Site Suitability Analysis for Solid Waste Disposal Using Multi-Criteria Analysis: A Case Study of Lae City, Morobe Province, Papua New Guinea

Den, E.[1] and Samanta, S.[2*]
School of Surveying and Land Studies, The Papua New Guinea University of Technology, Lae, Morobe Province, Papua New Guinea
E-mail: deneinstein05@gmail.com,[1] sailesh.samanta@pnguot.ac.pg,[2*] rsgis.sailesh@gmail.com[2]
Corresponding Author

DOI: https://doi.org/10.52939/ijg.v20i7.3399

Abstract
Solid waste management is one of the burning issues in this modern world because of the rapid growth of population and urbanization. Identifying sustainable handy disposal sites is challenging using the traditional site surveying process locally, which is time-consuming. Remote sensing (RS) and Geographical Information Systems (GIS) are alternative and effective tools for identifying suitable sites for the dumping of solid waste through multi-criteria analysis (MCA). This study was conducted in Lae city under the Morobe Province of Papua New Guinea (PNG). The main aim of this case study was to identify a suitable disposal site for dumping urban waste in the nearby location of Lae City using RS and GIS techniques. This study considered a handful of factors to become aware of appropriate stable waste disposal sites, particularly distance from important roads, rivers, lakes, coastline, hospitals, clinics, schools, residential, supermarkets, industries, topographic height, slope of the ground, land use/ land cover, hydrological soil characteristics, rainfall, and lithological setting. These factors were generated either using satellite images through the spatial analysis process or from the legacy national GIS database respectively. Weighted sum overlay operation was used in this study which worked based on user-specified weight to each parameter and rand to all the subclass under all the selected parameters. The study identifies 433 hectares of land (4% land area) as very highly suitable in the northwest and the northeast part of the study area. This result will be very helpful to the planners for the rehabilitation or construction of new dumping site/s for powerful control to triumph over the modern-day situation.

Keywords: Geographical Information System, Multi-Criteria Analysis, Overlay Analysis, Proximity Analysis, Remote Sensing, Solid Waste, Weight and Rank

1. Introduction

The major problem related to the environment that the world is facing today is managing and disposing of waste by both the countries that are fully developed and those that are in the process of development. The management and dumping of waste are a major concern and one of the problems faced by developing countries like Papua New Guinea and Lae City is no exception. Remote sensing (RS) and geographical information systems (GIS) are some of the most powerful tools that can be used in this twenty-first century where this type of problem can be solved using its best and best possible techniques. Therefore, many developed countries have utilized this technique to analyze the situation, identify disposal sites, and manage their solid waste in the city. Since there are no proper dumping areas, people are ignorant and the waste is being thrown in a location where that is unsuitable [1]. Illegal waste disposal sites may result in environmental pollution and health hazards because of disease outbreaks [2]. It has been seen that the residents around Lae City are not taking care of the waste that they generate each day. Some residents living on the riverside dispose of waste in the streams and rivers nearby, which leads to water pollution (river and sea) directly [3]. Installation of the waste bins helps reduce or minimize the waste being disposed of in a location that is not designated.

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online)

Therefore, this study of using RS and GIS techniques is essential to identify suitable disposal sites and will help inform the Lae city authority to make a better decision based on the proper analysis and to manage waste that is unnecessarily dumped. This will help people develop some sort of sense of understanding to properly manage their waste and that will enable them not to do illegal dumping and create disposal sites of their own that are not recognised. Choosing and locating a suitable solid waste dumping site is another challenge that is faced today in many urban centers while considering its ongoing development [4].

One of the major reasons behind rapid population growth at Lae is migration. Most of the population is relocating to Lae in quest of better living conditions, such as greater access to jobs, healthcare, and education. Therefore, solid waste generation is also increasing every day as the population and urbanization increase in the city. As understood, Lae City had not been planned properly since the establishment of the capital of Morobe province in the late sixties. It is therefore important to classify pieces of land lying around the Lae city area to identify suitable dumping sites scientifically, like land/site suitability analysis [5]. The purpose of the site suitability analysis is to locate the most suitable disposal site that perfectly fits the geographical setting of the locality [6] and [7]. Moreover, GIS is considered one of the useful tools that are used for performing suitability mapping by defining the proper location for agriculture [8], health care services [9], educational institutes [10], construction of roads [11], etc. A site suitability analysis can be recommended for making a better decision in such cases [7]. At present, GIS has been considered the most important aspect for analyzing the different land use and land cover analysis in many instances and identifying the borders of the different species of plants and animals residing in certain locations [12]. The GIS technique was also utilized to do planning and evaluation for future development including the properties owned personally or for the use of the public [13].

Finding a suitable site is just another issue counted while searching for a more suitable location based on the factors and parameters considered. The major goal of finding the suitability is to identify the boundary with other factors and the distance can be assigned concerning the distance from each factor [14]. The use of multi-criteria decision analysis (MCDA) and analytical hierarchy process (AHP) was recommended concerning the ecological process to identify suitable land for respective purposes, such as development, agriculture, and disposal site selection [15]. Certain areas may not be deemed appropriate for solid waste disposal due to various factors, such as soil composition and other related criteria. Evaluating these factors will provide valuable information on the suitability of potential sites. There can be complex decision-making situations that may require choosing the better alternatives [16]. To make the decision process easier, the major problem can be identified and its process can be dissolved into smaller parts in which each portion can be easily analyzed so the concept can be well understood [17]. Doing so will make it easier when deciding so it can be made with absolute confidence. Therefore, suitable site identification can be the portion of the land that will be utilized to locate the site specifically for disposal [18]. This research aimed to investigate and locate a sustainable suitable disposal site for dumping urban waste in Lae City based on a multi-criteria analysis (MCA). This will help the Lae city authority to make better-informed decisions by locating solid waste and adopting better waste management.

