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Geology and Land Suitability Analysis for Final Processing Waste Site in Ambon Island

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ABSTRACT

The production of waste in Ambon City increased from 200 tons per day to 297 tons per day between 2017 and 2021, yet the state of the Toisapu landfill in Ambon did not keep up with this growth. The Toisapu landfill has been in operation since 2007, however, due to its proximity to residential areas and slope of more than 20 percent, it is currently in an overload state and requires a re-evaluation. The goal of this study is to identify a different landfill to replace the Toisapu landfill that fulfills the Indonesian National Standards and functions as a Waste Processing and Final Processing Site (TPPAS). This study combines an evaluation of the geological and non-geological parameters using an environmental geological technique called Spatial Multi-Criteria Evaluation (SMCE). In order to determine the most possible land, the study findings for each parameter are superimposed, assigned a value, and then added together. According to the research's findings, Wakal, which has 126,668 hectares of land is the best option. Since the groundwater in this area is quite deep (>80 meters) and has low permeability, there is minimal possibility of leachate seepage contaminating the groundwater. Wakal, unlike the Toisapu landfill, is located far from inhabited areas and protected forests, with a slope of less than 20%.

Keywords: Ambon Island, waste, environmental geology, SMCE, waste processing, final processing.

INTRODUCTION

Ambon Island, which is made up of Central Maluku Regency and Ambon City, has a continuously increasing population. [1]. Ambon City's population has increased from 371,650 in 2018 to 387,102 in 2020 [2], while Central Maluku Regency has about 135,079 inhabitants [3]. The amount of waste produced on the island has increased as a result of population growth [4]. The amount of waste collected in Ambon City has grown from 1,985.60 tons per day in 2019 to 2,084,000 tons in 2020 [5]. All the waste is taken to the Landfill (TPAS) in Toisapu, Ambon City [6]. However, the TPAS Toisapu has its shortcomings, as it is located in a highland area, causing leachate from the waste pile to flow into nearby rivers and potentially causing water pollution and skin diseases [7].

The TPAS is also in overload status due to heavy equipment damage, and it has just three years left in its use [8]. Therefore, there is an urge for further evaluation to determine the suitability of landfills in Ambon City, as well as the establishment of a new Waste Final Processing Site (TPPAS) that can provide services to urban communities, provide benefits to the surrounding communities, and extend the technical life of TPPAS [9]. This study aims to find an alternative replacement for the Toisapu landfill with the status of a Waste Processing and Final Processing Site (TPPAS) that complies with Indonesian National Standards (SNI).

Regional Structural Geology

The geology of Ambon Island is dominated by Ambon volcanic rocks (Tpav), which are believed to have been formed due to volcanic events in the Pliocene, around the Ambon granite intruded during Mesozoic and Upper Paleozoic rocks [10]. The tectonic processes that occurred during the Quaternary era were not as strong as during the Middle Miocene-Pliocene era [11]. This process caused the Pleistocene limestone to be uplifted by more than 350 m.

In general, Ambon Island's faults trend northwest to southeast. It is most likely the case that the fault system surrounding Ambon Island is a continuation of the left horizontal fault line that stretches across the eastern point of the Taunusa Mountains and from Soleman Bay.

METHODOLOGY

This research uses an environmental geology approach based on Spatial Multi-Criteria Evaluation (SMCE), which combines geological and non-geological parameters. In geological parameters, the most suitable land will be studied for its geological aspects, like permeability, surface and subsurface lithology, and geomorphology. Permeability was measured through the infiltration aspect using the single-ring method [16]. The infiltration rate on suitable ground is less than 10^{-9} cm/s.

A trench pit measuring 1 m^2 and dug to a depth of 2 m was used to observe the lithology, while Wenner configuration were applied for the subsurface [17], [18]. A low permeability subsurface is needed in TPPAS to inhibit the spread of leachate from waste [19]. The most important geomorphological element based on SNI is a slope of less than 20%.

