http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 10 No 2 2025

RESEARCH ARTICLE

Geology and Identification of Freshwater Sources Using Water Resistivity Survey in Landu Village, Rote Ndao, East Nusa Tenggara, Indonesia

Indra Gunawan[1,*], Alfend Rudyawan[1], Astyka Pamumpuni[1], Alfita Puspa Handayani[1], Adinda Febrianti[1], Meli Hadiana[1], Benyamin Sapiie [1]

[1] *Geological Engineering Department, Institut Teknologi Bandung, Jalan Ganesa No. 10 Bandung, Indonesia*

* Corresponding author : indra.gunawan@geodin.net
Tel.:+62 8122265989
Received: March 17, 2025; Accepted: May 31, 2025.
DOI: 10.25299/jgeet.2025.10.02.21729

Abstract

Located within the tectonically complex Banda Arc of eastern Indonesia, Landu Island, in Rote Ndao, East Nusa Tenggara provides a unique setting to investigate the relationship between arc-continent collision, karst development, and groundwater dynamics. The island is primarily underlain by Quaternary limestones, which form the principal aquifer system. Despite this hydrogeological potential, Landu faces acute freshwater shortages, particularly during the dry season.

This study combines geological field mapping with a 1D electrical resistivity survey to characterize subsurface lithology, identify groundwater-bearing units, and assess the extent of seawater intrusion. The geological survey reveals slightly southward-tilted, fossiliferous limestones that exhibit clear evidence of karstification, indicating a history of tectonic uplift and surface water infiltration. A freshwater spring—currently the main source of potable water for the local population—was documented in the southeastern part of the island, with a total dissolved solids (TDS) concentration of 924 ppm, suggesting moderate water quality.

Resistivity modeling identifies two potential aquifers: a shallow zone at depths of 5.2–17.2 m, and a more extensive, deeper reservoir between 35.1–92.1 m. The shallow aquifer shows lower resistivity values, indicative of possible saltwater mixing, which correlates with historical reports of failed boreholes in this zone. In contrast, the deeper aquifer exhibits higher resistivity signatures, suggesting better preservation of freshwater and greater potential for sustainable extraction.

These findings highlight the critical influence of structural controls and karst processes on groundwater storage and quality. The study emphasizes the need for careful aquifer targeting and protection measures to prevent saltwater intrusion. Future work should focus on high-resolution geophysical imaging and long-term monitoring to support resilient water resource management on Landu Island.

Keywords: Landu, Rote Ndao, Limestone, Resistivity, Water Resource

1. Introduction

Indonesia, at the nexus of four tectonic plates, exhibits dynamic geological processes that shape its complex landscape. The Banda Arc, in particular, serves as a natural laboratory for studying arc-continent collision processes. This region transitions from subduction zones, such as the Java and Sunda Trenches, into collision zones, exemplifying interactions like slab tear and crustal shortening (Major et al., 2013; Roosmawati and Harris, 2009).

The Banda Arc's geological evolution is marked by a shift from subduction-dominated to collision-dominated processes about 3 million years ago. This transition, supported by coral terrace studies in Rote and Savu, highlights progressive underthrusting of the Australian continental margin (Roosmawati and Harris, 2009). Uplift rates vary significantly across the arc, reaching up to 2.3 mm/year on Savu and Rote Islands, reflecting differential strain along the collision complex (Merritts et al., 1998).

Small islands in the Banda Arc, including Kisar, Rote, and Timor, provide critical insights. Kisar, an emergent metamorphic island, records uplift rates of 0.5 mm/year due to active thrusting along the Kisar Thrust (Harris, 2011; Major et al., 2013; O'Connor et al., 2019; Pirazzoli et al., 1991). In contrast, Rote and Savu document rapid uplift and the westward propagation of the collision zone, evidenced by synorogenic deposits and coral terraces. Timor, the largest island, underscores the role of geological isolation in biodiversity, with high levels of endemism tied to its unique tectonic history.

