Application of Space Technology to Identifying Suitable Areas of Solid Waste Disposal in and Around Lae City, Papua New Guinea

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Abstract— Identification of suitable areas of solid waste disposal is crucial in solid waste management especially in large cities where municipal authorities of the city has to deal with the situation as a least trade-off to city's environment. While increasing population in cities or urban areas is the order of the day in commensurate with the proliferation of industries, commercial activities, public institutions and real estate enterprises; unprecedented pace of waste production is obvious. In order to cope with the situation it is paramount to find suitable landfill area to save the city's environment. This research study was carried out with a view to identifying suitable areas of solid waste disposal in Lae city utilising GIS and Remote sensing technology. With the multi-criteria evaluation process, the maps were prepared through overlay and suitability analysis. The city is densely populated with ever increasing industries and commercial activities, so the solid waste handling remains a serious challenge for the civic authority. In order to select suitable site of solid waste disposal, the area must be easily accessible from any corner of the city and at the same time the site must not pose health hazard to nearby residents, hence six factors were selected and analysed. These are slope, Land use Land cover (LULC), buffer zones from major road, public institution, 'settlements and housing' and main rivers. From the overlay analysis the final suitability map was produced and reclassed as unsuitable, moderately suitable and highly suitable areas. It was found out that 11.37% of Lae city area and surrounding are highly suitable for solid waste disposal. The largest highly suitable site found was in the north-east part of the city.

Key Words— Remote Sensing, GIS, Waste Disposal, Multi-criteria evaluation,

1 INTRODUCTION

1.1 Introduction

Solid waste management (SWM) is one of the major challenges globally, as the generation and disposal of waste has direct and indirect linkages to economic development as well as the health and welfare of the community. The better SWM practice leads to conducive and protective environment. SWM practice has been widely adopted, the quality of which is sometimes disappointing due to lack of funding and unscientific planning process. Waste management is the practice of using several techniques to manage and dispose of specific components of solid waste. Waste management techniques include avoidance, reduction, reuse, recycling, recovery, and disposal [4]. In some other developing countries, the solid wastes are disposed all over the place without any concern that it is extremely harmful to environment or surrounding community. According to Sulliman (2010), solid waste can cause harm or damage to people and environment. Therefore, the significance of finding out suitable areas for disposal cannot be over-emphasized. What actually constitutes solid waste has to be clarified precisely. According to Majibar (2008), Solid waste includes Industrial Waste, Agricultural Waste, Sewage Treatment Materials, Garbage's, Rubbish, Ashes, Dead Animals etc. The disposal of solid waste to suitable dumping areas in a city is the key to any worthwhile SWM practice.

Lae city is the second largest industrialised and commercial city in Papua New Guinea (PNG). The city is densely populated with increasing household and settlement areas. Poverty in rural areas causes urban drift as a natural migration. The city is experiencing rapid population growth due to gas, oil and mineral projects that principally are the harbinger of economic boom in the country for over a decade. Therefore the level of waste generation and management is becoming a real concern here. According to Wangi (2008), the waste management in Lae city is managed by Lae City Council (LCC), however authorities experience poor management standards due to insufficient funding (resources) or tools and no policy/strategy guidelines. Lae city's major dumping site is 'Second Seven' where all the industrial and commercial wastes are dumped or disposed. However the dumping site is very unsuitable due to high rate of pollution and also it is very near (about 1 to 5 meters away) to the major roads, public institutions and settlements. The situation warrants the necessity to identify 'highly suitable areas' as a part of scientific planning for solid waste disposal in Lae city. The Second seven dump site was mention as major dump site here in Lae city, however there are also other dumpsite that are not mention are currently existing in an around the city area. Proper investigation and management can assist in identifying suitable dumpsite here in the city.

