Case Study

Environmental geology assessment on the regional Pitay landfill site: a case study in Kupang, Indonesia

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Abstract

The Provincial Government of East Nusa Tenggara of Eastern Indonesia has intended to construct a new regional landfill site in Pitay–Kupang, which would accommodate municipal waste of two cities. Considering that environmental degradation in landfill sites has been a substantial issue for many developing cities in Indonesia, this study evaluates the pre-determined site on a local scale based on environmental geology parameters. It employs a conventional Geographical Information System based—Multi-Criteria Decision Analysis (GIS-MCDA) method which is based on the analysis of regional criterion, assessed by expressing values on each parameter presented on thematic maps and overlaid altogether as a screening process, and the exclusion criterion analysis, which sets a buffer zone to filter out irrelevant locations. The regional criterion parameters are: Lithology, groundwater depth, slope gradient and rainfall intensity, whilst the exclusion criterion parameters are: Distance from rivers and lakes, shorelines, settlements, main roads, airports and protected areas, distance from potential geological hazards such as fault zones, floods and mass movements, and distance from any geological potential which may be developed in the future. The biggest area reduction for suitable landfill site candidate is lithology, correlating with groundwater depths, and distance from rivers. Here we identified four potential sites located west and centre of Pitay, situated on Bobonaro scaly clay lithology unit, arguably possessing no groundwater with a slope gradient of 0–20%, rainfall intensity below 1000 mm, and is distant from any potential hazards, promising geological resources and other unfavorable criteria relating to environmental degradation.

Keywords GIS · MCDA · Landfill · Environmental geology · Site selection

1 Introduction

The lack of environmental assessment on the government's developing program on the construction of landfill sites would often lead to future problems. Besides political and social considerations, landfill development plans may be disadvantageous for the public health, ecology and the environment. This is shown in the case of the unlined municipal waste landfill in Alak–Kupang constructed in 1998, situating on a Quaternary coral limestone lithology [1]. Environmental assessments for infrastructural development are still scarce in East Nusa Tenggara, especially

in the late 1990s and early 2000s where environmental awareness was limited. Although only a few studies have been conducted to evaluate the social and livestock impacts on this site [2–4], there are no known investigations on its environmental impact. It would likely lead to future issues as these limestone possess a karst hydrology system with extensive dissolution processes, therefore may potentially develop numerous underground channels where groundwater flows in these conduits [5, 6], enlarging the probability of the infiltration of leachate, leading to groundwater contamination. Likewise the majority of landfills in Indonesia, the Alak Landfill still operates with an

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open dump system, which was forbidden by the nation's waste law (Indonesian Laws No. 18, 2008, Article 44), however, the implementation of such law may encounter problems due to local limitations, therefore a strong environment and geological assessment in landfill site selection remains vital [7, 8].

Oelamasi was appointed as the Capital of Kupang Regency in 2006 (Government Regulation No.3 2006). A new urban area will surely increase the amount of waste produced. The closest landfill is located in Alak, approximately 43 km away from Oelamasi. With an increasing amount of wastes entering the Alak Landfill, in a few years' time, it would no longer bear the wastes of both cities. The East Nusa Tenggara Provincial Government has determined Pitay, in the District of Sulamu, as the area suitable for the new location of the Regional Waste Landfill (Unpublished report from the Provincial Government 2008) and has been specified in the spatial and regional planning of the Kupang Regency (Unpublished report from BAPEDA, Kupang Regency 2010). The location was determined based on a regional scale evaluation of the SNI 03-3241-1994 regulation concerning the Landfill Site Selection Procedures determined by the Ministry of Public Works of Indonesia.

Methods on determining landfill sites have been extensively discussed [9–13], nonetheless, major issues concerning environmental degradation in Indonesia's landfill sites are still widely reported [14–18]. Most of these issues relate to groundwater contamination or are subject to geological principles. It occurs conceivably due to inadequate thorough considerations of geological principles, thus some areas may be considered inappropriate for landfill sites. Therefore the pre-determined Pitay landfill will be assessed specifically with environmental geology parameters to determine its feasibility as a potential regional Landfill Site. Geological information can be applied in various aspects of land use planning as it comprises fundamental aspects which maximize the advantageous potential for development, assessed by its physical characteristics with the aid of geological principles. This study integrates the national regulation with environmental geology parameters, hence emphasizing on decreasing the environmental degradation based on geological principles for sustainable development.