2. Methodology

2.1 Description of the Study Area

Lae City is one of nine districts of Morobe province of Papua New Guinea (PNG), where this study was conducted. The study area is situated on a flat plain and along the Huon coast of Morobe province and it is the end of Markham Valley plain and the gateway to the famous highland highway (Figure 1). The city is geographically located at the latitude of 6º 41′ 20″ South and longitude of 147º 0′ 40″ East. It is well known as the largest industrial hub, cargo port, and the second-largest city of PNG. There are also many commercial and industrial activities taking place. The approximate area coverage of the study area is 114.38 sq km. The total population of Lae City is approximately 76,255 as of 2021. Due to the rapid growth of industrialization and urbanization migration of the population into the Lae also significantly increased for better opportunities. This leads to the total quantity of solid waste, which has been significantly increased, and the disposal of waste has become a challenging issue. The current waste dump located in the second seventh is not actually in a suitable location where there are some bad side effects on people's health because of poor management. The very important thing about this research is to make an analysis and find a sustainable suitable site in a convenient location so that it helps the surrounding communities and helps Lae city authority to dump the solid waste in its rightful place.

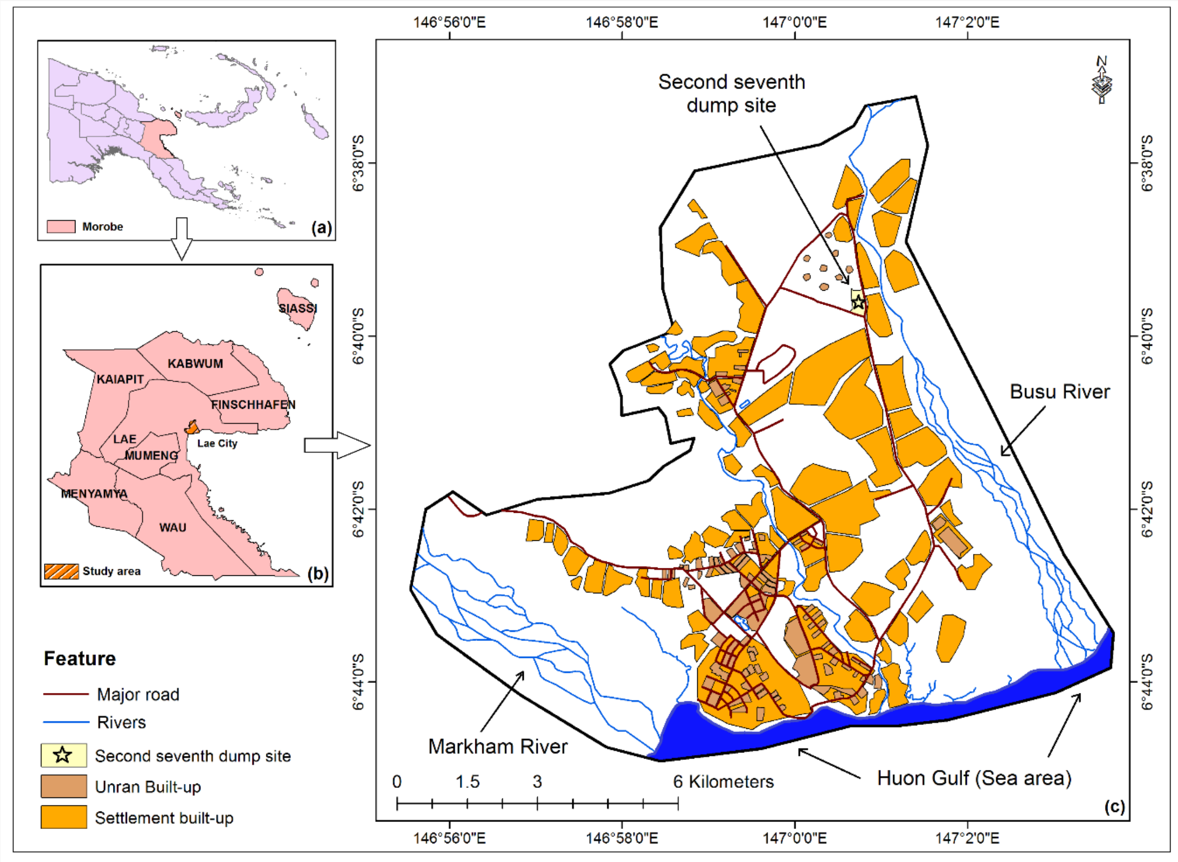

Figure 1: Location map of the study area: (a) Papua New Guinea, (b) Morobe Province, and (c) The study area

2.2 Selected Parameters and their Descriptions

There are many studies conducted in the recent past on identifying suitable disposal sites. The disposal sites are designed purposely to dump waste and other unwanted materials no longer needed for individual convenience. Therefore, before carrying out the study on identifying suitable dumping sites, it needs to consider important factors such as type of land use/land cover, distance from the rivers, streams, lakes, supermarkets, residential areas, schools, hospitals, and major institutions, topography, soil type, etc. The landfill/waste disposal site should be away from the living population outside of the suitable buffer zones. The MCA approach was used to determine the most suitable site for waste disposal. Ten (10) factors were considered as input parameters for this process. These factors include (i) distance from major roads, (ii) distance from river/lake/coastline, (iii) distance from hospital/clinic/school, (iv) distance from residential/supermarkets/industries, (v) height of the ground, (vi) slope of the land, (vii) land use and land cover, (viii) hydrological soil group, (ix) rainfall and (x) lithological setting. Different feature layers such as a river, lake, coastline, major roads, hospital schools, clinics, residential, supermarkets, urban centers, and industrial centers were extracted from high-resolution Lidar orthophoto (20 cm spatial resolution) using ArcGIS version 10.5. Altitude and slope information of the study area were derived from shuttle radar topographic mission (SRTM) data (30m spatial resolution). Land use/land cover classification was performed using a multispectral Ikonos satellite image (4 m spatial resolution). Other parameters namely, rainfall, geology, and soil texture were extracted from the Papua New Guinea Resource Information System (PNGRIS). Furthermore, the hydrological soil database was prepared from the soil texture data based on the infiltration potential of the soil after prolonged wetting and water.