The study aims at Identifying most suitable areas of solid waste disposal in Lae city through applying multi-criteria evaluation process in GIS and Remote sensing environment. According to Ebistu et al (2013), in any multi-criteria evaluation process, many data layers are to be handled by GIS and remote sensing in order to arrive at the suitable site; this can be achieved conventionally using GIS. Therefore for this research study, each environmental and political factor or thematic layer prepared such as slope, LULC, road buffer, river buffer, public institute buffer and settlements and housing buffer was assessed and each class or zone created in each

buffer was weighted according to its order of importance for identifying suitable areas for solid waste disposal. GIS and Remote sensing environment provide an excellent framework for data capture, storage, synthesis, measurement and analysis [2]. Through GIS and remote sensing technology, highly suitable areas for solid waste disposal can be identified as a means of scientific planning.

1.2 Nature of the problem

The city has experienced dramatic increase in industrial production and sales that has contributed to accelerated solid waste production. Accompanying dense population evidently contributed and worsened solid waste disposal scenario. Although informal dumpsites are reported to exist within the city limits, the only official municipal dumpsite is 'Second Seven' and is also located within the city limit which is considered as 'highly unsuitable' site. The 'Second Seven' dumpsite is happens to be very precarious to city dweller's health or ecological settings. Proper solid waste management is also a major problem in Lae city due to lack of financial support and tools. The disposal of waste in unsuitable areas is a common sight in the city. The unsuitable areas of solid waste disposal are identified as:

Areas very close to the main roads,
Areas close to the major rivers
Areas close to settlements and housing
Areas close to public institutions like; schools, health centres, etc.

Thus in any solid waste disposal these four areas as mentioned above are to be carefully considered in order to avoid certain environmental degradation in the city. The wastes are to be disposed of at suitable distance away from areas as mentioned and to a suitable lower slope area. For the higher slope area, the runoff can easily transport the harmful elements to the low lying areas [1]. Therefore it is important to discuss and analyse the common environmental factors and municipal factors like settlements, roads, slope, institutions, etc. through applying Remote Sensing and GIS technology into delineation or identification of most suitable areas of Lae city's solid waste dumpsites.

1.3 Aims and objective of the research study

The main aim of the study is to investigate and analyse the environmental and municipal factors and to identify the suitable sites for city's solid waste disposal.
With respect to the aim of the study, the objectives are:

- To investigate and prepare thematic layers (factors) that contributes to identification of suitable areas.
- To assign weights and percentage influence for each factor prepared with their classes according to how effectively they can contribute.
- To carry out 'weighted overlay analysis' by overlaying of weighted maps and producing a final output map of solid waste disposal suitability sites.

1.4 Study area

The area chosen to carry out the study was Lae city and surrounding. According to authors' point of view, the common solid waste disposal site, that is the 'second seven dumping site' in the heart of Lae city has high potential of causing pollution or negative impacts towards the nearby settlements and institutions. Based on that, the research study has been planned within the city and surrounding to identify the most suitable areas of solid waste disposal. The study area is mainly flat with three major rivers running straight encompassing the city. The study area is the second largest city of the country Papua New Guinea (PNG) with approximate area of 112 km2. It is located around 6°41'20"S and 147°0'40"E. The city is densely populated and is home to multiple of industrial and commercial activities. Figure 1 gives the impression of the current unscientific landfill site, while Figure 2 illustrates the location of study area.

Fig.1. Photograph of the common dumping area in Lae city - Second Seven (Source: Wangi. T, 2008)