2 Methodology

The methods used in this study comprises a conventional geographical information system (GIS) based—multi-criteria decision analysis (MCDA) [19], whilst considering the national standard of landfill site selection. There is no specific standard issued on the determination of a

regional landfill site, as the Indonesian National Standard (SNI 03-3241-1994) may be suitable for a municipal scale [20]. The GIS-based MCDA method has been a favorable approach for many landfill site selection studies [10, 21, 22].

MCDA is effective for evaluating multiple parameters relevant for decision making. Two MCDA methods were used; weighted linear combination (WLC), or also known as simple additive weighting (SAW), and analytical hierarchy process (AHP). WLC is applied by assigning scoring weights of each parameter based on its importance (in the form of maps). Each parameter has an alternative unit (attribute) where each is given a value based on its suitability. The evaluation score is calculated by multiplying each unit's value with the parameter's weighting score. The overall score of all alternatives are summed, and the one with the highest score is chosen. Each parameter is assigned on raster-based GIS overlaying process which filters out the least favorable option.

$$S_i = \sum_j^n w_j \times x_j$$

where S = suitability level of the landfill site (i), w_j = parameter score weighting (j), x_j = parameter score (j), n, j = amount of parameters. The analytical hierarchy process (AHP) [23] is often used in complex decision makings by establishing priorities of each parameter and making a pairwise comparison based on the importance of its utmost intention, which is in this case for landfill site selection [12, 24]. AHP is an efficient approach to quantify the qualitative factors and comparing the relative importance of each parameter [25].

The parameters selected for the landfill site selection are based on the adjustment and integration of the nation's standard landfill site selection procedure (SNI 03-3241-1994). The national standard is primarily based on the analysis of three criteria, which are; (1) regional criterion, (2) exclusion criterion, and (3) determination criterion. The regional criterion is used to map the region into potential zones, classified based on its geological and hydrological conditions, slope, distance to airports, nature preserves, and a 25-year periodical flood, whereas the exclusion criterion produces 2–3 potential sites whilst excluding other alternatives by supplementary parameters, including climate, utility, biological environment, soil conditions, demography, administrative boundary, noise and odor pollution, aesthetics, and economy. The determination criterion requires the approval and confirmation of the alternative sites by a relevant institution based on its local policy, in which here is the provincial government.

The parameters selected here are adjusted and emphasized on geological information. The results of each

location are grouped into zones of 4 feasibility levels: not feasible (0–18), low feasibility (19–36), medium feasibility (37–55), and high feasibility (56–70). The determined parameters are presented on thematic maps and overlaid as a screening process using ArcGIS, as it can manage a wide range and multiple spatial datasets (Fig. 1). Each score is summed, resulting in a range of total scores in which the level of feasibility is presented. Most thematic maps are accumulated from the local governmental archive and various literature, however, if such data is limited, it is necessary to produce new maps, which, in this study the slope map, generated by developing a raster layer from 30 m digital elevation map (DEM) simultaneously that categorize the slope gradient, and the geological potential map, which is a combination of old government documents, gathering information from the locals, and a brief field observation to locate any possible geological potential.

3 Results and discussions

There are 14 parameters chosen for the study, which are categorized into regional analysis and exclusion analysis. The regional analysis is assessed by expressing values on each parameter, whilst the exclusion criterion sets a buffer zone to filter out irrelevant locations (Table 1). The regional parameters consist of lithology, groundwater depth, slope gradient, and rainfall intensity, whereas the exclusion parameters are; distance from fault zones, mass movements, flood vulnerability, distance from rivers and lakes, distance from shorelines and potential geological resources, distance from settlements, protected areas,

distance from main roads, and distance from airports. The regional parameters classify zones of potential through a screening process, where the result is then overlaid by various exclusion parameters, eliminating unwanted sites, thus producing the final map that outlines the potential zones (Fig. 1).