The major road network is one of the useful factors when performing site suitability analysis. It is also important in terms of making transportation possible to transfer solid waste to a disposal site. For most of the literature reviewed and the studies conducted in the past, the solid waste disposal site should be located at a specific distance from the high-risk zones [19].

The disposal sites should not be located closer to the major roads and highways or the streets, city, or the major routes of land transportation. River, lake, and shoreline were together considered another factor. As usual, it is understood that waste substances being disposed of in or near rivers, lakes, or streams can pollute water and cause health, agricultural, and ecological problems. The disposal site must not be close to the surface water area [20]. There are three major rivers in the study area, namely the Busu River, Bumbu River, and Markham River. One lake was identified within the heart of Lae City located just opposite the Lae showground. Few other unnamed streams linking towards the sea and the shoreline were considered under this parameter. Hospitals, clinics, and schools are the most critical areas, which need to be given quiet attention for the selection of waste dumping sites. The disposal site should be far away from these locations where essential activities are much more active. If the location is close to these services, it will be uncomfortable for the people to have access to basic services. All three parameters were merged into board single parameters. Residential, supermarkets, and industrial areas are also considered important factors in this study. Engagement of the population in the supermarket and industrial area must not be unhealthy, which could be caused by the nearest waste disposal site. The waste disposal site must be far away from the residential area so that people can live their lives in a healthy pollution-free environment [21].

Proximity analysis was performed on the first four parameters namely (i) distance from major roads, (ii) distance from river/lake/coastline, (iii) distance from hospital/clinic/school, and (iv) distance from residential/supermarkets/ industries. The multiple buffer zones (5 buffer zones) were created by assigning specific distances (in the interval of 250m) to identify a suitable and unsuitable site for solid waste disposal. The area within a distance of 0 – 250 meters was deemed unsuitable for locating the disposal sites. The range of 250 – 500 meters was categorized as less suitable. Locations falling within the range of 500 – 750 meters were considered moderately suitable. The range of 750 – 1,000 meters was deemed suitable for locating the disposal sites. Finally, locations that exceeded a distance of 1,000 meters were indicated as highly suitable (Figures 2(a), 2(b), 2(c) and 2(d)).

The height of the ground or elevation was derived from the SRTM digital elevation model (DEM) data. The maximum height was measured as 275m and it was observed in the north part of the study area, whereas the minimum height value of 0 was measured in the southern part. The altitude dataset was further classified into 5 groups, namely (i) unsuitable area having a value of 0m or less, 0 to 50m as less suitable, 50 to 100m as highly suitable, 100 to 150m as suitable, and more than 150m as moderately suitable (Figure 2(e)). The slope is another important factor that has to be considered for identifying solid waste disposal sites. It is understood that slope is a restricted element that cannot easily be changed [11]. The locations with higher slope values were considered unsuitable for locating disposal sites because, during heavy rain, all the water from waste disposed of could be washed down towards the downslope causing massive pollution to the residential areas. The slope in degree was calculated from the elevation dataset and further, it was reclassified into five classes. The flat land with a 0-degree slope was considered an unsuitable location because the area may be affected by floods during heavy rain. The slope value of 0 to 2 degrees was considered a highly suitable place for the disposal site for solid waste. The slope range of 2 to 5 degrees was reclassified as a suitable area and 5 to 10 degrees as moderately suitable. The final class, more than a 10-degree slope was considered a less suitable area (Figure 2(f)) because it has the highest slope and the highest probability of instability and causing pollution when a solid waste disposal site is located in this location.

Land use and land cover characteristics are the most important factors that have been taken into consideration. The land use land cover database was derived through supervised classification. The satellite image was classified into five classes, namely built-up area, water surface, natural vegetation, shrub land, and bare/grass cover land (Figure 2(g)). Bare/grass cover land is the major class in the study area occupying 31% land area and dominating the middle, north, and eastern parts of the study area. Bare land was considered as most suitable, shrub land moderately suitable, natural vegetation moderately suitable, and water and built-up areas unsuitable locations for the waste disposal site.

The soil texture data set of the study area shows six types of soil, namely gravel, sand, sandy loam, silt loam, silt clay loam, and sandy clay (Figure 2(h)). Based on water holding capacity and infiltration rate the soil texture data set was reclassified into 3 major hydrological soil groups, namely A, B, and D (Table 1). The infiltration rate of soil group A is greater than 0.3 inches per hour in wet conditions, which is very high and the group was labeled as unsuitable. If the disposal site location happens to be on this group of soil, then much of the liquid waste will be infiltrated when leaching takes place and the underground water will be polluted.