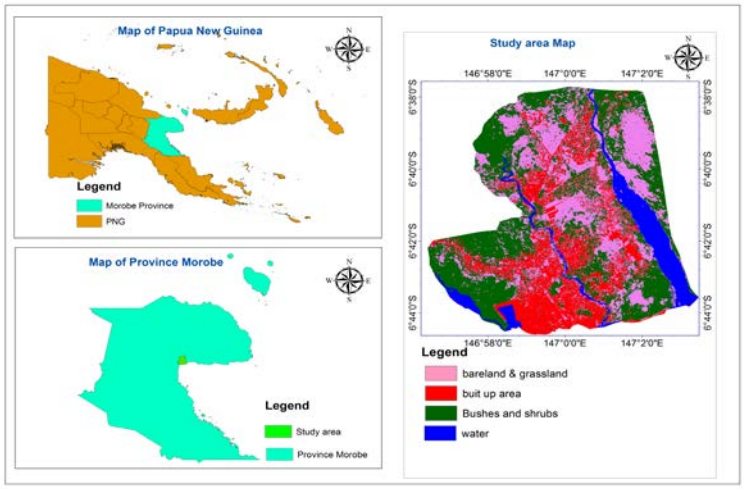

Fig.2. Study area map

2 MATERIALS AND METHODS

2.1 Preparation of thematic layers

There were about six (6) factors or data layers used in this study. The thematic layers for six factors were prepared and weighted according to the extent of influence to each thematic layer with their classes. The data types used was municipal data layers extracted from high resolution LiDAR orthophoto at 20 cm spatial resolution, topographical data layer and Landsat 8 Land optical image (LOI) at 30m spatial resolution. The municipal data layers such as; Lae city major roads, public institution, settlements and housing and major rivers running within city was digitized and extracted from high resolution orthophoto using ArcGIS 10 and MapInfo Professional 10.1 software. The buffer zones were created for each municipal factor and their thematic layers were prepared. The topographical factor that is slope was prepared from SRTM DEM data at 30m spatial resolution. The slope thematic layer was prepared and reclassed to four classes. The highest slope for the study area is 34 degree. The LULC thematic layer was prepared from Landsat 8 LOI. Four (4) classes of LULC were defined, that is mixture of grassland and bare land, bushes and shrubs, built-up areas and water.

2.1.1 Buffering of four municipal factors

Buffer is one of the spatial analyst tools in ArcGIS software. It is simply a proximity analysis tool. The question like; what is near what? This a simple question usually asked in GIS environment or in any GIS analysis. For example; how far is that settlement area from Second Seven dumpsite? Or what is the distance between two locations?

For this research study, the buffer tool was used to define an area within a specified distance around a municipal features like roads, river, settlements and housing and public institutions. The buffer distances assigned were based on interview process with local authorities and communities with the help of high resolution LiDAR orthophoto at 20cm spatial resolution where every land features can be clearly viewed. Several buffer zones were created at each specified distance in meters for each municipal feature. Buffer zones were created around the river to identify land areas that can be or cannot be suitable for solid waste disposal (Figure 5 (C) and Table 2). This buffering technique was applied to three other municipal factors as well. After the buffer zones were created for each municipal factor, their thematic layers were prepared and ready for assigning weightage and % influence to each zones created. The extents of buffer zones created were to the extent of city boundary demarcated. While Table 1 displays the data layer used and the source, the buffer zones created according to specified distance are tabulated in Table 2.

Table 1: Data layers used in the study

Data layers	Description	Source
Slope factor	Extracted from PNG SRTM DEM (30m Spatial resolution)	PNG University of Technology
Land use Land cover factor/layer	Generated from Landsat 8 satellite image(28.5m spatial resolution)	PNG University of Technology
River layer	Digitized and extracted from LiDAR orthophoto (20cm spatial resolution)	PNG University of Technology
Settlements & Housing	Digitized and extracted from LiDAR orthophoto (20cm spatial resolution)	PNG University of Technology
Major Road Layer	Digitized and extracted from LiDAR orthophoto (20cm spatial resolution)	PNG University of Technology
Public Institutions	Digitized and extracted from LiDAR orthophoto (20cm spatial resolution)	PNG University of Technology

2.2 Background Knowledge of weightage and % influence assigned

Weighted overlay is a spatial analysis tool in ArcGIS that is used to assess and analyse multiple factors and to derive final output result in single map. When performing a weighted overlay analysis, several factors with their classes are assigned weights as per % of influence.

