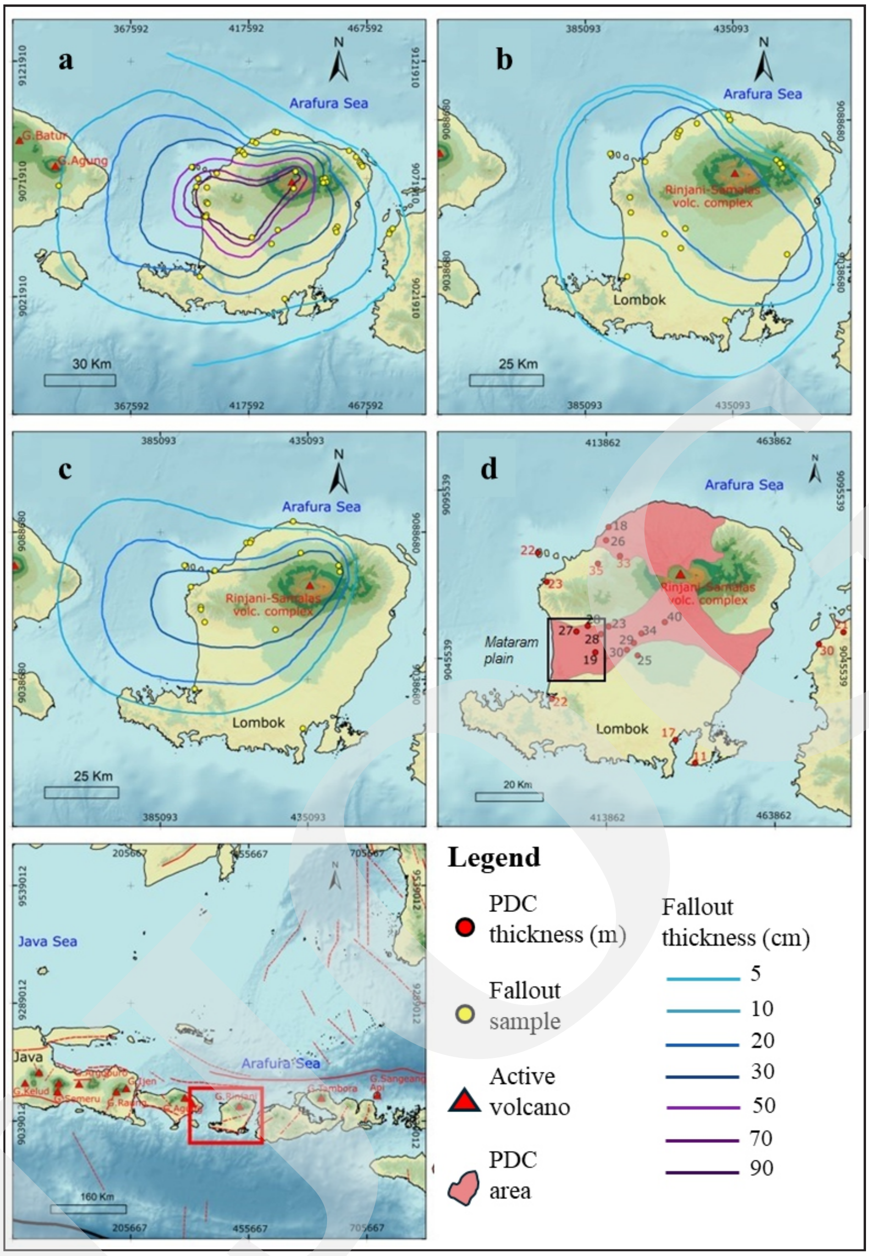

Figure 1. Map of the ejected materials during the Samalas eruption in 1257 CE. The eruption consisted of four phases; phases one to three were characterized by fallout deposits (maps a, b, and c, respectively) and were followed by phase four, the pumice-rich pyroclastic density currents (PDC) (Map d). The studied area is indicated by the black box in map d. (Fallout and PDC mapping are summarized from Lavigne *et al*., 2013; Vidal *et al*., 2015)

of ejected materials from the 1257 CE Samalas eruption, the western region around Mataram City was heavily impacted (Vidal *et al*., 2015). This area has had no further investigation relating to the local impacts caused by this eruption. The local impacts of volcanic eruptions vary depending on the landscape characteristics, including morphological changes in the volcanic edifice or surrounding landscape, the evolution of the river and drainage system, impacts on the water body, and the perturbation of the environment and societies (Waythomas, 2015; Malawani *et al*., 2021).