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) | © Geoinformatics International

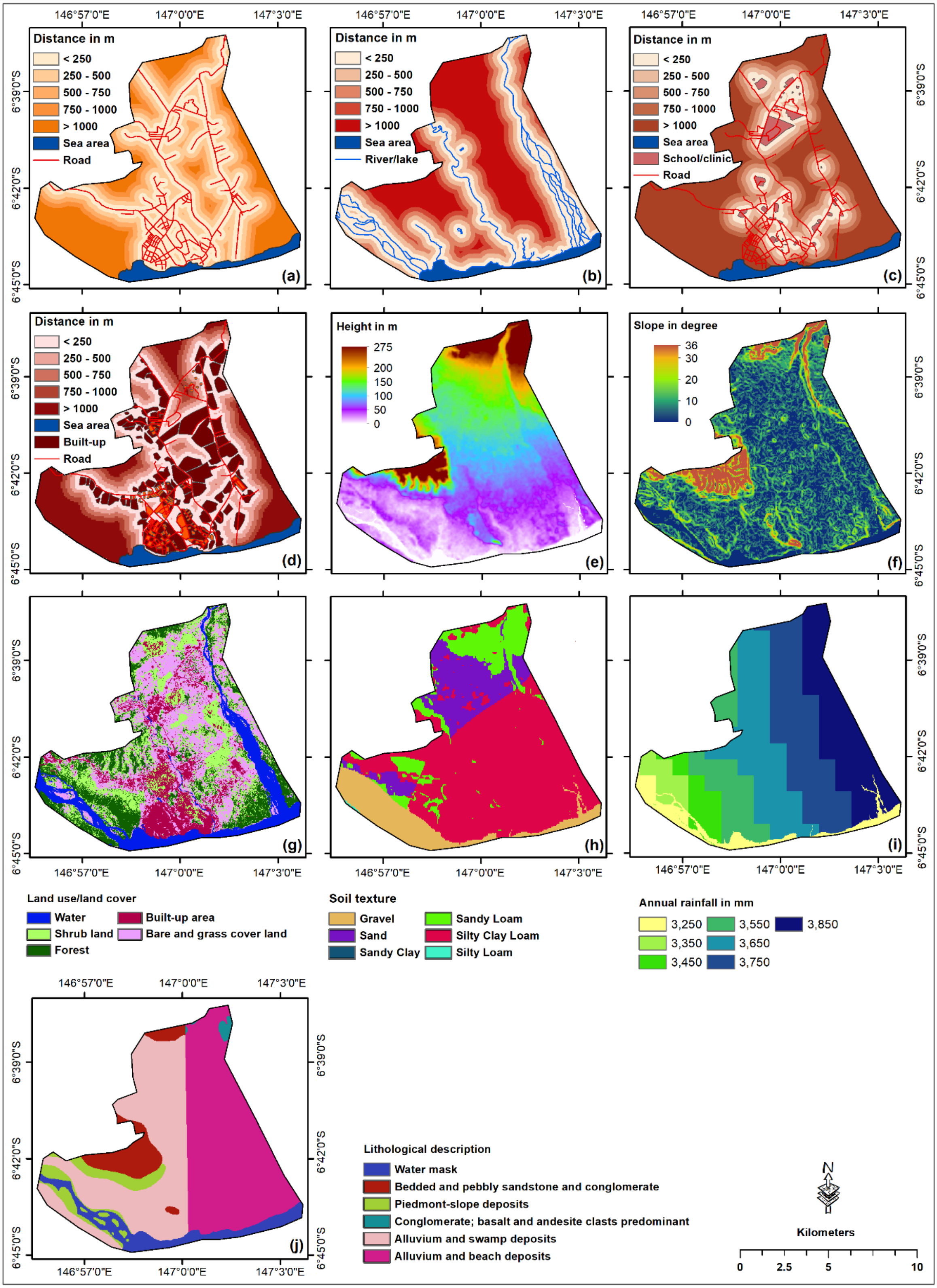

Figure 2: Input parameters for site suitability analysis: distance from (a) major roads, (b) rivers/lakes/coastline, (c) hospitals/clinics/schools, (d) residential/supermarkets/industries (e) height (f) slope of the land (g) land use/land cover, (h) soil texture, (i) annual rainfall, and (j) lithological characteristics of the study area

Table 1: Statistical table of land use and land cover, lithology, and soil parameter

Parameters	Sub-class	Area in hectares	Coverage in percentages
Land use and land cover	Built up	1,631	14
	Water	1,557	14
	Natural Vegetation	2,182	19
	Shrub land	2,514	22
	Bare land	3,554	31
	Total	11,438	100
Lithological description	Water mask	938	8
	Alluvium and swamp deposits	4,061	36
	Conglomerate, gravel, sand, silt: piedmont-slope deposits	710	6
	Conglomerate; basalt and andesite clasts pre-dominant	84	1
	Bedded and pebbly sandstone and conglomerate	839	7
	Alluvium and beach deposits	4,806	42
	Total	11,438	100
Soil texture / hydrological soil group	Gravel / Group A	1,454	12.71
	Sand / Group A	1,749	15.29
	Sandy loam / Group A	1,511	13.21
	Silt loam / Group B	12	0.10
	Silt clay loam / Group D	6,708	58.65
	Sandy Clay/ Group D	4	0.03
	Total	11,438	100

The suitable class for the selection of disposal sites is soil group D, where the infiltration rate is only 0 to 0.05 inches/hr in wet conditions. Hydrological soil group D was identified as a highly suitable class for the dump site. The study area experienced very high rainfall all over the year. The average annual rainfall ranges from 3,250 mm to 3,850 mm (Figure 2(i)). The rainfall increases from the coastline (South) towards the mountain area (Northwest) of the study area. Higher rainfall areas were labeled as unsuitable for the studies (Table 1). The final parameter, which is selected for this study, is the lithological setting. The lithological information was extracted from the national-level geology database. The lithological characteristics of the study area were characterized by six identical classes including the water mask (Figure 2(j) and Table 1). Water mask was considered an unsuitable surface to locate solid waste disposal sites since the risk of pollution is much higher. The major lithological class is alluvium and beach deposits (quaternary deposits), which dominate in the eastern part of the study area. The details on the class statistics of three (3) parameters, namely land use land cover, soil, and lithology are presented in Table 1.