After preparing six thematic layers (river buffer zones, road buffer zones, land use land cover, slope, settlements and housing buffer zones and public institution buffer zones), their individual classes were reclassified using "reclassify" tool in ArcGIS 10 according to the weights scale range of 1 to 4. The weights were assigned to each class depending on their relative importance in contribution to identifying suitable sites for waste disposal. To identify more suitable areas to unsuitable areas for solid waste disposal, the weight 4 indicates "high contributions" and weight 1 indicates "low contribution". For example, the class "bare land &grassland" in the factor LULC was given the weight of value "4" because this class was identified as a very high suitable area for solid waste disposal. On the other hand, the class "water" is given the weight of "1" which is the lowest value because it is the class that was identified as very unsuitable area for solid waste disposal due to high contribution to water pollution. When looking at buffer zones, for example, the class "200 meter buffer zone" in the factor river buffer was given the weight of "1" which is the lowest value because it is the zone that was identified as very unsuitable area for solid waste disposal, where as the class " > 800 m buffer zone" was given the weight of "4" because this zone is identified as highly suitable zone or site for solid waste disposal. The weightage were assigned to each factor's classes and % of influence was assigned to each factor. Thus the weightage and % of influence assigned for each factor or class

was decided based on lessons gleaned from literature, formal discussion and interview process. Thus all the other factors with their classes were given weightage or % influence following the same knowledge or procedures. Table 2 shows the weightage and % of influence assigned to each factors and their classes.