For the purpose of this study, two villages will be assessed, considering that Pantai Beringin (situated east of Pitay) was part of Pitay before the regulation in 2005 to split the region into two separate villages.

3.1 Lithology

The lithology of an area helps to avoid or decrease the contamination of surface and groundwater from leachates. The permeability, filtration ability and the absorbent of certain rocks are majorly important in assessing the feasibility of the landfill site. Generally, consolidated fine-grained materials have lower permeability than coarse-grained rocks, whilst karts and alluvial areas tend to have cavities and bigger permeability. This criterion may also be supported by the installation of landfill liner, which will act as a low permeable barrier.

There are five lithological units in Pitay presented in a recent regional geological map produced in 2013 [26] (Fig. 2), where the assessed value for each lithology is presented in Table 1. This map was interpreted by the integration of Landsat 7 ETM + RGB 457 image and TerraSAR-X, whilst referencing the previous regional geological map issued in 1979 [1]. The units reported here are Cablac limestone, Bobonaro scaly clay, Noele sandy marl, Quaternary limestone, Quaternary silt/clay, and several huge randomly distributed unidentified rock unit, which may represent

Fig. 1 Screening process of regional criterion which overlays the exclusion criterion leading to the elimination of unwanted candidate, thus leading to clusters of potential sites, presented in the final map

Table 1 Environmental geology parameters comprising of regional and exclusion criterion

No	Parameters	Units	Value	Weight	Score
Regional criterion					
1	Lithology	Bobonaro scaly clay	5	5	25
		Quaternary silt/clay	4		20
		Noele sandy marl	3		15
		Exotic blocks	2		10
		Cablac limestone	0		0
		Quaternary limestone	0		0
2	Groundwater depth	No groundwater	5	4	20
		Medium to deep	3		12
		Shallow	1		4
3	Slope gradient	0–20%	5	3	15
		20–40%	3		9
		40–100%	0		0
4	Rainfall	0–1000 mm/year	5	2	10
		1000–2000 mm/year	4		8
		2000–3000 mm/year	3		6
		> 3000 mm/year	2		4
Exclusion criterion					
5	Distance from fault zones	< 100 m	–	–	Not feasible
6	Floods	< 25 years	–	–	Not feasible
7	Mass movements	Medium–high	–	–	Not feasible
8	Distance from rivers and lakes	< 150 m	–	–	Not feasible
9	Shoreline	< 500 m	–	–	Not feasible
10	Protected areas	Protected forest, nature reserves, etc	–	–	Not feasible
11	Distance from settlements	< 300 m	–	–	Not feasible
12	Distance from main roads	< 150 m	–	–	Not feasible
13	Distance from airports	< 3000 m	–	–	Not feasible
14	Potential Geological Resources	Water, mineral and energy	–	–	Not feasible

Modified from SNI 03-3241-1994

the exotic blocks of the Bobonaro Scaly Clay mélange [27]. These blocks are of different types, and is chaotic and randomly oriented. They vary in size from silt particle grade particles to blocks more than 0.5 km long, and vary in age from pre-Permian to Lower Miocene [27].

The oldest unit is the Cablac limestone, consisting of Peloid and Oolitic limestone, calcilutite, and carbonate pelagite ranging from Upper Triassic to Lower Miocene [28, 29]. This unit is dominant in Nuaf Fatuwehendak, situated NE of Pitay which has potential marl resources (Unpublished report from the Department of Mining, Kupang Regency 2001). One of the youngest units of the sequence is the coral limestone (Quaternary) which varies in color, often seen as white, yellowish or reddish and some are in forms of marly limestones, and at times developed as reefal limestone with a rough surface caused by cavities [1]. This unit is exposed mainly to the coast, southwest of Pitay, forming a gentle slope terrain and possesses a relatively deep groundwater table.

Field observation indicates both units forming a karst topography, familiar with the ones in Kupang [5], therefore extra attention is in need if it is selected for landfill construction, considering engineering factors due to its instability in the presence of cavities and its highly fractured nature may support groundwater contamination [30–33]. Both units are considered the least favorable for the landfill site emplacement.