These islands share common geological features such as accretionary wedges and foraminifera-rich deposits that track uplift over millennia. The region's tectonic activity not only shapes its physical landscape but also influences its susceptibility to seismic and tsunami hazards, necessitating further multidisciplinary research to unravel its complexities and mitigate risks (Roosmawati and Harris, 2009). Water resources on small islands are critical for the sustainability of local communities, ecosystems, and economic activities. In Indonesia, an archipelago with over 17,000 islands, small islands face unique challenges in managing their water resources due to their limited size, isolation, and vulnerability to environmental changes as mentioned in many cases across the archipelago such as Lam Apeng, Aceh Besar (Darisma et al., 2020), Bengkalis (Islami et al., 2023), Pisang Island, Lampung (Sinaga et al., 2024), North Samarinda (Sadewo et al., 2025), Manggar, Balikpapan (Sastrawan et al., 2020), South Sulawesi (Rahmaniah et al., 2021), Tual (Latupapua, 2022), Baai Island, Bengkulu (Rafly et al., 2024), Lombok Island (Zuhdi

et al., 2023), and Tumbur Island, Tanimbar (Serang, 2023). Understanding the surface geology and subsurface characteristics through geophysical methods such as 1D resistivity surveys is essential for effective water resource management.

Geoelectrical methods are widely employed for subsoil and subsurface investigations across a range of applications. Numerous studies have explored their use in various fields, including: groundwater exploration (Sulaiman et al., 2022; Sayed et al., 2023; Sehah et al., 2021; Handika and Sehah., 2020; Darsono et al., 2023) soil and groundwater contamination mapping (Wahab et al., 2021; Park et al., 2016; Carpenter et al., 2012); environmental studies.

This study aims to investigate the water resources of a small island in Indonesia, which is underlain by Quaternary limestones, by analyzing its surface geology and conducting a 1D resistivity survey to identify potential groundwater reservoirs and assess the impact of seawater intrusion as often became the main challenge for small islands water conservation (Baharudin et al., 2018; Stanic et al., 2024), for example in Selangor, Malaysia (Baharuddin et al., 2018), Pelau-Kariew, Maluku (Rumpakwakra et al., 2024), Bengkalis (Putra et al., 2019),

Landu island is the southernmost island nearby Rote Island, inhabited by more than 700 people, oflen lacks fresh water sources in the dry season. This paper aims to identifiy the geological condition of the island in relation to its water sources. In the past there was a sporadic effort to drill a well next to the local spring, however, it was resulted in salt water intrusion into the freshwater spring and it took 2 years for the spring to recover.

2. Regional Geology and Hydrogeology

The study area is underlain by Quaternary reef limestone formations, predominantly composed of carbonate materials derived from marine organisms. These formations are characterized by porous and fractured zones, commonly associated with karst topography.

Rote Island forms part of the Banda Arc system, a geologically complex region shaped by the ongoing convergence of the Indo-Australian and Eurasian tectonic plates (Spakman, W., & Hall, R. (2010)). The island's lithology primarily consists of uplifted coral reef limestones and volcaniclastics. The structural framework of the Banda Arc contributes to significant folding and faulting,which influence groundwater flow and aquifer development.

The limestone formations in Rote Island exhibit extensive karstification, resulting in solution cavities, conduits, and fracture networks that play a crucial role in the hydrological dynamics of the area. Karst landscapes, governed by diffuse or conduit flow in autogenic and allogenic systems, are highly vulnerable to environmental stresses, including contamination, drought, and seawater intrusion. Rote Island, Indonesia, with its carbonate geology, faces freshwater scarcity exacerbated by climate change and population growth driven by decentralization (Dua et al., 2020).

Hydrogeological assessments categorize the area as having moderately productive localized aquifers. Groundwater occurrence is typically confined to fractures, dissolution cavities, and conduits within the limestone. Hydrogeological maps indicate limited aquifer recharge due to sparse vegetation and rapid surface runoff (Geological Survey of Indonesia (2020). Water availability is often seasonal and dependent on subsurface storage in karst features. Tamelan (2015) suggest that Rote Ndao has seasonal water scarcity, with a 7–9 month dry season. It consists mainly of Quaternary and Tertiary formations, with 500–1000 mm annual rainfall. Only 10% of the land has moderate aquifers (>5 L/s flow), while 60% has limited groundwater (<5 L/s), and 30% has low productivity.

3. Methods

Geological mapping was conducted to understand the surface geology of the study area. This involved description and documentation the various rock types, structures, and geological features present on the island. The mapping process included the collection of rock samples, measurement of geological structures such as faults and folds, and the creation of detailed geological maps. These maps provided a comprehensive overview of the island's geological framework, highlighting areas of Quaternary limestones and other significant geological formations. The geological mapping was essential for identifying potential groundwater reservoirs and understanding the geological controls on water distribution.