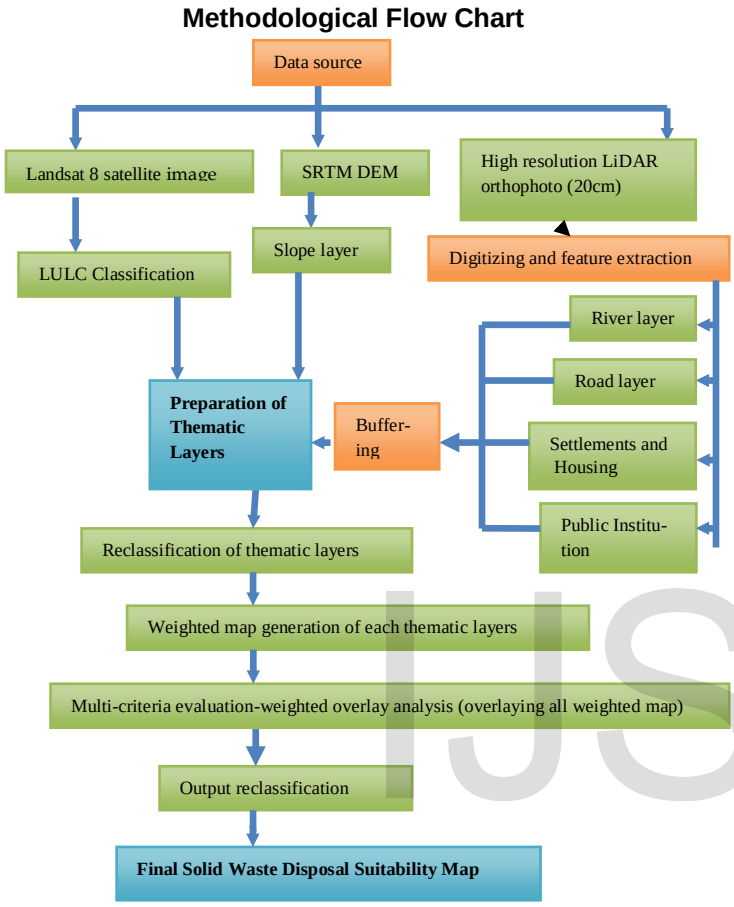

Fig.3. Flow chart of metnods applied in the study

3 RESULTS AND DISCUSSION

From the discussion and interview process with some leaders and communities of the city, the common dumping sites in Lae city is Second Seven. However, due to expansion of the city of Lae, the dumping site is no longer suitable. Therefore, the task is to identify suitable areas for solid waste dumping. In order to find suitable areas, settlements and housing with public institutions locations are to be considered, that is, how far they are going to be from dumpsite due to possible contribution to air pollution; the slope of the study area due to run-off potential is also to be considered; river network is also to be considered due to possible river pollution; the LULC features are also to be considered, to identify proper land cover like grassland or bare land area where dumpsite can be situated and finally the road network, that is to identify how far or how close is the road network to the dumpsite. The six (6) factors that were integrated and analysed in GIS environment to identify suitable sites for solid waste disposal are discussed here;

3.1 Land use land cover factor

When doing the classification, the LULC factor was prepared with four classes, that is, 'Bare land and Grassland', Built-up areas, 'Bushes and shrubs' and water. In this study the factor was considered as very important key factor in doing solid waste disposal site selection. In the classification process, the features were identified and weightages were assigned. According to several literatures reviewed, bare lands and grasslands are considered as highly suitable areas for solid waste disposal. Thus higher weightage of value four (4) was assigned. The built-up areas and water was considered as very unsuitable sites for solid waste disposal. Thus weightage of value four (1) was assigned. However, other factors are also needed to be considered and integrated with LULC factor to arrive at final result. The thematic map prepared is shown in figure 4(A) and the general information, which is weightage and % influence assigned, area in both kilometre square and percentage is tabulated in Table 2.

3.2 Public Institutions suitability

Public institutions are the protected areas such as church ground, schools, law enforcement base, health centres, etc. The environment surrounding these areas should remain pollution free. They are revered and protected zones. With this in mind, the buffer zones were created around all public institutions that were identified and extracted from high resolution LiDAR orthophoto. With specified distance in meters, four zones were created. The zones were created to identify suitability of each zone in solid waste disposal. Buffer zone surrounding the public institutions from 0 - 400m distance was considered unsuitable sites, 400 - 800m was considered less suitable, 800 - 1200m was considered moderately suitable and > 1600m was considered highly suitable. The greater weightage value of four (4) was assigned to the class or zone > 1600, while lower weightage was assigned to class or zone 0 - 400m. However other factors are also needed to be considered and integrated with public institution buffer zones factor to arrive at final result. The thematic map prepared is shown in figure 4(B) and the general information, which is weightage and % influence assigned, area in both kilometre square and percentage are tabulated in Table 2.

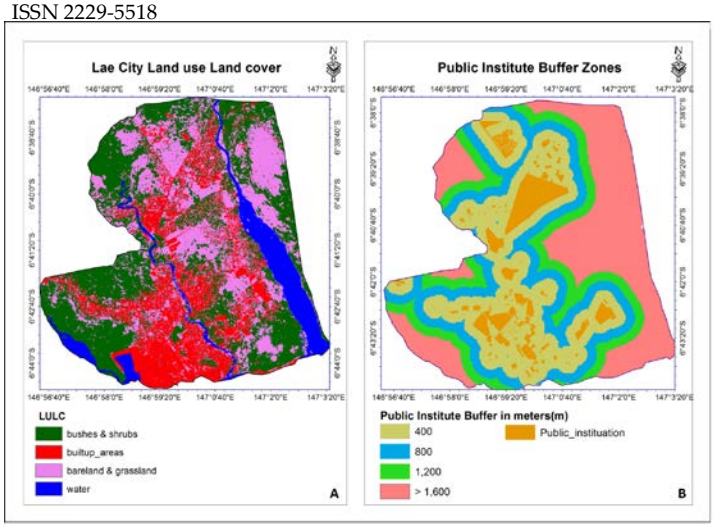

Fig. 4. Thematic layer for LULC and Public Institutions buffer zones.