The non-geological characteristics are based on the standard SNI 03-3241-1994. There are two stages applied for this parameter: regional and elimination stages. The regional stage produces a map containing several suitable alternative sites. The regional stage is carried out by overlaying each criterion on QGIS 3.24.1-Tisler. The input is several sets of maps: distance from faults, main rivers, highways, distance from airports, geological hazards (floods and tsunamis), protected forests, and slope (SNI 03-3241-1994) [12], [13]. Whereas, the elimination stage produces one suitable alternative site. Suitable alternative sites will be assessed at the elimination stage using a form that contains aspects of administrative area; land owner and capacity; the intensity of rain; road access; agriculture; and aesthetics [14], [15].

RESULTS AND DISCUSSION

Analysis of Land Suitability of Toisapu Landfill (Non-geological parameters only)

The analysis of land suitability started by analyzing the non-geological parameters. In the regional stage, some regional parameters were scored to meet the requirements of land suitability. The parameters were scored 0 or 1, where 1 indicates that the parameter meets the requirements.

The proposed area is located within 100 meters of faults, main river, and main roads. These conditions make the landfill area not located in geological hazard zones (flood and tsunami). The airport in the area is located far 3000 meters from the landfill. Unfortunately, the area is located in a protected area/nature reserve. The slope of the area is more than 20%. The parameters scoring is shown in Table 1.

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Table 1. Regional Stage of land suitability in Toisapu

No	Regional Parameters	Score
1	Within 100 meters of the Fault	1
2	100 meters away from Main River	1
3	Within 100 meters from Main Road	1
4	3000 meters away from Airport	1
5	Not located in Geological Hazard Zone (Flood)	1
6	Not located in Geological Hazard Zone (Tsunami)	1
7	Not located in a Protected Area/Nature Reserve	0
8	Slope Zone < 20%	0
	Total	6

The suitability of Toisapu Landfill was assessed in the regional parameter, with the highest score of 8, the lowest score of 0, and two classes required:

$$\text{Ki} = \frac{8-0}{2} = 4 \quad (1)$$

The suitability of the area was then determined by using the assessment. Values 0–4 are classified as not suitable, while 5–8 are suitable (Table 2). Toisapu landfill is still in the suitable category.

Table 2. Regional Classification of Toisapu Landfill

Grade	Value	Suitability Value
I	0 – 4	Not Suitable
II	5 – 8	Suitable

The land suitability assessment of the Toisapu landfill based on the elimination parameters in SNI follows Table 3. The assessment uses 16 categories, based on the administrative properties of the area. All the parameters are weighed and then calculated. The total number of values will determine if the area is suitable or not.

Table 3. Elimination Stage of land suitability in Toisapu

No	Elimination Parameters	Weight	Value	Total
1	Administrative Boundary	5	10	5
2	Landowner	3	7	21
3	Number of Landowners	3	10	30
4	Land Capacity	5	10	40
5	Community Participation	3	10	30
6	Flood hazard	2	10	20
7	Rain Intensity	3	1	30
8	Road to Site	5	10	5
9	Garbage Transport	5	10	5
10	Traffic	3	1	30
11	Land Use	5	5	25
12	Agriculture	3	8	24
13	Protected Area/Nature Reserve	2	10	20
14	Biological	3	1	30
15	Noise and Odor	2	1	20
16	Aesthetics	3	10	30
	Total			351

The suitability of Toisapu Landfill was assessed in the elimination parameter, with the highest score of 550, the lowest score of 55, and two classes required:

$$\text{Ki} = \frac{550-55}{2} = 247.5 \quad (2)$$

From the equation, the suitability of the area is then determined. Values 55–302 are classified as not suitable, while 303–550 are suitable (Table 4). Toisapu Landfill is still in the suitable category.

Table 4. Elimination classification of Toisapu Landfill

Grade	Value	Suitability Value
I	55 – 302	Not Suitable
II	303 – 550	Suitable

Analysis of Alternative Land Suitability of Final Waste Processing Sites in Ambon

After all the maps are overlaid, given a value, and sum, this stage produced the two best alternative sites in Hitu (127.085 ha) and Wakal (126.668 ha). In the elimination stage, it shows that Wakal is the most suitable alternative site based on the SNI. The calculations can be seen in Tables 5 and 6.