2.3Assignment of Rank and Weight

All subclasses of all the selected parameters were ranked based on their preferences for the waste dumping site selection, from not suitable to highly suitable. To rank all the sub-class under each parameter a simple ranking criterion was adopted [22]. The fundamental scale of 1 to 5 was considered instead of 1, 3, 5, 7, 9, and intermediate values [23]. These rank values were assigned to each sub-class of all the parameters according to their relative importance. The weights were assigned to each parameter to identify which criterion has a more favorable influence on the suitability analysis and which has less based on the local expert's knowledge. Table 2 represents all selected parameters with weight and subclasses with rank. All reclassified parameters based on the suitability rank value and the weighted sum overlay analysis were performed using the spatial analysis tools in ArcGIS version 10.5 to produce the final suitability map for the possible waste disposal sites.

3. Results and Discussion

A landfill site suitability map for Lae City was generated using the weight sum analysis. The resulting output was further reclassified into five (5) suitability groups based on the suitability index value, namely (i) not suitable (index value of less than 35), (ii) moderate to less suitable (35 to 40), (iii) moderately suitable (40 to 45), (iv) moderate to highly suitable (45 to 50) and (v) highly suitable (more than 50).

Table 2: Parameters used for disposal site suitability analysis with rank and weight

Factors	Sub-class	Suitability rating	Rank	Weight
Major road (buffer in meters)	< 250	Unsuitable	1	1
	250 – 500	Less suitable	2	
	500 – 750	Moderately suitable	3	
	750 – 1,000	Suitable	4	
	> 1,000	Highly suitable	5	
River, Lake, Coastline (buffer in meters)	< 250	Unsuitable	1	2
	250 – 500	Less suitable	2	
	500 – 750	Moderately suitable	3	
	750 – 1,000	Suitable	4	
	> 1000	Highly suitable	5	
Hospital, Clinic, and School (Buffer distance in meters)	0 – 250	Unsuitable	1	1
	250 – 500	Less suitable	2	
	500 – 750	Moderately suitable	3	
	750 – 1,000	Suitable	4	
	>1,000	Highly suitable	5	
Residential, Supermarket, &Industrial (buffer in meter)	0 – 250	Unsuitable	1	1
	250 – 500	Less suitable	2	
	500 – 750	Moderately suitable	3	
	750 – 1,000	Suitable	4	
	>1,000	Highly suitable	5	
Altitude (in meters)	0	Unsuitable	1	1
	0 – 50	Less suitable	2	
	50 – 100	Highly suitable	5	
	100 – 150	Suitable	4	
	>150	Moderately suitable	3	
Slope in Degrees	0	Unsuitable	1	2
	0 – 2	Highly suitable	5	
	2 – 5	Suitable	4	
	5 – 10	Moderately suitable	3	
	>10	Less suitable	2	
Land Use and Land Cover	Built up	Unsuitable	1	1
	Water	Unsuitable	1	
	Natural Vegetation	Less suitable	2	
	Shrub land	Moderately suitable	3	
	Bare and grass cover land	Highly suitable	5	
Soil Texture/ Hydrological Soil Group	Gravel / Group A	Unsuitable	1	2
	Sand / Group A	Unsuitable	1	
	Sandy loam / Group A	Unsuitable	1	
	Silt loam / Group B	Moderately suitable	3	
	Silt clay loam / Group D	Highly suitable	5	
	Sandy Clay/ Group D	Highly suitable	5	
Rainfall in (mm)	<3,400	Highly suitable	5	1
	3,200 – 3,400	Suitable	4	
	3,400 – 3,600	Moderately suitable	3	
	3,600 – 3,800	Less suitable	2	
	>3,800	Unsuitable	1	
Lithological characteristics	Water mask	Unsuitable	1	1
	Alluvium and swamp deposits	Less suitable	2	
	Conglomerate, gravel, sand, silt: piedmont-slope deposits	Moderately suitable	3	
	Conglomerate; basalt and andesite clasts predominant	Suitable	4	
	Bedded and pebbly sandstone and conglomerate	Suitable	4	
	Alluvium and beach deposits	Highly suitable	5	

Furthermore, in perspective of the physical limitation of the land the highly suitable class refers to the suitable land with negligible limitations and the not suitable class refers to the unsuitable land with extreme limitations. The dark green colour pixels are referred to as the highly suitable area for the disposal site. The total area for each suitability class was calculated in hectares and percentages (Table 3). The bar chart (Figure 3) displays the percentage of the area covered belonging to each suitability class. Not suitable areas are restricted by urban settlement, major services, roads, rivers, as well as other factors, and occupy about 2,628 hectares or 40.59% of the study area. On the other hand, a highly suitable area covers only 433 hectares or 4% of the study area which satisfies mostly all factors. The major suitable area was labeled with their location names, such as Busu, Bumayong, Buimo, Yalu, and Omili (Figure 4). Some other areas with single or few red pixels were not selected as suitable areas because of the limitation of the size/area for the disposal site. This study addresses a crucial void in the identification of disposal sites for solid waste disposal with the help of the GIS technique. The weighted sum overlay analysis was used in this study based on the given weight to each parameter and assigned a rank to each subclass belonging to each parameter. The technique is very useful to handle vast quantities of spatial data from various sources [24]. The outcome of the work establishes that the proximity to roads, rivers/ lakes/ coastlines, hospitals/ clinics/ schools, residential/ supermarkets/ industries as well as land use and land cover, soil type, and lithology have played a significant role in the selection of suitable disposal site. In the ignorance above the closest river, the lake, or the seawater may be subjected to leach contamination from disposal sites [25] and [26]. The current second seven disposal sites for the dumping of solid waste are not situated in any of the suitable classes but are located in a less suitable or not suitable area. Air pollution is very much visible around this disposal site as it is situated along the main road and nearby settlement built-up (Figure 4). Hence, this study suggested closing or relocating the disposal site to any of the suitable locations as per the suitability map.