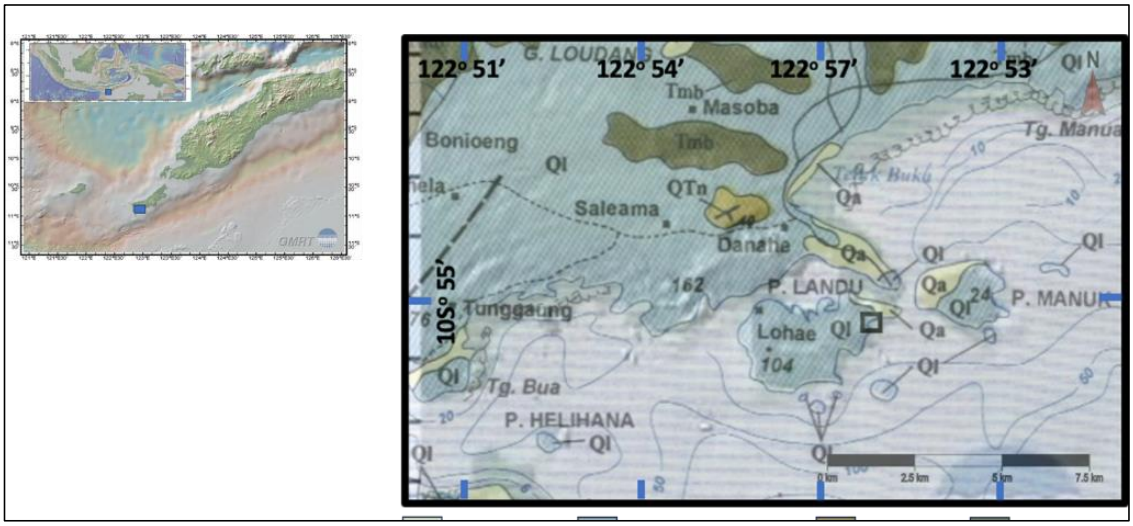

Fig 1. Geological Map of Rote Island and Landu Village, rectified from the geological agency map (Rosidi & Tjokrosapoetro (1996)) showing the extensive distribution of Quaternary Limestones overlying the Miocene syn-orogenic deposits of Bobonaro Complex and Noele Formation

The 1D geoelectric resistivity survey was employed to investigate the subsurface characteristics of the island in two neighboring locations (Figure 1). This geophysical method involves measuring the electrical resistivity of the ground to identify different subsurface layers and detect groundwater reservoirs. The survey was conducted using a series of electrodes placed in the ground along a linear profile. Electrical currents were injected into the ground, and the resulting potential differences were measured to calculate the resistivity of the subsurface materials. The data obtained from the resistivity survey were analyzed to create resistivity profiles, which provided insights into the distribution of soil and rock layers, the presence of groundwater, and the extent of seawater intrusion. This method was particularly useful for identifying potential aquifers within the Quaternary limestones and assessing their suitability for water extraction.

4. Data and Results

Surface mapping and 1D resistivity study has been carried out resulting the following data. Lithologically the Landu Island is underlain by slightly southward tilted, karstified, Quaternary Limestones. These limestones are composed primarily of fossiliferous materials, including coral fragments, mollusk shells, and foraminifera. The presence of well-preserved reef structures, such as branching and massive coral colonies, indicates their deposition in shallow marine environments during periods of sea-level highstands.

Stratigraphically, the coral terraces unconformably overlie older Gondwana Sequence rocks and synorogenic deposits (exposed in Rote Island). The terraces are sequentially arranged, with older formations at higher elevations and younger ones closer to present sea level. This arrangement reflects progressive tectonic uplift. The highest terraces, reaching elevations of up to 80 meters in Landu Island and 200 meters in Rote Island, provide key evidence for the rapid vertical movement of the island during the ongoing arc-continent collision.

4.1 Water Spring

Water spring mapping result around the island is compiled in the Table 1.. One freshwater spring was identified in the southeast corner of the island, has been the resource for fresh water (TDS: 924 ppm, PH: 7.85) for the Landu Island inhabitants. Other spring locations found in the island indicating high TDS and PH > 7).