The Bobonaro scaly clay unit [1, 27] consists of scaly clays with fragments of chaotic rock. This unit is distributed equally in Pitay with its exotic blocks, commonly found in gentle slope terrains. Field observation shows the surface rocks consist of siltstone, silty clay and low permeable compacted clay. Natural clay can adequately protect from landfill contaminants [34–36], therefore it would be a favorable unit for the site. The exotic materials within the clay (exposed as isolated hills) is potentially a product of olistostrome [27], mélange [37] or shale diapirism [38] which has undergone multiple tectonic deformations and

Fig. 2 Lithology map of Pitay, from Suwijanto (2013) and Rosidi et al. (1979) [1, 26]

has relatively high erodability [27], therefore may be fairly fractured like most alienated rock fragments in Timor.

The Noele dominates the southwestern part of Pitay. This unit consists of sandy marl interbedded with sandstone, conglomerate and dacite tuff [1]. These lithologies may considerably be suitable for the landfill site. Similarly, the Quaternary silt/clay unit is located SE of Pitay, near the coastal plains and salt evaporation ponds used for salt harvesting by the locals of Pitay and Pariti. This newly deposited unit consists of soils composing saturated silt and clay, which can be considered for the site emplacement.

3.2 Groundwater depth

Shallow groundwater tends to be predominantly exposed to contamination compared to deeper ones. The lithology of the area act as reservoirs (groundwater bearers), or as conduits to the aquifer, therefore there tends to be a relation between the two parameters. However, the relation between rock types and groundwater depth does not necessarily exist as aquifer types and its extent beneath the

exposed surface rocks should be considered. The concern of this parameter lies in the existence of leachate, liquids collected at the bottom of the landfill caused by the percolation of precipitation and may potentially infiltrate and contaminate the aquifer. The huge demand for groundwater in these parts of the region makes the preservation of the aquifer's quality vital.

The majority of environmental issues for landfill site selection exists in this parameter. Numerous reports of groundwater contamination in the landfill lie in shallow groundwater aquifers [15–18]. Groundwater in Pitay generally exists in alluvial and low hill land units [39] (Fig. 3). It is classified into 3 zones; shallow groundwater and medium groundwater, and no groundwater. It is obvious that the regional hydrogeological map [39] was generated by intensely referring to the regional geology map [1].

The shallow groundwater exists in the unconfined alluvial deposits, containing sand, gravel, clay and mud. The position of an aquifer in shallow groundwater is diverse, having medium productivity. Common alluvial aquifers have a medium to high coarse-grained and low

Fig. 3 Hydrogeological Map of Pitay displaying various groundwater levels (from Sukrisno et al. [39])

permeability. The medium to deep groundwater lies on the limestone units. Karst aquifers can be very deep, ranging from tens to hundreds of meters, as they tend to have moderate to high permeability and the water flow is limited to fractures and dissolution zones. The scaly clay is believed to contain no groundwater due to its impermeable character. Additionally, it is very common for the population in West Timor to avoid water well drilling in this unit, as they would consider it as a futile effort.

3.3 Slope gradient

The concern for the landfill's slope/topography, which is considerably controlled by the geology of the area, relates to the drainage system and landfill operations. Areas with gentle slopes are much preferred than steeper ones. The slope gradient is the key in determining the amount of precipitation runoff. Normally steeper slopes have fewer chances of infiltration, as water is likely to flow downward and accumulate at the base of the slope.

This introduces new problems as the steep slopes are occupied by limestones, which are decent catchment areas. The national site selection law (SNI 03–3241-1994) notes that areas with slopes steeper than 20% should not be considered as a potential site. Although the high slope gradients can be attenuated by excavation, major investments would be required in the process.

The slope gradient of Pitay is categorized into three classes generated from 30 m digital elevation map (DEM) using spatial analyst tools in ArcGIS (Fig. 4). Areas with 0–20% gradient have relatively flat morphology with unequal distribution in the center and south of Pitay, and is preferable as the most suitable site candidate. Areas with 20–40% gradient have gentle hill morphology with unequal distribution towards the north, whilst the 40–100% gradient is located on the mountain areas (locally referred as *nuaf*). Areas with slope classes above 20% are considered as unsuitable candidates, however, objective considerations are made to include these as alternative sites, assessing it with a low score.