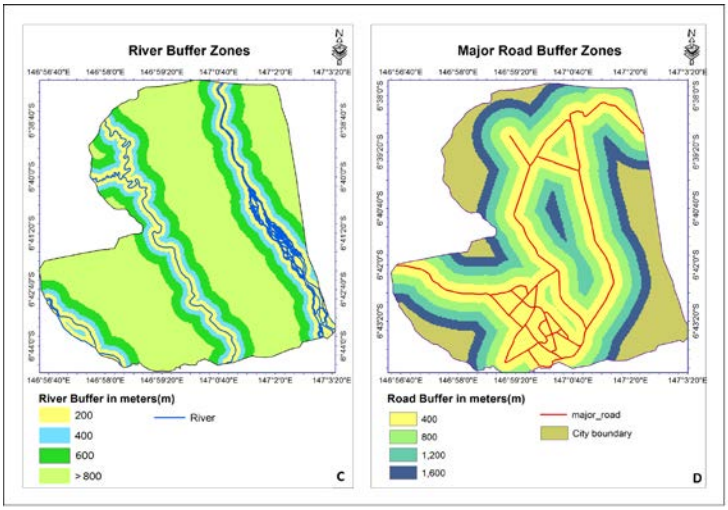

Fig. 5: Thematic layer for river buffer and road buffer.

3.3 Major River suitability

Three (3) major rivers encompassing Lae city were identified and extracted from high resolution LiDAR orthophoto. The dumping of waste along or near the river leads to river pollution. That is during the heavy rainfall, the solid waste materials and the harmful soluble components of it are easily washed down to main river stream creating pollution. Therefore it is vital to select a dumpsite far away from the flowing rivers. Four (4) buffer zones were created giving specific distance away from the flowing river to identify suitable dumpsites. Buffer zone surrounding the river at 0 - 200m distance was considered as unsuitable areas for solid waste disposal, 200 - 400m was considered less suitable, 400 - 600m was considered moderately suitable and greater then 800m was considered highly suitable sites for solid waste disposal. However other factors are also needed to be considered and integrated with river buffer zones factor to arrive at final result. The thematic map prepared is shown in figure 5(C) and the general information, which is weightage and % influence assigned, area in both kilometre square and percentage are tabulate in Table 2.

3.4 Major road suitability

According to Ebusti et al (2013), the landfills or dumping sites shall not be located within 100 m of any major highways, city streets or other transportation routes. Solid waste dumping site must be located at suitable distance from roads network in order to facilitate transportation and consequently to reduce relative costs. According to the extent of the city and the boundary demarcated, four (4) buffer zones were created to identify most suitable areas of solid waste dumping. Buffer zone surrounding the major road at 0 - 400m distance was considered unsuitable sites, 400 - 800m was considered less suitable, 800 - 1200m was considered moderate and from 1200 - 1600m was considered highly suitable. However other factors are also needed to be considered and do integration to arrive at final output results. The thematic map prepared is shown in figure 5(D) and the general information, which is weightage and % influence assigned, area in both kilometre square and percentage are tabulated in Table 2.

3.5 Settlements and housing suitability

Settlements and housing are the key components to be considered because this is where huge population exists. With respect to quality health of the people or community the dumpsites near the settlements and housing is considered as risky. The dumpsite is to be located at specific distance away from settlements and housing. With that in mind, the buffer zones were created with specified distance away from the settlements and housing area. Four zones were created. The zone created with buffer distance from 0 - 400m was considered unsuitable areas for solid waste disposal, 400 - 800m is less suitable, 800 - 1200m is moderately suitable and grater than 1600m is considered as highly suitable. However other factors are also needed to be considered and integrated with settlement and housing buffer zones to arrive at final result. The thematic map prepared is shown in figure 6(E) and the general information, which is weightage and % influence assigned, area in both kilometre square and percentage are tabulated in Table 2.