4.2 Resistivity Survey Results

No operational wells were observed within the vicinity of the survey points, underscoring the need for exploratory drilling. In location PL 1-2 resistivity survey VES01 was carried out. The results indicate shallow aquifer was encountered, located at depths of 5.24–17.2 m with a resistivity of 8.91 Ωm, indicative of saturated porous limestone. At slightly deeper depth, another zone of the aquifer is identified at 35.1–92.1 m depth with a resistivity of 8.21 Ωm, suggesting a significant groundwater reservoir.

Fig 2. Resistivity survey location in Landu Island (yellow pin near PL-1-2 (Table 1).

Table 1. Water spring location around Landu Island, Rote.

Code	Coordinate		Elevation	Remarks
	x	y		
PL-1-2	496006	8792470	18	Spring that connect to a well @Depth of 108 meter TDS: 924 ppm Water Temperature: 288 C EC: -241 mV pH: 785
PL-2-2	494169	8792061	28	Spring next to a lake coming out from karstified limestones TDS: 3999 ppm Water Temperature: 285 C EC: -30 mV pH: 8
PL-3-1	496373	8792774	16	Water in public well brackish water TDS: 3999 ppm Water Temperature: 29 C EC: -386 mV pH: 81
PL-3-2	496257	8792768	16	Water in public well brackish water TDS: 3999 ppm Water Temperature: 252 C EC: -285 mV pH: 793
PL-4-1	495787	8792522	42	Local depression catchment area for mini dam Length: 25m Height: 2m

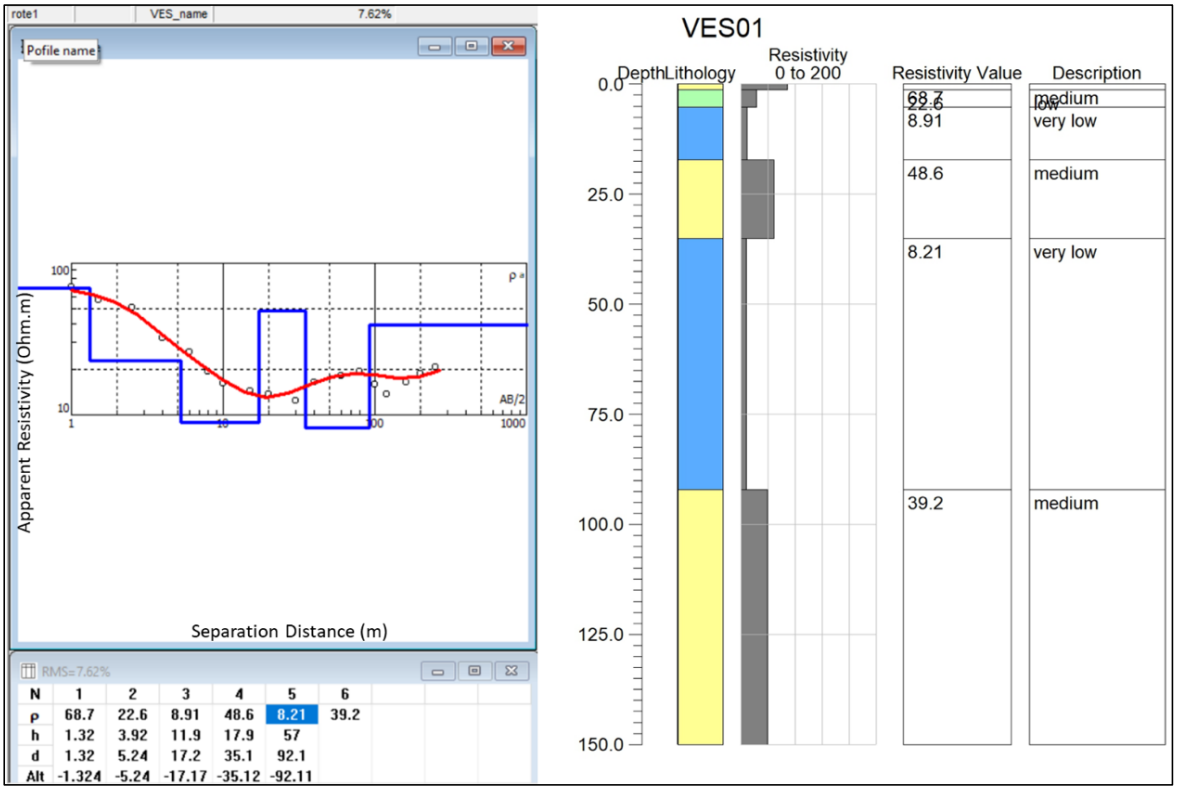

Fig 3. Results from VES01 survey location showing two intervals of saturated aquifer zone, one at shallow less than 5 meters deep from the nearby spring and the other at depth between 35 to 92 meters respectively