Fig. 4 Slope map of Pitay

3.4 Rainfall intensity

The amount of rainfall is related to the level of difficulty in providing and maintaining landfill facilities like drainage runoff, leachate ponds and oxidation ponds [40]. This parameter also aids the selection of landfill covers to limit the entry of surface waters and avoid the formation of puddles [41]. The average rainfall in the Kupang Regency in 2019 based on the records of the Kupang Climatology Class II Station is 711.2 mm/year, and most of it occurs in December–March with just a total of 92 rainy days (Statistics of Kupang Regency 2020). The rainfall in the past few years does not vary much within this range and always falls less than 1000 mm/year. As there are no local climate data available, the same score of this parameter will be applied to all areas within Pitay.

3.5 Exclusion criterion

The exclusion parameters eliminate areas situated in the buffer zone that is considered unsuitable for the landfill

site. It is important that the site is distant from rivers, lakes, or shorelines, as these parameters act as buffer zones and borders for river/coastal management. Main rivers in Pitay are the Tanisa River, Netatetok, Lutufatu and the Oetufi River and other seasonal rivers that have important benefits to maintain the sustainability of river functions, likewise, the areas along coastlines have important benefits to maintain the sustainability of coastal functions. The distance determined for the buffer zone of the Pitay landfill site selection for rivers and lakes is 150 m, and 500 m for shorelines. It should also be of 3000 m from the closest airport. Besides aesthetic and health concerns, birds are easily attracted by organic wastes, hence their presence would be a danger for airplanes [42]. The nearest airport to Pitay is the El-Tari Penfui–Kupang, located ± 18 km away, thus the landfill operation will not affect the activity of the airport.

Landfill sites must be distant of at least 300 m from any residential areas as it may engage the water, odor, and noise pollution. The settlement areas in Pitay have a linear pattern that follows the main road network, mostly in

the southern part of Pitay Village (Fig. 5). The landfill site must also be off 150 m from main roads as a new landfill could generate traffics. Anggraini and Darwati (2016) [20] emphasizes on the importance of investment and operational costs as the biggest concern for landfill site selection, which also accounts for the waste transport and the traffic route in which it will operate. The distance to the Pitay Landfill by road is approximately 40 km from Oelamasi and around 76 km from Kupang. The vast distance would majorly affect waste management and operational cost and would be time-consuming during operation and waste transportation. This may only be possible if the landfill restricts its service to Oelamasi and the areas around it (though then it may not be categorized as a regional landfill), or reasonably establish waste transfer stations that link the final waste disposal with the municipal waste.

3.6 Geological hazards

It is essential to apply geological information on spatial planning for regional development and environment

management by informing the physical characteristics of the area. Two important factors are geological hazards and potential geological resources (Fig. 5). This study considers the two factors for the landfill site selection, where the former avoids construction and operation damages, whilst the latter introduces the potential for future development of mineral/water/energy resources, a factor that should be acknowledged in a developing region.

Hazards like mass movements may occur if the landfill load exceeds the ground stability, existence of faults may introduce severe damage if earthquakes occur, and floods may lead to the destruction of infrastructures. Mass movements commonly occur in relatively steep areas especially in highly weathered and eroded rock or within the existence of faults. Areas with a medium to high mass movement vulnerability will be excluded from landfill site selection. The characteristics of flooding in Pitay are flash floods with a short period of inundation, located at several points on NW and SE of Pitay. Protected areas are also not suitable for landfill sites as specified by law, specifically in areas like: protected forest, nature reserves, cultural heritage site,

Fig. 5 Exclusion criterion including geological hazards and geological potential of Pitay. The delineation of several criteria are slightly modified from governmental archive. Extensive description in text

and protected geological areas. Fortunately, such areas does not occupy Pitay as its land cover mostly consist of shrubs and bushes, covering approximately 80% of Pitay and 20% of open land located in the west, which would be advantageous for land clearing costs and operations.