The latest evolution of Lombok morphology, as well as the deposition of the surface materials, was formed during the Pleistocene to the Holocene (Mangga *et al*., 1994; Zubaidah *et al*., 2014). However, the most recent process that was highly influential on the surface morphology and subsurface material composition of Lombok was the eruption of the Samalas Volcano in 1257 CE (Lavigne *et al.*, 2013; Vidal *et al.*, 2015; Métrich *et al.*, 2017; Mutaqin *et al.*, 2019). These processes might affect the formation of aquifer layers in the impacted area. Previous studies using stratigraphic data and geo-electric measurements demonstrated that the Mataram plain has several distinctive subsurface layers (Hiden *et al.*, 2017; Sudrajat *et al.*, 2017; Malawani *et al.*, 2023). Researchers have looked into the aquifer layers in the northern Lombok area that was affected by the Samalas eruption in 1257 CE. They found a link between recent sedimentary processes and the formation of layers below the surface (Nugraha *et al.*, 2022). The result shows that sedimentation during and after the Samalas eruption formed aquifer layers that significantly impacted the groundwater resources in the studied area. Due to relatively similar regional characteristics, the massive influx of pyroclastic sediments may also have influenced the groundwater resources of the Mataram area. The goal of this review paper is to look at the effects of the 1257 CE Samalas eruption in the Mataram area, which saw changes in the landscape and the layers of rock that formed on top of each other, as well as how these changes affect the hydrogeological features. Data from previous studies in the Mataram area is summarized and reinterpreted (*e.g.* Hiden *et al.*, 2017; Sudrajat *et al.*, 2017; and Malawani *et al.*, 2023). Data collected from new fieldwork is also presented.

Geology of Mataram Area

The configuration of the Mataram area is a plain facing the ocean with a span of +20 km. This plain area is surrounded by hilly areas in the northern and southern parts. In the north, an old volcanic formation composed of breccia and lava was formed during the Tertiary (Figure 2) (Mangga *et al.*, 1994). In the southern part of Mataram, there are similar aged rocks composed of quartz, sandstone, carbonate, and tuff. The Mataram area is covered by alluvium formations (Mangga *et al.*, 1994). Most of the alluvium is derived from Lekopiko Formations (Qvl) and modern Rinjani deposits (Qhv(r)) (Mangga *et al.*, 1994; Marjiyanto, 2016). These formations are composed of loose materials such as sand, gravel, tuff, and pumice. In addition to the supply from these two formations, the alluvium also

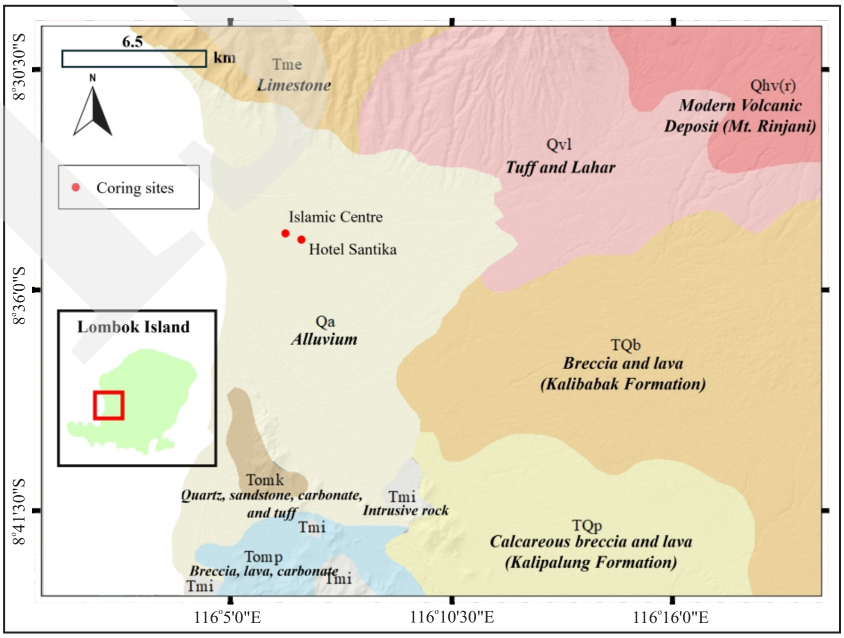

Figure 2. Rock formations map in the Mataram area. Source: Geological Map 1:100,000 (Mangga *et al.*, 1999).