5. Discussion

Published ages from radiometric dating methods, such as U-series dating, have been used to determine the ages of these terraces. Results show they formed during the late Quaternary, correlating with interglacial periods when global sea levels were relatively stable. The distinct layering of terraces indicates episodic uplift events, likely associated with thrusting and seismic activity along faults in the Banda Arc system (Roosmawati and Harris, 2009).

Morphologically, the terraces exhibit features like wave-cut notches, reef flats, and seaward-dipping profiles, which are characteristic of coral reef systems exposed during sea-level regression and subsequent tectonic uplift. These features serve as paleo-horizontal markers, enabling the reconstruction of uplift rates and deformation patterns.

The coral terraces of Rote Island not only provide a record of geological processes but also offer insights into the interaction between global sea-level changes and local tectonic dynamics. Its uplift history play a pivotal roles in the karstification process on the limestones. The quaternary limestones are dipping gently to the south as a result of uplift on the northern side. This condition resulted in localised freshwater spring in Landu Village.

It appears that the freshwater in local spring influenced by the surface accumulation of water in the nearby depression (Figure 4). Fresh water only reach up to 5 meter below surface in the spring location as the resistivity suggest that there is a change in resistivity value. It is interpreted that the changes in resistivity resulted from the saltwater contamination at sea level as observed in few places including the salt water lake at the centre of the island.(Figure 4).

Another aquifer is identified at depth ranges from 35 – 92 meters as suggested by the resistivity reading. This is interpreted to be controlled by the regional dip of the limestones (Figure 5). In the main Rote Island, the nearby shorelines have numerous freshwater sources.

Fig 4. Measurements of saltwater lake of Landu Island that surrounded is surrounded by the karstified quaternary limestones. Measurement result is in PL-2-2 location in Table 1.