The potential landfill site must be distant from any geological faults as these weak zones will be extremely unstable if seismicity occurs. There are several inferred normal faults identified in Pitay showing a NW–SE trend [26] (Fig. 5). Although the interpretation of these faults seemed rather exaggerated, the lineaments of the area shows similar orientation with the main fault line. The lineaments were interpreted from DEM and areas of dense lineaments were highlighted, indicating such areas as risky zones (Fig. 5). The seismicity data of the area acquired from USGS shows several historical earthquakes (Table 2) and is located at a fair distance from the inferred fault lines which may indicate its active status (Fig. 5), however, it's fair to state that the seismicity in Pitay is simply less intensive than other parts of West Timor. Mud volcano eruptions are also very common in Timor and may present major risks to construction sites if triggered by earthquakes, yet such data are limited. Likewise, data regarding landslide susceptibility are limited, however, the Bobonaro Scaly Clay and Noele units are often considered as unstable units, whereas the Cablac and Quaternary Limestones are relatively stable [43]. These would also be depended on the slope gradient and position of these units, therefore further geotechnical investigations are required.

3.7 Geological potential

Potential geological resources are essential for a region's economy and development in the future, therefore the construction of landfill should not be within the areas of potential. The geological resources include; water, mineral, energy and land resources. The geological potential resources is often given too little attention and is rarely or even sometimes never considered in urban spatial planning for regional development. This may be caused by the lack of data, possibly due to the relatively high cost

of survey and data collection, especially in Timor, where the area is known for its remote and complex area, which makes it difficult and time/cost consuming to assess. This can be managed by remote sensing surveys which should be developed more in these parts of the region.

There are several potential geological resources in Pitay that could be developed in the future. The Nuaf Fatuwendak and Nuaf Fatumelon situated in NE of Pitay has Marble potential with a reported estimation reserves of 8,766,000 m³ (Unpublished report from the Department of Mining, Kupang Regency 2001). Potential ores like Manganese also are present in Pitay. Although there are no data available on the reserves of these manganese, a brief reconnaissance in Pitay shows that there were several small-scaled mining sites on the banks of Noel Tanisa, western Pitay. Manganese in Timor are generally present in the Jurassic—Late Cretaceous (?) succession that is exposed within the overlain Scaly Clay Unit [44]. Areas with such geological potentials may not be suitable for a landfill site as there may be mining activities to be developed in the future. There are also several rainwater catchment reservoir projects in Pitay, known as *Embung* (retention basins). These man-made basins are built to provide water for the community as the region is known for its long dry season with limited natural water reservoirs as the region is predominantly consists of the impermeable Scaly Clay unit. It has been one of the main government agenda to build many retention basins in these regions. Salt evaporation ponds are also developed in the region with a promising future potential.

3.8 Potential sites

Overlaying the geology, hydrogeology and slope map (regional criterion) resulted in a large reduction of site candidates at the north and southwest of Pitay, as these areas are dominantly composed of Limestone Units with relatively steep slope and comprising shallow to deep groundwater. Based on the specified assessment criteria, these areas are, to some extent, unsuitable for a landfill site. All areas are summed based on the determined parameter's weight and unit's values (Table 1), hence each potential area is classified upon its feasibility levels, based on its total score (Fig. 6). Four blocks of area with the highest score are chosen and are specified as having a high feasibility level (Table 3). Other low scoring areas are shaded in red, with scores ranging from 22 to 56.

The regional criterion map is overlaid by the accumulation of thematic maps of the exclusion parameters, eliminating areas that are considered unfeasible for the landfill site. This includes; settlement areas along the main road on the south of Pitay, areas of potential hazards like floods, landslide and weak zones, areas that

Table 2 Historical earthquakes in Pitay (USGS)

No	Location	Year	Magnitude	Depth
1	North of Pitay 9.958°S 123.692°E	1999	4.9	33.00 km
2	Center of Pitay 9.997°S 123.683°E	1976	5.3	08.00 km
3	South of Pitay 10.028°S 123.661°E	2009	5.5	48.80 km
4	South of Pitay 10.031°S 123.668°E	2016	4.5	34.34 km

Fig. 6 Four potential landfill sites of Pitay chosen within the four feasible/potential zones with the highest evaluation scores

Table 3 The regional (lithology, groundwater, slope and rainfall) and exclusion criterion analysis for the landfill site selection had resulted in 4 prospective areas selected on account of having the highest feasibility level based on its total score