originated from marine depositional processes (Marjiyanto, 2016). The marine deposits cover the coastal areas of Mataram consisting of black and white sands, pumice, and foraminifera, or coral fragments in several places (Marjiyanto, 2016). On the upper layer, the most common material has a texture of sandy silt. In the lower layer, the material texture is dominated by sandy material, either medium or coarse sand (Agustawijaya and Samsyudin, 2012). Seismic identification shows that alluvium deposits in Mataram have a maximum thickness of up to 43 m. Alluvium bedding in Mataram is also heterogeneous, indicating a complex depositional process and the evolution of the depositional environment (Marjiyanto, 2016). The soil formations in the Mataram area are relatively homogenous due to similar parent materials, with an average thickness of 2−5 m (Agustawijaya and Samsyudin, 2012). The topsoil is dominated by sandy-silt materials. Due to its flat area, this topsoil layer is included as an aquifer with a shallow groundwater table (Agustawijaya and Samsyudin, 2012).

Stratigraphy

Stratigraphic data in the Mataram area was collected based on coring data from the Ministry of Energy and Mineral Resources (ESDM office) of West Nusa Tenggara Province. Figure 3 shows the lithology of the studied area based on the coring data. Coring data is the detailed data that can be used to examine the existing subsurface conditions of the Mataram area. However, this data is limited in Mataram. Two coring data are examined, namely Islamic Centre (C1) and Hotel Santika (C2) which have depths of more than 10 m each. Coring C1 is located near the middle of Mataram City. In this location, the stratigraphic formation consists of thick top soil containing silty sand, underlain by coarser materials including sand and pumice fragments (0.5−2 cm) to 6 m deep. The pumice fragment subsequently becomes finer, with an average diameter of 0.5−1 cm. Finer sand materials are found at the depth of 10 m. A relatively similar formation can be found in coring C2, situated ~700 m from C1, where an anthropogenic infill is present at the top. No pumice fragments are present in this location until 2.4 m deep. The pumice fragments present at the depth of 2.4 - 5.6 m intermix with sandy-silt materials. Groundwater table is in the C1 at the depth of 4 m, whereas in the C2 is at the depth of 4.5 m. This shows that the recent material from the Samalas eruption has made a significant contribution to the formation of a suitable, unconfined aquifer in the studied area.

Discussion

Aquifer Formations

The Mataram area has high groundwater potential compared to the surrounding regions. In the current state, the groundwater availability of the Mataram area can be divided into three classes of productivity (Figure 4). The area with the highest productivity is located in the area, which consists of alluvium deposits. This location is mainly in the coastal zone of Mataram, which is suspected to be the zone of accumulation from sedimentation processes following the 1257 CE Samalas eruption, as indicated in Figure 1d. In this accumulation zone, marine sediments are intercalated with fluvial or laharic sediments. Other areas surrounding it have medium and low groundwater productivities. Despite having various groundwater potentials as shown in Figure 4, the subsurface conditions are not necessarily homogeneous, as shown in the stratigraphic charts (Figure 3).