Table 5. Elimination Stage of land suitability in Hitu

Location: Hitu
Area: 127.058 Ha

No	Elimination Parameters	Weight	Value	Total
1	Administrative Boundary	5	1	5
2	Landowner	3	10	30
3	Number of Landowners	3	10	30
4	Land Capacity	5	10	50
5	Community Participation	3	1	3
6	Flood hazard	2	10	20
7	Rain Intensity	3	10	30
8	Road to Site	5	1	5
9	Garbage Transport	5	1	5
10	Traffic	3	10	30
11	Land Use	5	5	25
12	Agriculture	3	1	3
13	Protected Area/Nature Reserve	2	10	20
14	Biological	3	10	30
15	Noise and Odor	2	10	20
16	Aesthetics	3	10	30
	Total			336

Table 6. Elimination Stage of land suitability in Wakal

Location: Wakal
Area: 126.668 Ha

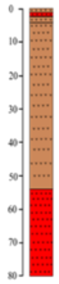
No	Elimination Parameters	Weight	Value	Total
1	Administrative Boundary	5	1	5
2	Landowner	3	10	30
3	Number of Landowners	3	10	30
4	Land Capacity	5	10	50
5	Community Participation	3	1	3
6	Flood hazard	2	10	20
7	Rain Intensity	3	10	30
8	Road to Site	5	10	50
9	Garbage Transport	5	10	50
10	Traffic	3	10	30
11	Land Use	5	5	25
12	Agriculture	3	10	30
13	Protected Area/Nature Reserve	2	10	20
14	Biological	3	10	30
15	Noise and Odor	2	10	20
16	Aesthetics	3	10	30
	Total			453

Geological Stage

Based on 8 one-ring measurement plots, 6 plots need more than 2 hours to decrease for 1 cm, so the permeability is $<10^{-9}\ ^{cm}/_{s}$. Less permeability means less harmful the leachate for groundwater quality.

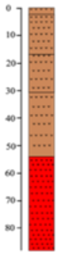
The trench pit shows contact between weathered limestone and Ambon volcanic rocks. The soil color changes from black to red and white, with black soil resulting from limestone weathering and reacting with HCl. The layer of limestone weathering is decreasing to the southeast, as depicted on the regional geological map of Ambon Island scale 1: 25,000 [10]. The results of lithology measurements are presented in Figure 1 to Figure 5.

Lithology in the form of soil formed by the weathering of Ambon volcanic rock and reef limestone was discovered at the proper TPPAS location. Andesite from the Ambon volcanic rock formation, which was created by Pliocene volcanic activity, is the oldest lithology found in the area [10].



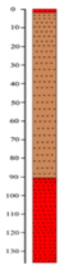
Depth 1	Depth 2	Resistivity	Lithology	Status
0	1	37.48	Top Soil (Tuff)	Top Soil
1	2.34	238.47	Andesite Lava	Aquifug
2.34	4.72	4.00	Fine Tuff	Aquiclude
4.72	62	25.64	Fine Tuff	Aquiclude
62	80	128.65	Andesite Lava	Aquifug

Figure 1. Electrical Resistivity Interpretation GL-HW-01



Depth 1	Depth 2	Resistivity	Lithology	Status
0	1.71	80.35	Top Soil (Tuff)	Top Soil
1.71	16.7	18.553	Fine Tuff	Aquifug
16.7	29.4	54.95	Fine Tuff	Aquiclude
29.4	62.9	4.22	Fine Tuff	Aquiclude
62.9	80	804.44	Andesite Lava	Aquifug

Figure 2. Electrical Resistivity Interpretation GL-HW-02



Depth 1	Depth 2	Resistivity	Lithology	Status
0	2.04	121.31	Top Soil (Tuff)	Top Soil
2.04	74.1	13.12	Fine Tuff	Aquiclude
74.1	130	4963.41	Andesite Lava	Aquifug

Figure 3. Electrical Resistivity Interpretation GL-HW-03

The disintegration of the reef limestone above the Ambon volcanic rock accounts for the only exposure of the andesite (Ambon volcanic rock) lithology, in addition to the minerals' natural weathering. At 200–250 meters above sea level, limestone lithology can be discovered. Its thickness in a trench pit is between 10 and 15 cm. Weathered soil is another type of lithology seen at appropriate TPPAS locations. This happens as a result of the substantial influence that the abundant vegetation has on it. The somewhat worn limestone outcrop by the side of the road that leads to the TPPAS viable location is another example of this. Numerous fibrous tree roots that are securely linked to the outcrop's body are seen in these outcrops. Although tectonic events leading to elevation occurred throughout the Quaternary, the Reef Limestone was deposited in a shallow marine environment. The unconformably layered limestone that covers the volcanic rocks of Ambon is believed to date from the Upper Pleistocene to the Holocene [10].