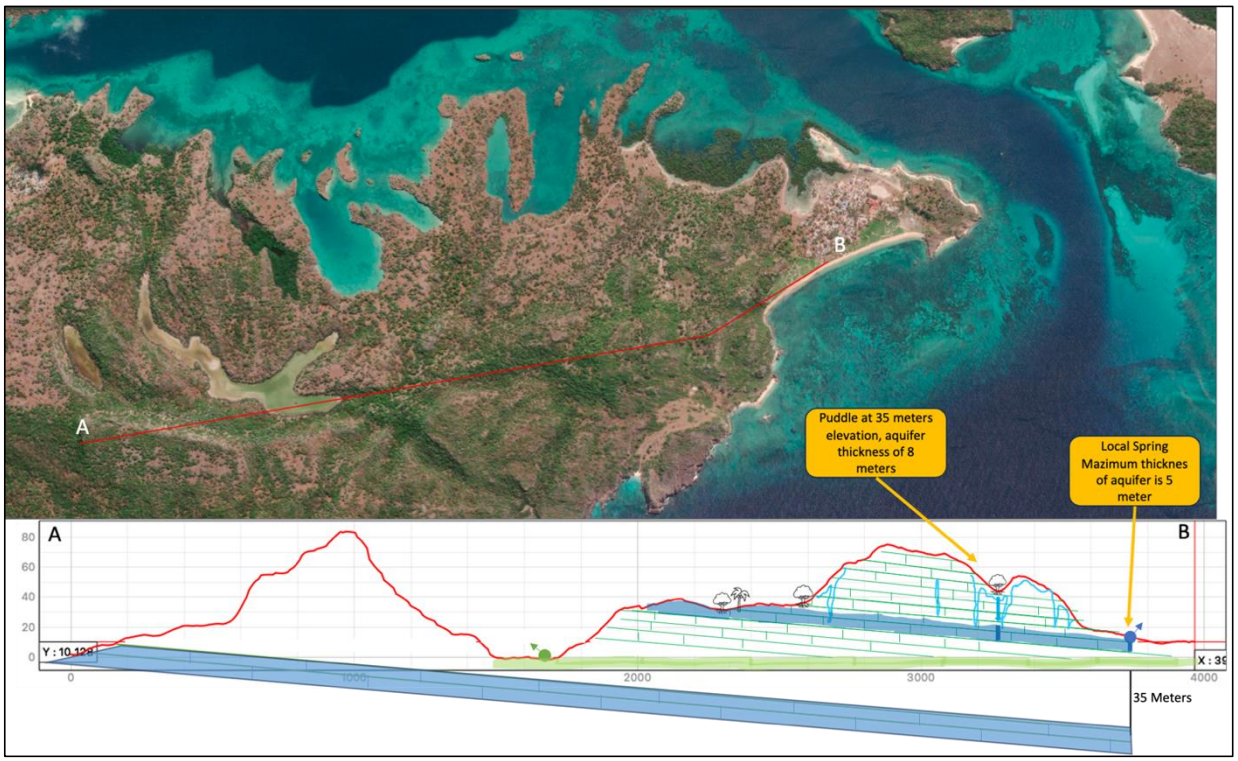

Fig 5. E-W geological cross section in Landu Village showing gently dipping Quaternary Carbonates. It is interpreted that the shallow fresh water aquifer in Landu Village sourced from very limited area to the west of the village. It is vulnerable to salt water intrusions

The occurence of salt water bearing layers of the limestones is interpreted due to the karstified nature of the limestone that permits fluids to enter and dsitributed accros the layers. However, the resisitivity also suggest that there are layers of tighter older limestones in the subsurface that may not have been exposed and karstified as compared to the upper layers. Therefore, the saltwater can only penetrate the uppermost near surface limestones (Figure 5). It is interesting to see whether these older limestone layers are still of Quaternary ages or perhaps much older as it will define the hydrogeology of the area, especially representing the hydrogeology of small island bounded by seas.

Another important aspect is that the distribution of flat terrain as also illustrated with occurence of trees in Figure 5 to hold the potential of holding water in the surface just enough time to be able to penetrate the karstified limestones. These areas need to be preserved, perhaps by planting more trees. Moreover, the outlet of these flat areas / basins could also be blocked by small dam to conserve the water in the surface and minimise the soil erosion from the movement of the surface water.

6. Conclusions

The geological and hydrogeological investigation of Landu Island, situated within the tectonically active Banda Arc system, provides valuable insights into the interplay between arc-continent collision, karst processes, and freshwater resource distribution. The island's geological framework, dominated by gently southward-dipping Quaternary limestones, reflects a dynamic tectonic history marked by uplift associated with the ongoing collision between the Australian and Eurasian plates. This tectonic activity has shaped the island's morphology, as evidenced by elevated coral terraces and localized deformation structures.

Surface geological mapping and 1D resistivity surveys reveal the presence of two primary groundwater-bearing zones: a shallow aquifer system located within 5–17 meters depth, and a deeper potential aquifer between 35–92 meters. The shallow aquifer, which feeds the only known freshwater spring in the southeast of the island, is vulnerable to saltwater intrusion, likely driven by sea-level proximity, limited recharge, and the highly karstified nature of the host limestone. The deeper aquifer shows promise for water extraction, though further validation through exploratory drilling is necessary.

Generally, small islands have very limited freshwater resources, making water balance studies particularly important in these settings. However, in the case of Landu Island, geological and geophysical evidence suggests that the subsurface may still be connected to the mainland. This connection could explain the occurrence of a deeper aquifer, which presents an alternative opportunity for freshwater sourcing by the Landu community. Nevertheless, accessing this deep groundwater system requires caution. Detailed subsurface investigations, including logging while drilling, are critical to accurately delineate the aquifer zone and avoid overexploitation or unintended contamination. It is to be noted that when such drilling carried out, the drilling process should consider put casing between 5,24 – 17.2 meters as it is indicated a potentially wet aquifer. However, the occurence of inland saline lake at the sea level could suggest salt water intrusion that may altered the water quality and availability.

This study underscores the role of tectonic uplift in shaping karst development and controlling freshwater availability in small island environments. It also highlights the importance of integrating geophysical techniques and geological mapping in groundwater exploration. Ultimately, these findings reinforce the urgent need for sustainable and well-informed water resource management strategies,

particularly in tectonically complex and environmentally sensitive regions like Landu Island.

Acknowledgements

Authors would like to thank FITB for the 2023 research collaboration funding and DRPM ITB for the community development program 2023 funding that make the fieldworks and analyses for this paper possible.

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