Table 3: Class statistics of site suitability results for solid waste disposal

Sl. No.	Suitability class/suitability value range	Area (hectare)	Coverage area (%)
1	Not suitable (Less than 35)	2,682	23
2	Moderate to less suitable (35 to 40)	3,811	33
3	Moderately suitable (40 to 45)	2,944	26
4	Moderate to highly suitable (45 to 50)	1,567	14
5	Highly suitable (More than 50)	433	4
	Total	11,438	100

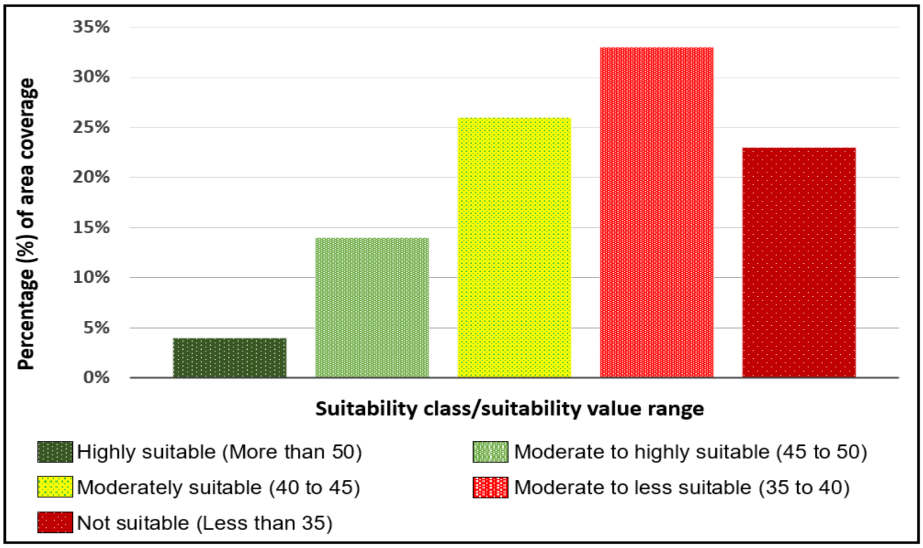

Figure 3: Statistical representation of different site suitability categories

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) | © Geoinformatics International