Based on morphology (Figure 6), morphometry (Figure 7), and morphogenetic aspects (Figure 8), geomorphological conditions at the location are divided into Denudational Sedimentary Flat Unit and Denudational Sedimentary Undulating Unit (Table 7, Figure 9) [20], [21]. The first geomorphological unit dominates all TPPAS feasible locations, around 95% of all locations. This unit is found in the Wakal Forest, Central Maluku Regency. This unit has a low hilly landform, a rectangular drainage pattern, and sparse contour density. The U-shaped valley with erosion is very dominant. This unit has an elevation of 100 – 200 meters above sea level with a slope of 0 – 10%. This unit is composed of limestone that has experienced weathering and erosion. The combination of stratigraphy, geomorphology, lithology, and non-geological aspects’s final scores support that the Wakal area is suitable as a proposed landfill equipped with TPPAS function, in the future.

Table 7. Geomorphology units of the suitable land for TPPAS in Ambon

Geomorpho-logical Units	**Symbol**	**Geomorphological Characteristics**								
		Morphography		**Morphometry**				**Morphogenetics**		
		Flow Pattern	**Landform**	**Valley Shape**	**Elevation (masl)**	**Slope (°)**	**Slope (%)**	**Lithology**	**Exogen**	**Endogen**
Denudational Sedimentary Flat Unit		Rectangular	Flat	U	100-200	0-10	0-10	Limestone, Andesite	Weathering, Erosion	Tectonic
Denudational Sedimentary Undulating Unit		Rectangular	Undulating	U	200-500	10-30	10-20	Limestone, Andesite	Weathering, Erosion	Tectonic