Zones	Parameters					Total score	Information
	Lithology	Groundwater	Slope	Rainfall	Exclusion criterion		
1	25	20	15	10	✓	70	Clay, no groundwater, 0–20% slope
2	25	20	9	10	✓	64	Clay, no groundwater, 20–40% slope
3	25	12	15	10	✓	62	Clay, medium/deep groundwater, 0–20% slope
4	15	20	15	10	✓	60	Marl, no groundwater, 0–20% slope

are close to rivers and coastlines as it will interfere with its management, and in areas of potential resources like manganese and marble. The biggest elimination of suitable candidates for the exclusion parameters is the distance from rivers, for Pitay has an arguable amount of river networks due to its hilly terrain on the north of Pitay. This process has narrowed down the potential sites on the north, south and west of Pitay, exposing the center parts of Pitay as favorable candidates. Hence, four

potential sites are chosen within the four-block areas (coloured) possessing the highest scores (Fig. 6).

The four potential sites are all situated in the scaly clay unit, arguably possessing no groundwater, within the 0–40% classification of slope gradient, and are in distant/buffered out of any parameters determined in the exclusion criterion. Sites 1 and 2 may be preferred for it is situated near the main road, an advantage for future landfill operations, whereas sites 3 and 4 may be suitable

alternatives because it is located near the dense lineament areas, especially site 4, which is located near Noel Tanisa, a major upstream river that flows westward and disem-bogues in Sulamu. These favorable sites occupy more than 8 hectares of land which would be sufficient for the construction and operation of the landfill. The operation of garbage trucks in this area may not have a significant effect as the population density here is considerably small. However, the area would need the approval and confirmation by the local institution/government, therefore a supplementary assessment of socio-economy factors [20], or a geotechnical and hydrological study would be beneficial.

The methods used in this assessment are practicable in land use determination. A simple combination of geological and environmental knowledge can be applied in land-use evaluation, by a simple calculation of the necessary parameters. A substantial problem would be the total investment needed in surveying and collecting data in such a relatively remote area, as the reliance of geological data in environmental studies is immense, therefore the abundance and accuracy of such datasets are important in the assessment. The governmental archive can be obtained and revisited, albeit they may contain limited information in underexplored regions. Recent advancements in remote sensing may be applied in this situation with appreciably lesser costs and time compared to ground surveys [45].

This assessment exhibits the importance of the collaboration between geoscientists and environmental scientist with urban planners. It introduces the significance of geoscience and environmental science in potential landfill site selection, which is compatible and is a generalized version of the national regulation on the physical environmental aspects (SNI 03-3241-1994). Thought this method filters out socio-economic impact, the connection seems irrefutable. Environmental degradation may negatively affect the socio-economy of the community in the long run and vice versa. A strong environmental geology assessment in urban planning also minimizes the degradation of natural resources due to population growth and urbanization, thus leading to sustainable development.

4 Conclusions

There are 14 parameters chosen for this study, categorized into regional criterion and exclusion criterion. The regional analysis is assessed by expressing values on each parameter, displayed on a map, whilst the exclusion criterion sets a buffer zone to filter out irrelevant locations. The regional criterion map is overlaid by the accumulation of thematic maps of the exclusion parameters, eliminating areas that are considered unfeasible for the landfill site,

thus, exposing dominantly the center parts of Pitay as suitable candidates. Four prospective blocks of areas within Pitay is considered feasible for the site based on the assessment of environmental geology. Four potential sites are then selected within the four block areas possessing the highest scores. These four potential sites are all situated in the scaly clay unit, arguably possessing no groundwater, and is within the 0–40% classification of slope gradient, and are in distant/buffered out of any parameters determined on the exclusion criterion. This approach shows the importance of the collaboration between geoscientists and environmental scientist with urban planners, and the methods used in this assessment is practicable in land use determination. A simple combination of geological and environmental knowledge can be used for land-use evaluation by a simple calculation of the necessary parameters. This study introduces the significance of geoscience and environmental science in assessing potential landfill sites, which are compatible and is a generalized version of the national regulation on the physical environmental aspects (SNI 03-3241-1994).

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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