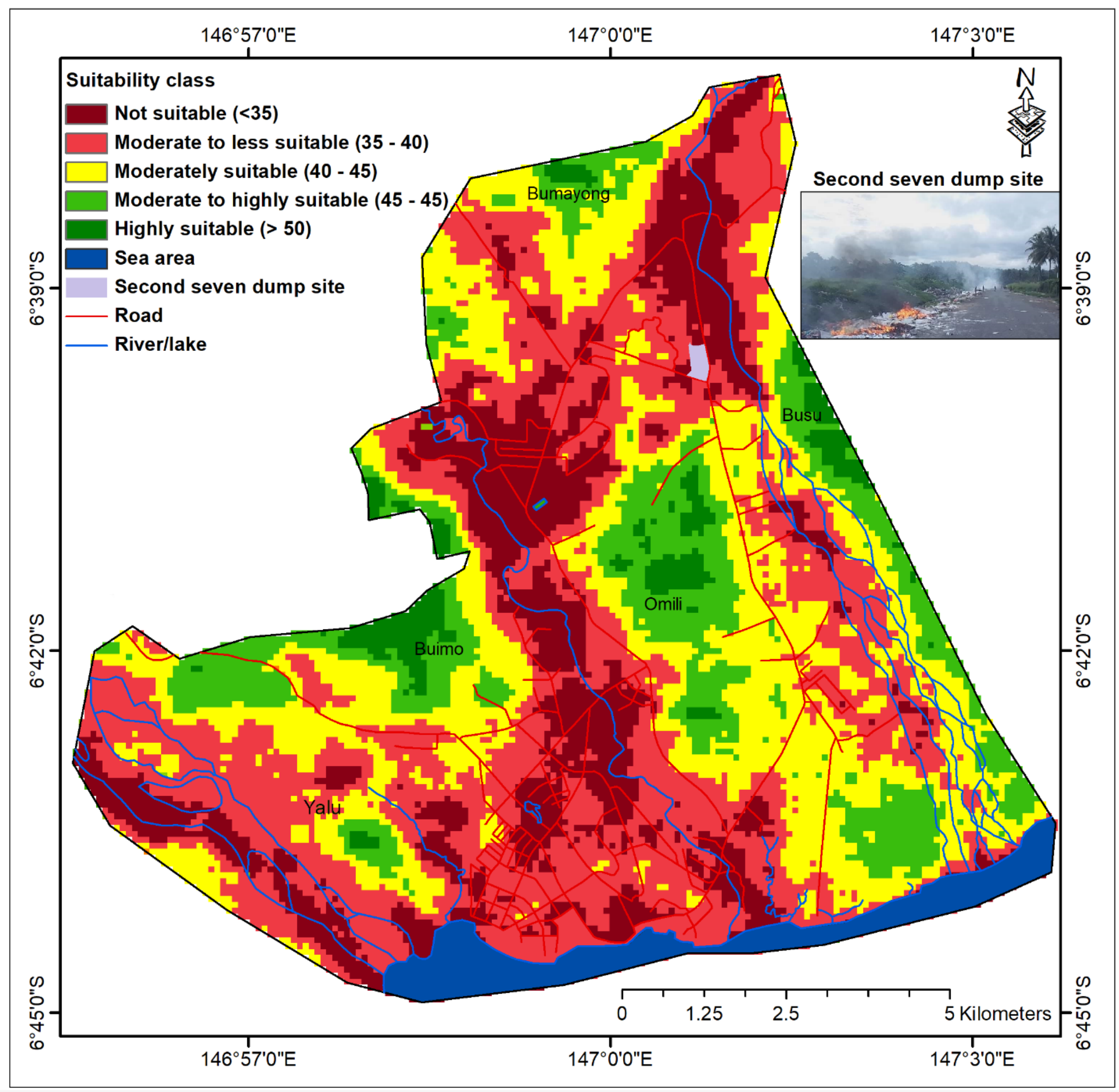

Figure 4: Landfill site suitability map along with 5 most preferred candidate sites with (a) class statistics and (b) current condition of the second seven disposal site

4. Conclusion

The generation of solid waste has been extensively increased due to rapid urban expansion and population pressure in Lae city. A significant amount (0.312 kg/capita) of solid waste is being produced every day from industrial, commercial, and household activities [1]. Identification of a suitable disposal site was carried out using the MCA approach with the help of infrastructures, hydrological, topographical, and lithological parameters. Proximity analysis was performed to construct spatial databases on infrastructure, namely distance from major roads, distance from rivers/lakes/coastline, distance from hospitals/clinics/schools, and distance from residential/supermarkets/ industries. Land use land cover was derived from satellite images. On the other hand, topographic height and slope were derived through surface analysis using elevation data. The weighted sum overlay method combined all the weight and rank assigned to each parameter and their sub-classes respectively. The result shows only 4% of the land surface area is very suitable for solid waste dumps with minimum restriction apart from the exclusion of the restricted land. These suitable areas are concentrated in the Busu, Bumayong, Buimo, Yalu, and Omili areas as shown in Figure 4. Some of the proposed disposal sites can be further reviewed based on the trend of population growth, infrastructure availability, and choice of bigger landfills over smaller ones for a prolonged period to cut the expenses of landfill reconstruction [27].

The methodology used in this study is quite user-friendly to be employed by the city waste management authorities. It can handle and manage a large number and volume of spatial and non-spatial datasets from various sources within a short period. Although the weighted sum method was used in this case study, many other methods such as utility-based MCDA (AHP), goal programming, and fuzzy MCDA techniques can also produce similar results based on decision-maker preferences. This study's major limitation is the use of low-resolution GIS databases such as soil databases (500m spatial resolution) and lithological databases (1,000m spatial resolution).

We do not have any other source of higher-resolution national GIS databases. The use of higher-resolution geospatial database is another preference to yield better results. City planners, local authorities, and the local government can adopt the results for future progress. Lae city authority faces many challenges that need to be addressed and properly dealt with by responsible bodies. One of the effective solutions is waste minimization through recycling and reuse, and waste transformation alternatives as done in other parts of the World.

References

[1] Subramanyam, R., (2021). Solid Waste Management in Lae City, Papua New Guinea. *J. Solid Waste Tech. Manag.*, Vol. 42(2). https://doi.org/10.5276/JSWTM/2021.371.

[2] Triassi, M., Alfano, R., Illario, M., Nardone, A., Caporale, O. and Montuori, P., (2015). Environmental Pollution from Illegal Waste Disposal and Health Effects: A Review on the “Triangle of Death”. *Int. J. Environ. Res. Public Health*, Vol. 12(2). https://doi.org/10.3390/ijerph120201216.

[3] Indrawati, D. and Purwaningrum, P., (2018). *Identification and Analysis the Illegal Dumping Spot of Solid Waste at Ciliwung Segment 5 Riverbanks*. IOP Conference Series: Earth and Environmental Science, August 9-10, 2017, Jakarta, Indonesia: IOP Publishing. https://doi.org/10.1088/1755-1315/106/1/0120 43.

[4] Alam, R., Chowdhury, M. A. I., Hasan, G. M. J., Karanjit, B. and Shrestha, L. R., (2008). Generation, Storage, Collection and Transportation of Municipal Solid Waste: A Case Study in the City of Kathmandu, Capital of Nepal. *Waste Manag.*, Vol. 28(6). https://doi.org/10.1016/j.wasman.2006.12.024.

[5] Puntsag, G., (2014). Land Suitability Analysis for Urban and Agricultural Land Using GIS: Case Study in Hvita to Hvita, Iceland. *United Nations University Land Restoration Training Programme*. Available: https://www.grocentre.is/static/gro/publication/434/document/puntsag2014.pdf [Accessed Feb. 18, 2021].

[6] Esnard, A. M., (2006). *Hypothetical City Workbook III: Exercises, Spreadsheets, and GIS Data to Accompany Urban Land Use Planning*. University of Illinois Press, United States.

[7] Steiner, F., McSherry, L. and Cohen, J., (2000). Land Suitability Analysis for the Upper Gila River Watershed. *Landsc. Urban Plan.*, Vol. 50. https://doi.org/10.1016/S0169-2046(00)00093-1.

[8] Samanta, S., Pal, B. and Pal, D. K., (2011). Land Suitability Analysis for Rice Cultivation Based on Multi-Criteria Decision Approach through GIS. *Int. J. Sci. Emerg. Tech.*, Vol. 2(1), 12–20.

[9] Parvin, F., Ali, S. A., Hashmi, S. and Khatoon, A., (2021). Accessibility and Site Suitability for Healthcare Services Using GIS-based Hybrid Decision-Making Approach: A Study in Murshidabad, India. *Spat. Inf. Res.*, Vol. 29(1). https://doi.org/10.1007/s41324-020-00330-0.