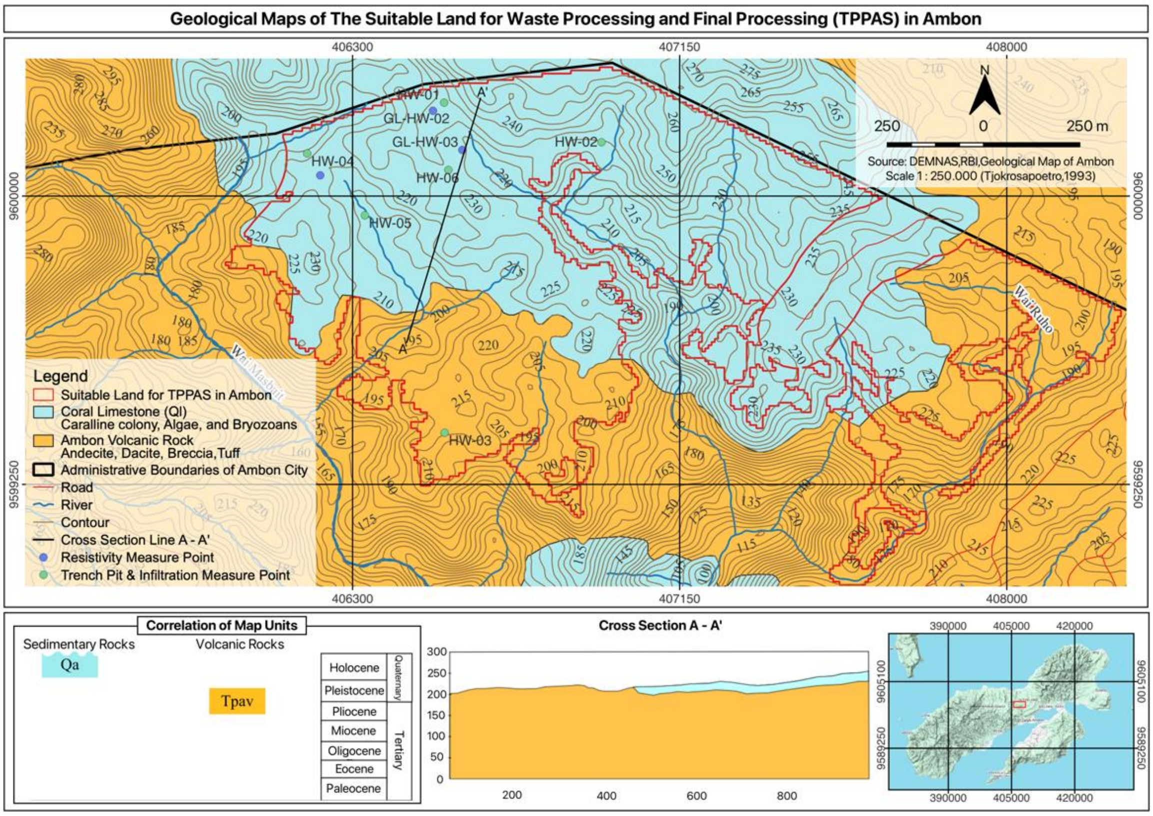


Figure 4. Geological map of the suitable alternative land for TPPAS in Ambon

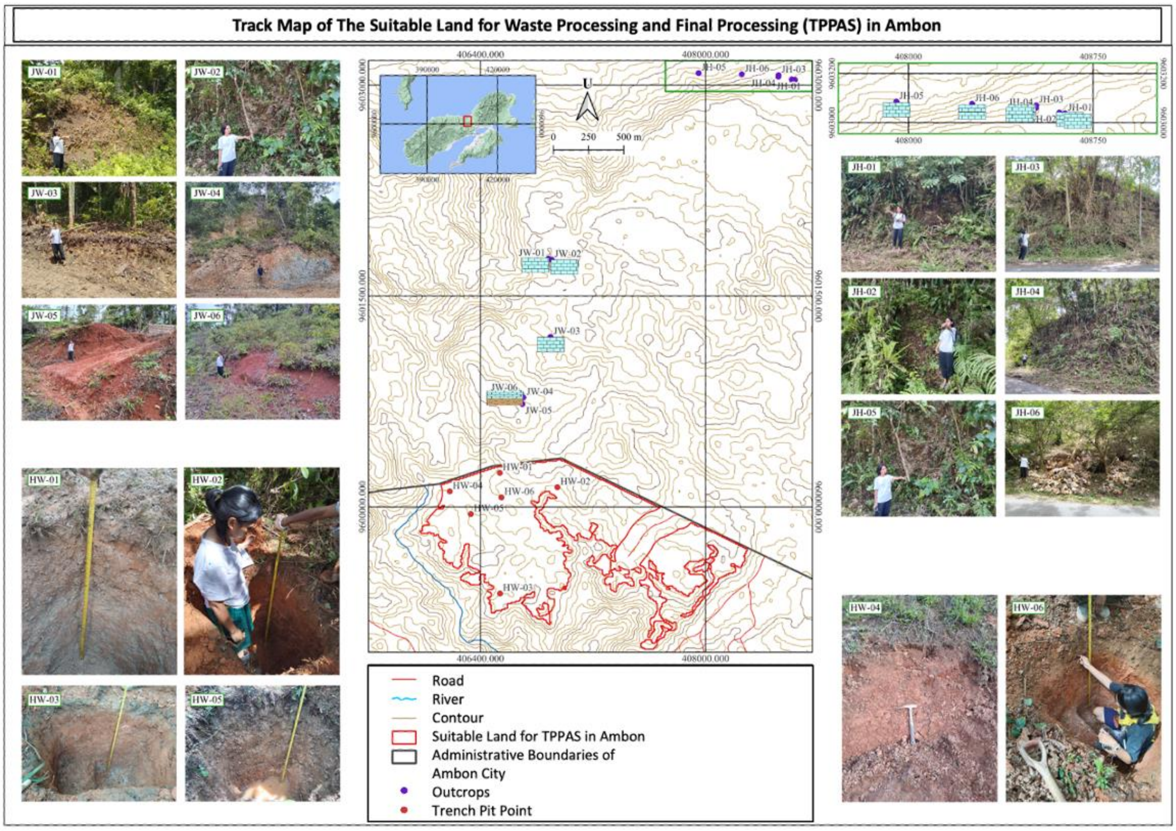


Figure 5. Track map of the suitable alternative land for TPPAS in Ambon

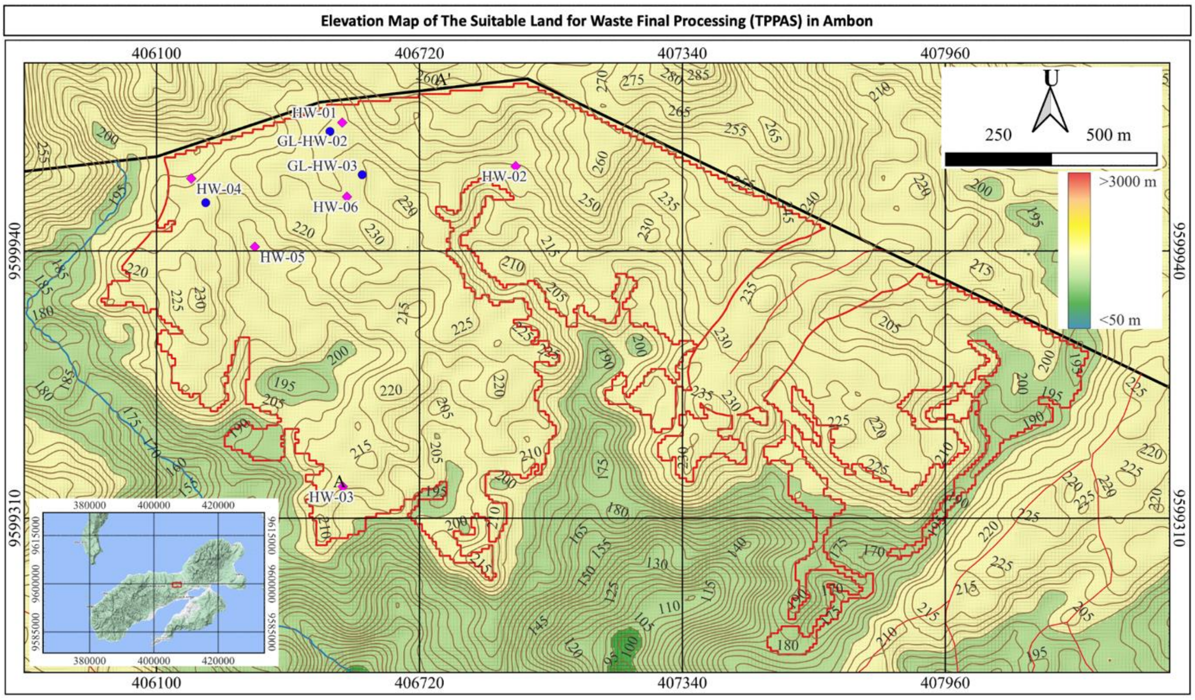


Figure 6. Elevation map of the suitable alternative land for TPPAS in Ambon