In the northern part of Lombok, investigation of aquifer layers using geo-electrical measurement has been conducted (Nugraha *et al.*, 2022). Having similar region characteristics that were impacted by the PDC of the 1257 CE Samalas eruption, the previous resistivity measurements were reinterpreted in the Mataram area using the classification carried out by Nugraha *et al.* (2022), *e.g.* tuffaceous pumice, volcanic breccia, and tuffaceous sandstone. The resistivity interpretation of Malawani *et al.* (2023) in the same studied area is also used as a reference, *e.g.* sandy

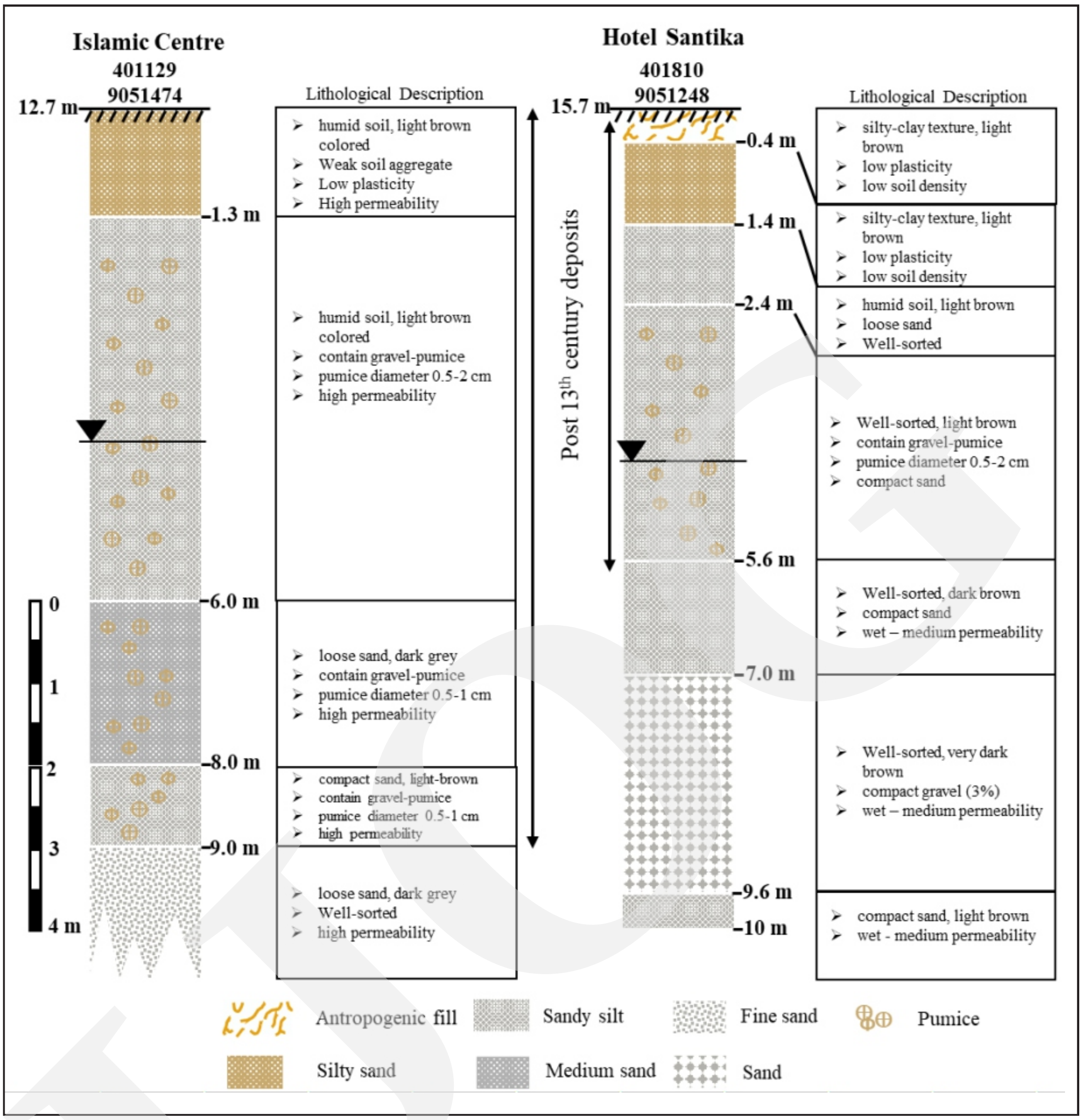

Figure 3. Columnar stratigraphic charts from sediment coring in the Mataram plain. The deposits from the post-Samalas eruption in the thirteenth century consist of sandy material with pumiceous deposits ranging from 0.5 to 2 cm in diameter. The groundwater table is indicated by a black inverted triangle.