3.6 Slope factor

Slope is one of the key factors that is to be considered when dealing with suitable sites identification. The higher sloppy area is considered unsafe for solid waste disposal because during heavy rainfall, all the dumped materials with their dissolved components are washed down to lower slopes where the city or settlements are located and hence can prove fatal as far as pollution potentials are considered. Hence lower sloppy area was considered as high suitable areas for solid waste disposal. The slope in degree was reclassified to four classes that is < 3 degree slope which was considered as most suitable area, 3 - 7 degree slope which was considered as moderately suitable, 7 - 15 degree slope which is considered as less suitable and 15 - 34 degree slope which is considered as unsuitable site for solid waste disposal. High weightage of value four (4) was assigned to lower slope and less weightage was assigned to higher slope. However, other factors are also needed to be considered and integrated with slope factor to arrive at final result. The thematic map prepared is shown in figure 6(F) and the general information, which is weightage and % influence

assigned, area in both kilometre square and percentage is tabulate in Table 2.

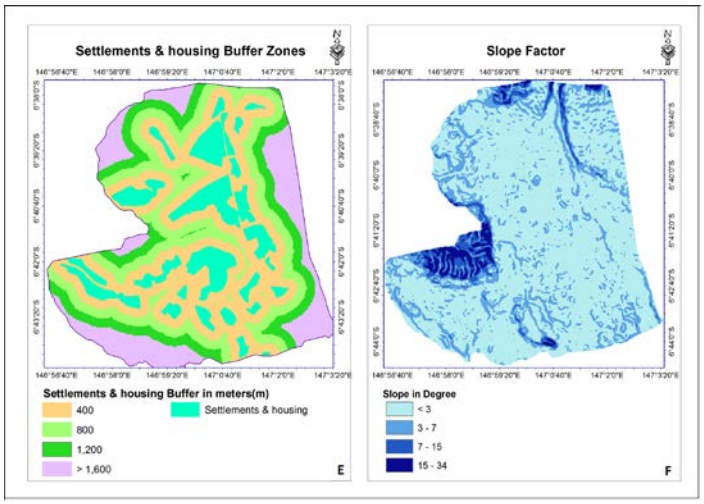

Fig.6. Thematic layer for settlements and housing buffer zones and Slope factor

After preparing all the thematic layers as discussed above, weighted overlay analysis was carried out. This is where all the factors as discussed above are overlaid onto each other and based upon the weightage and % influence assigned, the final suitability map was generated (Figure 7). All the necessary information about six (6) thematic layers generated are tabulated in Table 2.

As it can be seen from the Table 2 below, for each factor the % influence was assigned according to each importance in contribution to identify solid waste disposal sites, for each classes of each factor the weightage was assigned. When integrating all these information in GIS environment, the final solid waste disposal sites suitability map was created. Also from Table 2, the total area for each class was computed. Table 3 tabulates the general information of the final output suitability map that was created. The final output map created was again reclassified to three (3) classes. It was found that 10.27% of total study area was highly suitable sites for solid waste disposal (Site A, Site B, Site C, Site D, Site E and Site F according to their area size) (Figure 7), 53.87% was moderate suitable and 36.14% was unsuitable sites for solid waste disposal.

Table 2: General information for six (6) thematic layers

Thematic Layers	% Influence	Classes /Zones	Weightage	Area (square km)	Area (%)
Public Institutions Buffer Zones(m)	20				
		400	1	40	35.71
		800	2	21	18.75
		1,200	3	16	14.29
		> 1,600	4	35	31.25
River Buffer Zones(m)	10			Total = 112	
		200	1	18	16.07
		400	2	12	10.71
		600	3	21	18.75
		> 800	4	61	54.46
Settlements & Housing Buffer Zones(m)	23			Total = 112	
		400	1	56	50
		800	2	23	20.54
		1200	3	14	12.5
		> 1,600	4	19	16.96
LULC	27			Total = 112	
		bushes & shrubs	3	42	37.84
		Built-up areas	2	24	21.62
		bare land & grassland	4	34	30.63
		water	2	11	9.91
Slope in degree	15			Total = 111	
		< 3	1	80	72.72
		3-7	2	22	20
		7-15	3	5	4.55
		15-34	4	3	2.73
Road buffer Zones(m)	5			Total = 110	
		400	1	37	47.66
		800	2	23	25.27
		1200	3	18	19.78
		1600	4	13	14.2
					9
				Total = 91	