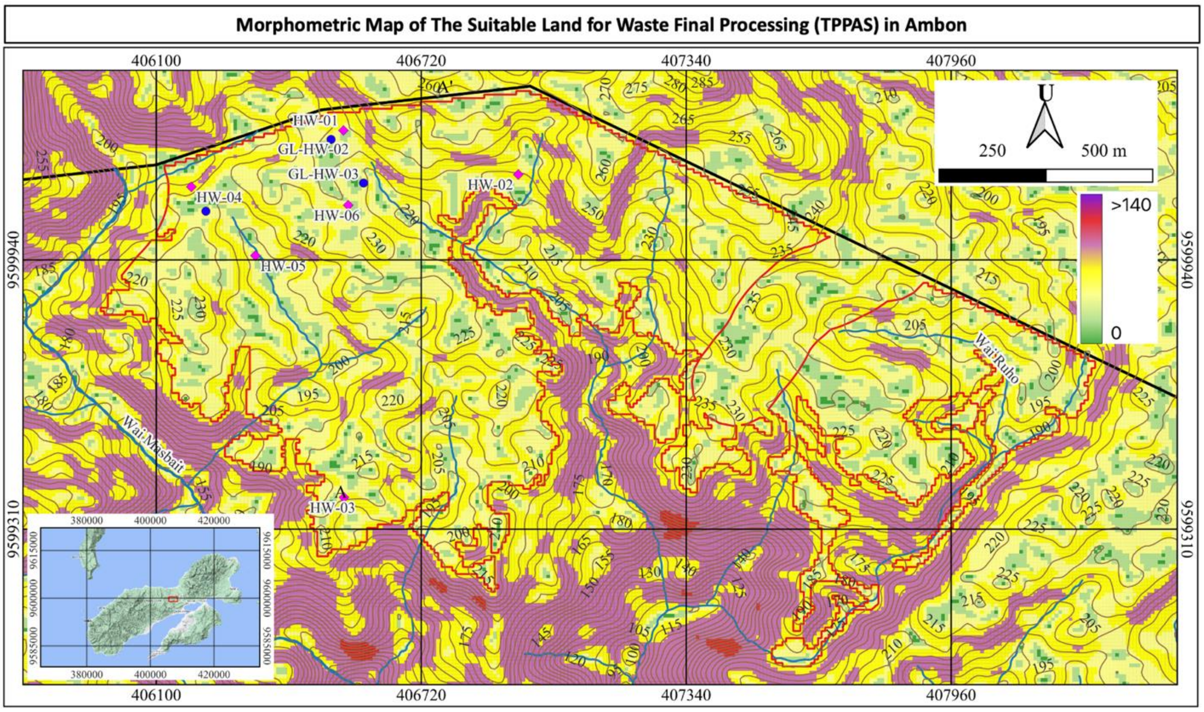


Figure 7. Morphometric map of the suitable alternative land for TPPAS in Ambon

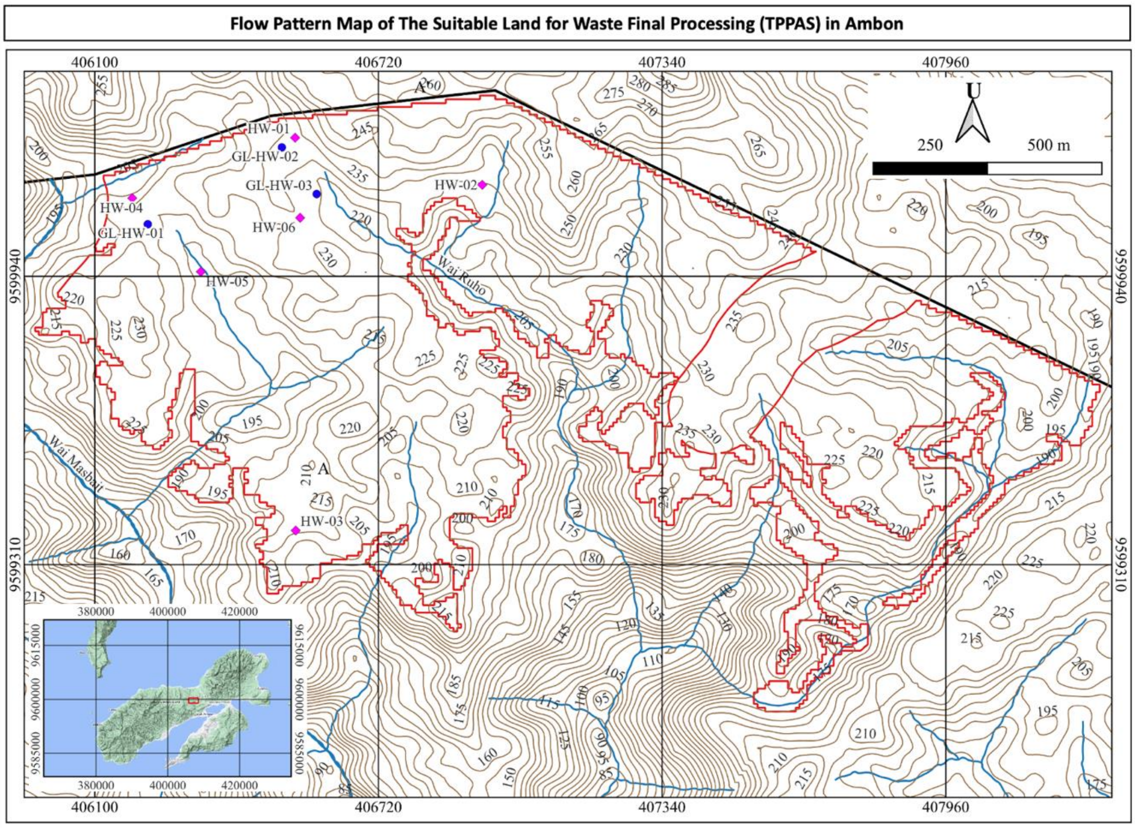


Figure 8. Flow pattern map of the suitable alternative land for TPPAS in Ambon

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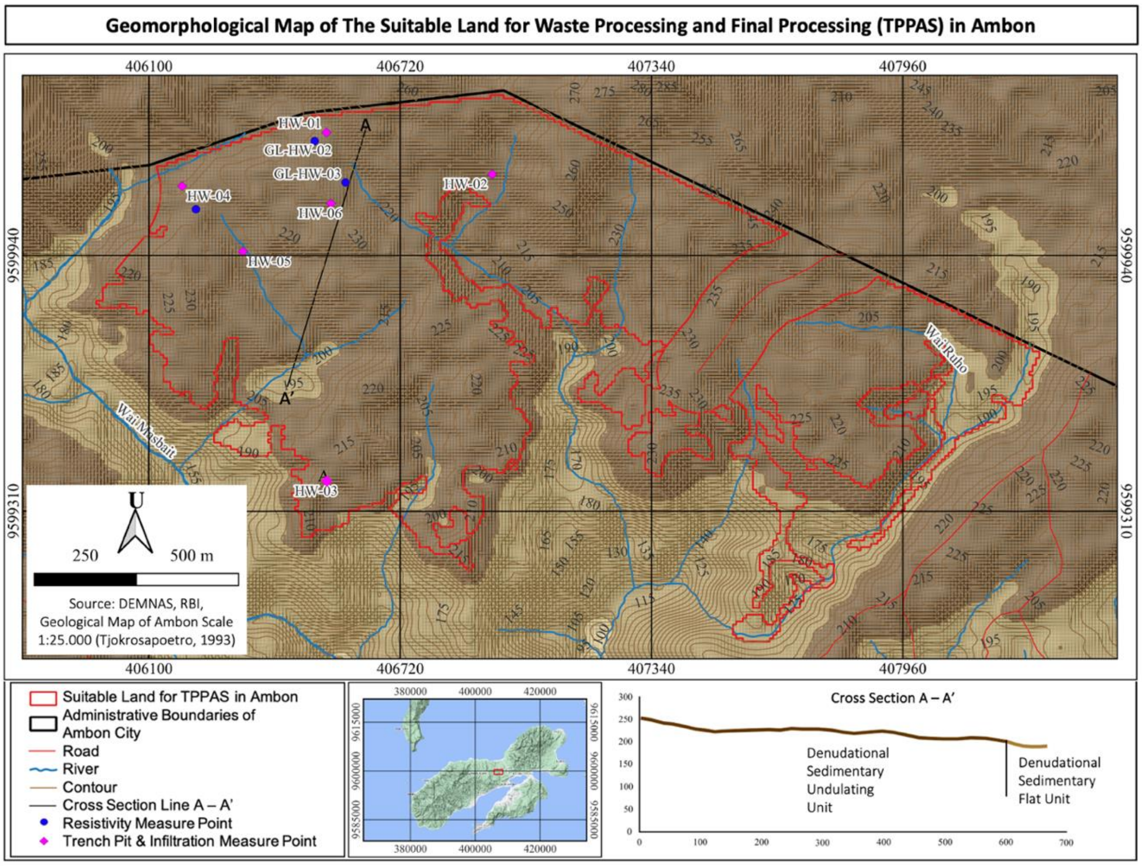

Figure 9. Geomorphological map of the suitable alternative land for TPPAS in Ambon

CONCLUSION

Toisapu Landfill is still considered practical even though it does not yet meet all SNI requirements. It is vital to hunt for replacement land because its use period is about to expire in three years. A larger TPPAS that can handle trash from all across Ambon Island will be created using the alternate land. At a depth of between 0 and 130 meters, the weathered limestone and volcanic rock lithology of Wakal's 126,668 hectares operate as an aquifuge and aquiclude, preventing leachate from moving. According to SNI, Wakal has a geomorphological slope of less than 20%, making it a good choice for a new TPPAS location.

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