pumiceous materials (30–300 Ωm) and clay and mud materials (<30 Ωm). A previous investigation was conducted by Sudrajat *et al.* (2017) in Cakranegara, the centre area of Mataram, using the dipole-dipole configuration. In this location, two measurement lines have similar characteristics: they are located in the middle of Mataram City, *i.e.* Antereja and Sriwedari roads (Figure 5). With the help of resistivity values from Hiden *et al.* (2017), Sudrajat *et al.* (2017), Nugraha *et al.* (2022), and Malawani *et al.* (2023) as well as coring data (Figure 3), it is possible to figure out the type of rock and predict the type of aquifer. In these two measured lines, both lithology and aquifer characteristics are relatively similar. Based on the resistivity value, at the top layer, it is identified as a pumiceous material with an average depth of 14 m. Below this layer, finer materials are present, as indicated by the lower resitivity value: clay and mud materials. This layer is likely to be an aquitard formation. At the depth of 50 m, more porous materials, such

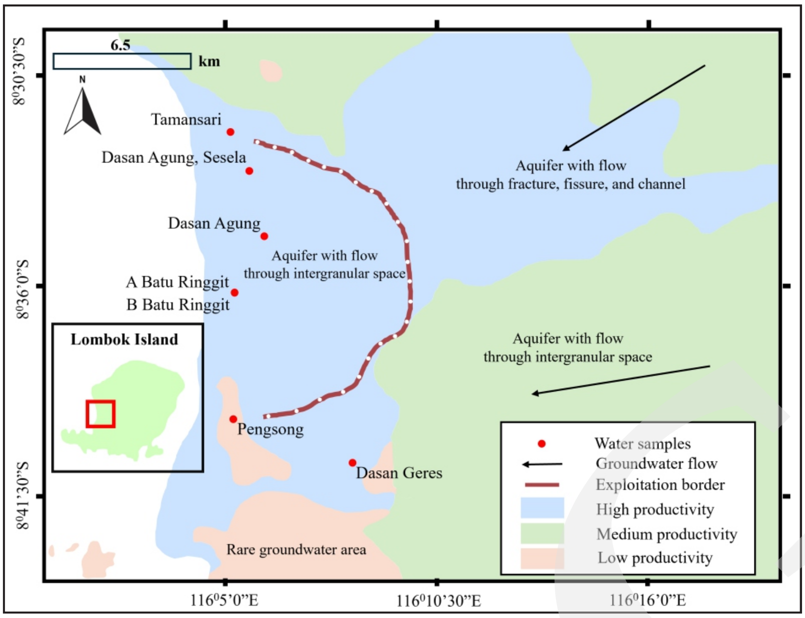

Figure 4. Map of groundwater availability and aquifer characteristics in the Mataram plain (Ridwan and Sudadi, 2000).