[10] Baser, V., (2020). Effectiveness of School Site Decisions on Land Use Policy in the Planning Process. ISPRS *Int. J. Geo-Inf.*, Vol. 9(11). https://doi.org/10.3390/ijgi9110662.

[11] Poi, N., Samanta, S. and Sekac, T., (2021). Site Suitability Analysis for Road in Mountainous Terrain Region of Papua New Guinea. *Int. J. Geoinformatics.*, Vol. 17(2). https://doi.org/10.52939/ijg.v17i2.1751.

[12] Store, R. and Kangas, J., (2001). Integrating Spatial Multi-Criteria Evaluation and Expert Knowledge for GIS-Based Habitat Suitability Modelling. *Landsc. Urban Plan.*, Vol. 55. https://doi.org/10.1016/S0169-2046(01)00120-7.

[13] Mammadova, M. and Jabrayilova, Z., (2014). Application of Fuzzy Optimization Method in Decision-Making for Personnel Selection. *Intelligent Control and Automation*, Vol. 5, 190-204. https://doi.org/10.4236/ica.2014.54021.

[14] Kumne, W., and Samanta, S. (2023). Geospatial Mapping of Inland Flood Susceptibility Based on Multi-Criteria Analysis – A Case Study in the Final Flow of Busu River Basin, Papua New Guinea. *Int. J. Geoinformatics*, Vol. 19(6), 31–48. https://doi. org/10.52939/ijg.v19i6.2693.

[15] Uy, P. D. and Nakagoshi, N. (2008). Application of Land Suitability Analysis and Landscape Ecology to Urban Greenspace Planning in Hanoi, Vietnam. *Urban For. Urban Green.*, Vol. 7(1). https://doi.org/10.1016/j.ufug.2007.09.002.

[16] Wallenius, J., Fishburn, P. C., Zionts, S., Dyer, J. S., Steuer, R. E. and Deb, K., (2008). Multiple Criteria Decision Making, Multiattribute Utility Theory: Recent Accomplishments and What Lies Ahead. *Manag. Sci.*, Vol. 54(7). https://doi.org/10.1287/mnsc.1070.0838.

[17] Malczewski, J., (2006). GIS-based Multi-criteria Decision Analysis: A Survey of the Literature. *Int. J. Geogr. Inf. Sci.,* Vol. 20(7). https://doi.org/10.1080/13658810600661508.

[18] Singha, C. and Swain, K. C., (2016). Land Suitability Evaluation Criteria for Agricultural Crop Selection: A Review. *Agric. Rev.*, Vol. 37, 125-132. https://doi.org/10.18805/ar.v37i2.10737

[19] Oanh, N., Thanh, P., Long, N., Chien, L., Dinh, N., Thom, T., Bich, N., and Elshewy, M. (2024). Optimal Solid Waste Landfill Site Identification Employing GIS-Based Multi-Criteria Decision Analysis Within the Thach That District, Hanoi, Vietnam. *Int. J. Geoinformatics*, Vol. 20(1), 12–24. https://doi.org/10.52939/ijg.v20i1.3021.

[20] Mussa, A. and Suryabhagavan, K. V., (2019). Solid Waste Dumping Site Selection Using GIS-Based Multi-Criteria Spatial Modeling: A Case Study in Logia town, Afar Region, Ethiopia. *Geol. Ecol. Landsc.*, Vol. 5(3). https://doi.org/10.1080/24749508.2019.1703311.

[21] Njoku, P. O., Edokpayi, J. N. and Odiyo, J. O., (2019). Health and Environmental Risks of Residents Living Close to a Landfill: A Case Study of Thohoyandou Landfill, Limpopo Province, South Africa. *Int. J. Environ. Res. Public Health*, Vol. 16(12). https://doi.org/10.3390/ijerph16122125.

[22] Saaty, R. W., (1987). The Analytic Hierarchy Process-What it is and How it is Used. *Math. Model.*, Vol. 9(3-5). https://doi.org/10.1016/0270-0255(87)90473-8.

[23] Morea, H. and Samanta, S., (2020). Multi-criteria Decision Approach to Identify Flood Vulnerability Zones Using Geospatial Technology in the Kemp-Welch Catchment, Central Province, Papua New Guinea. *Appl. Geomat.,* Vol. 12. https://doi.org/10.1007/s12518-020-00315-6.

[24] Kao, J. J., Lin, H. Y. and Chen, W. Y., (1997). Network Geographic Information System for Landfill Siting. *Waste Manag. Res.,* Vol. 15. https://doi.org/10.1177/0734242X9701500.

[25] Chakraborty, R. and Mukherjee, A., (2009). Mutagenicity and Genotoxicity of Coal Fly Ash Water Leachate. *Ecotoxicol. Environ. Saf.*, Vol. 72(3). https://doi.org/10.1016/j.ecoenv.2008.09.023.

[26] Maiti, S. K., De, S., Hazra, T., Debsarkar, A. and Dutta, A., (2016). Characterization of Leachate and Its Impact on Surface and Groundwater Quality of a Closed Dumpsite – A Case Study at Dhapa, Kolkata. India. *Procedia Environ. Sci.*, Vol. 35. https://doi.org/10.1016/j.proenv.2016.07.019.

[27] Kabite, G., Suryabhagavan, K. V., Argaw, M. and Sulaiman, H., (2012). GIS and Remote Sensing Based Solid Waste Landfill Site Selection: A Case of Addis Ababa City. Ethiopia. *Int. J. Ecol. Environ. Sci.*, Vol. 38(2-3), 59-72.