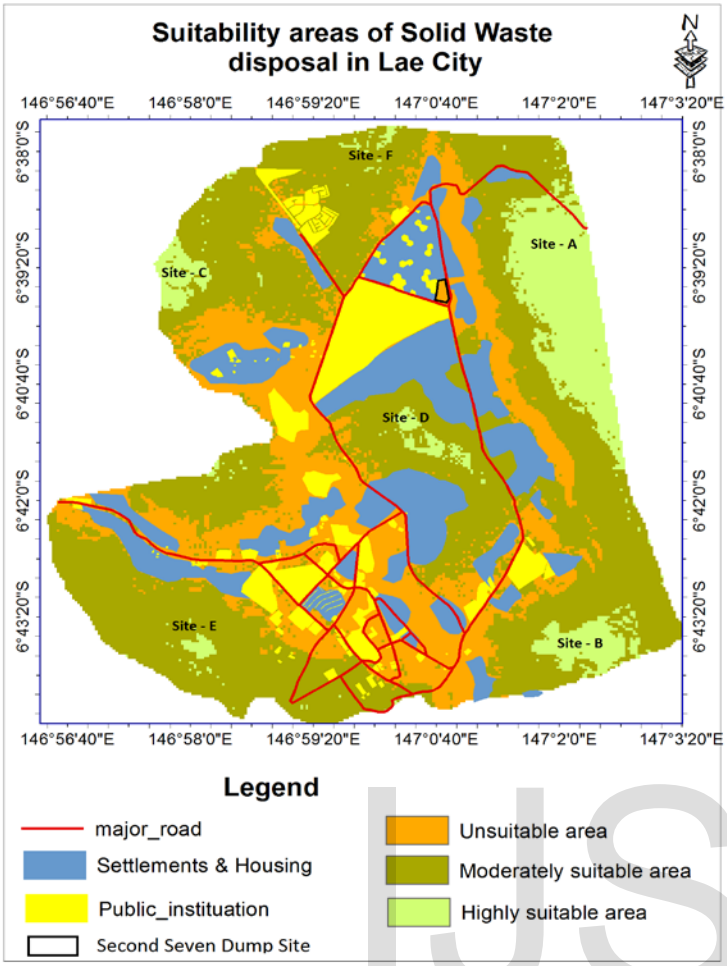

Fig. 7. Solid waste disposal sites suitability map

Table 3: General information of the final output suitability map that was Created (figure 2)

Suitability	Suitability Intensity Value	Area in km2	Area in %
Unsuitable area	1	39.75	36.14
Moderately Suitable area	2	59.63	53.84
Highly Suitable area	4	11.37	10.27
Total		110.75	100

4 CONCLUSION

Due to urban sprawl and accompanying increase of population pressure, the priority task for municipal governing bodies is to make proper planning for a sustainable, pollution-free environment. Thus identification of suitable areas for waste disposal is of paramount importance for urban planning due overarching civic concern for pollution and health care. In this research study through applying GIS and Remote sensing techniques, there are about six (6) sites in Lae city and surrounding, which were identified as highly suitable areas for solid waste disposal. The six sites were lettered as Site A to Site F according to its area size. The six (6) municipal and environmental factors were assessed and analysed in GIS environment. By going through weighted overlay analysis process, the suitability sites were identified. From our analysis and other local authorities' point of view the six sites generated will be highly suitable areas for solid waste disposal (Figure 7). Apart from these six sites, the second seven dump site and others that currently exist or have existed are considered unsuitable or moderately suitable.

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