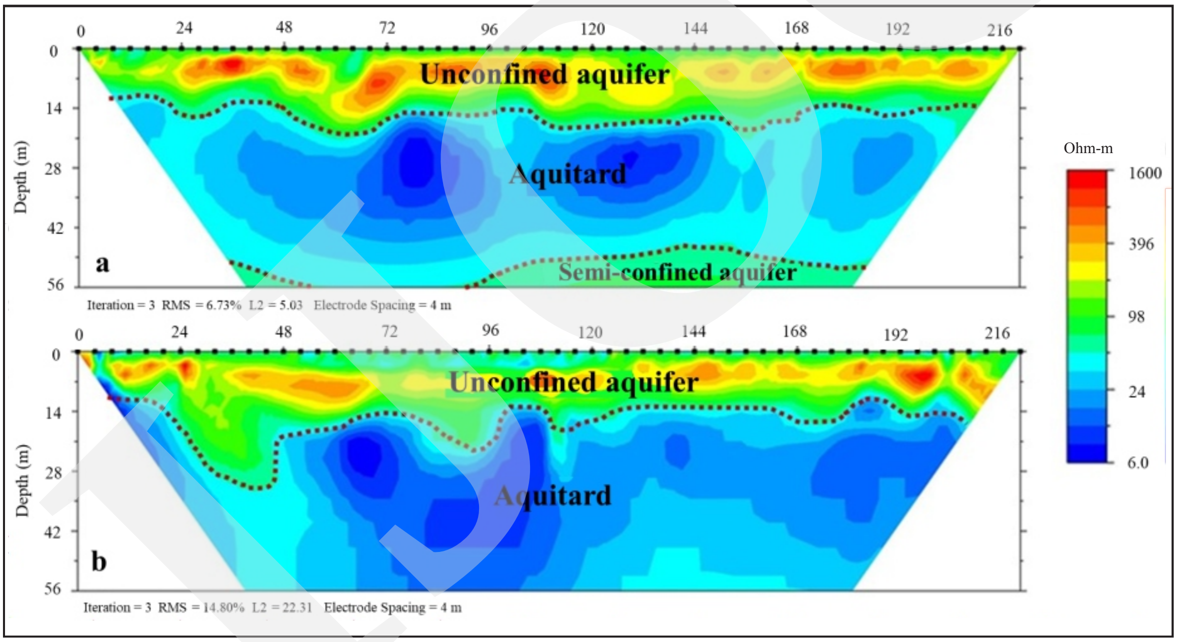

Figure 5. Reinterpretation of subsurface materials from the geoelectrical measurements in Cakranegara, Mataram. a: Antareja Road; b: Sriwedari Road (Sudrajat *et al.*, 2017). The location of these two lines is indicated in Figure 6.

as sandy deposits, are identified as a semi-unconfined aquifer.

Another measurement by Hiden *et al.* (2017) is located in the southern area of Mataram, near the Jeranjang power plant (Figure 6). In this location, two types of layers were identified: unconfined aquifer (composed of sandy pumiceous rock) and aquitard (composed of clay and mud). The maximum depth of the sandy pumiceous layer reaches 30 m, with the average of about 18 m. This condition indicates that the approximate depth of the unconfined aquifer in the Mataram area, formed from sandy pumiceous material derived from the deposits of the 1257 CE Samalas eruption, is 14 - 18 m. In the Jeranjang area, it is necessary to consider that at the depth of

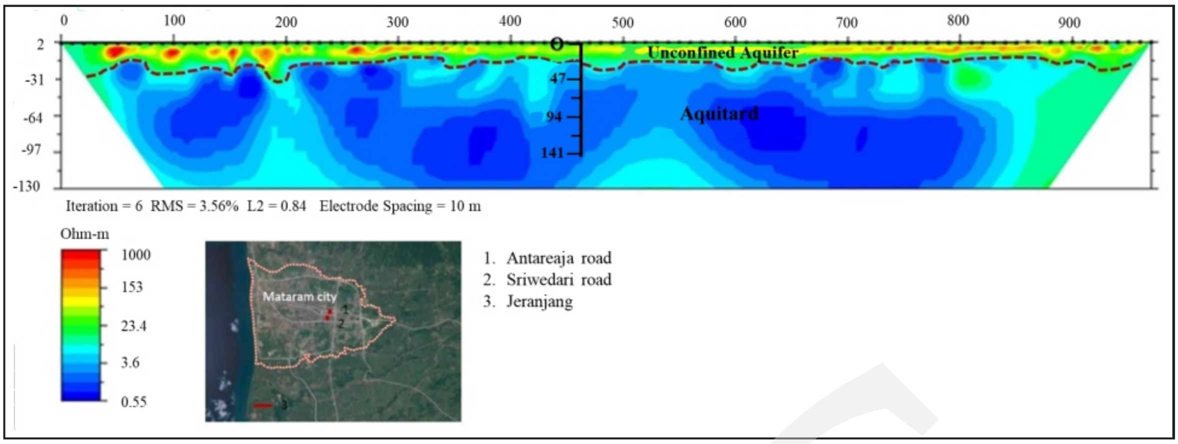

Figure 6. Reinterpretation of subsurface materials from the geoelectrical measurements in Jeranjang (Hiden *et al*., 2017).

more than 40 m, it is possible to discover saline groundwater that is not suitable for domestic use, because this location is close to the sea. Sudrajat *et al*. (2017) suggest that ancient seawater traps may have formed as a result of the formation of the Mataram plain by the interaction between fluvial and marine processes. Another finding suggests that seawater traps in the Mataram area are plausible, because Mataram has undergone an abrupt and progressive landscape evolution from a shallow marine environment to a fluvio-marine plain following the eruption of Samalas over the past ~700 years (Malawani *et al*., 2023).

Groundwater Quality

The chemical type of groundwater can be determined by plotting the chemical composition of cations and anions on a trilinear Piper diagram (Figure 7) (Piper, 1944). The trilinear piper diagram consists of a cation triangle at the bottom left, an anion triangle at the bottom right, and a parallelogram at the top centre. The cation triangle of the Piper diagram indicates that the water samples are clustered in the lower right section, signifying that the dominant cations in the groundwater are sodium (Na) and potassium (K). Meanwhile, the anion triangle shows that the samples are clustered at the bottom left, indicating that bicarbonate (HCO_3) is the dominant anion. The triangular section formed between the cation and anion triangles also shows clustering in the lower part, which reflects the overall composition of the groundwater samples, primarily composed of sodium bicarbonate ($Na(K)HCO_3$). The predominant sodium bicarbonate ions can also result from various geochemical processes, not only from recent rainfall and atmospheric interactions. In this regard, this study does not further address the significant processes of groundwater origin and dynamic ion changes. However, two water samples are more dominant in the calcium magnesium bicarbonate ($Ca(Mg)HCO_3$) groundwater type, *i.e.* samples from Taman Sari and Pengsong. The high concentration of sodium (Na) in the groundwater is not accompanied by a corresponding increase in chloride (Cl), indicating that there is no significant weathering activity affecting the groundwater quality. The absence of chloride suggests that the groundwater samples collected from the unconfined aquifer in the studied area are not influenced by direct seawater contamination. However, these data show that the groundwater in the studied area is fresh-tasting and of good quality for domestic uses and is usually found in areas that are genetically classified as Quaternary deposits, such as alluvial plains (see the correlation between Figures 2 and 4).

In this study, the possibility of saline groundwater at depths exceeding 40 m is recognized, as suggested by Sudrajat *et al*. (2017) and Malawani *et al*. (2023). However, the data does not show a significant chloride content in the collected groundwater samples (Figure 7). This suggests

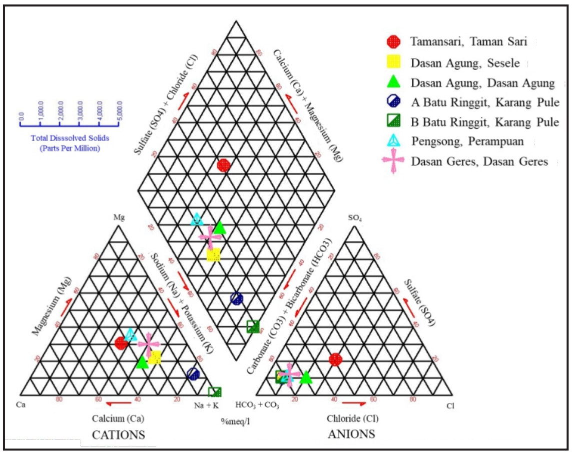

Figure 7. Triliner piper diagram of the groundwater samples in the studied area. Diagram from Piper (1944).

that the collected groundwater samples are not directly affected by seawater intrusion, at least at the depth and location sampled. This study did not include data from the brackish zone for a direct comparison. Future research incorporating such data would be useful for a more comprehensive understanding of the interaction between groundwater quality and seawater intrusion.

CONCLUSIONS

The aquifer configuration in Mataram is strongly influenced by the depositional processes that created this region: a combination of fluvial-volcanic and marine processes. Using the information from geological maps, stratigraphy, resistivity profiles, and groundwater quality, the aquifers that are present in Mataram plain can be identified. The recent material from the Samalas deposits of the 1257 CE eruption has evolved into an unconfined aquifer across the Mataram plain. This aquifer consists of sandy pumiceous materials. Less productive aquifers are also available in older layers, which are predominantly composed of sand-silt-clay materials. Groundwater in the unconfined aquifer in Mataram has a good quality for domestic use. However, deep drilling wells near the coast may require precautions because, at some locations, they may encounter brackish water from ancient marine water traps.

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