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GIS and Multicriteria Analysis Application on Suitable Site Selection for Municipal Solid Waste Transfer Station in Greater Monrovia, Liberia

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Abstract – The inability of existing transfer stations in Greater Monrovia, Liberia, to handle municipal solid waste collected daily from designated collection points for temporary storage and final disposal has resulted in a number of issues such as abandonment of overfilled skip buckets and reinforced concrete bins, indiscriminate waste disposal into drainages, along roadside, river banks, and so on. This situation has also resulted in a number of negative consequences, including environmental degradation, public health concerns, depreciation of the value of adjacent properties, and decrease in the quality of life of the population. The local authorities have made relentless efforts to secure funding through its international partners to construct a well-designed municipal solid waste transfer station, However, due to the study area's topographic complexities, it is difficult for them to select an ideal site for a municipal solid waste transfer station to collect waste from designated and illegal collection points on time. To solve this issue, the research will analyze and identify potential sites while keeping the environment and population within the study area in mind. The research employs a comprehensive evaluation of multiple factors, including lithology, slope, drainage density and land use through GIS tool like Analytic Hierarchy Process (AHP) to identify potential sites that meets sustainable waste management's requirements. The results showed that 43% of the study area is not suitable, 20% is least suitable, 20% is moderately suitable, 11% is suitable and 6% highly suitable for an environmentally-friendly transfer station. Central Monrovia A and B, and Northwest of Paynesville are areas identified to be suitable for municipal solid waste transfer station.

Keywords – Multicriteria Analysis, Geographic Information System, Transfer Station, Skip Buckets, Re-Enforced Concrete Bins.

INTRODUCTION

The population of Greater Monrovia, Liberia has increased 13-fold over the past 50 years, from 80,000 in the 1960s to its present size. While consistent census data is not immediately accessible, the wider region of Greater Monrovia including Paynesville has an estimated population of 1.5 million which accounts for approximately one third of the total Liberia population. With this population, an estimated 272,238 tons of municipal solid waste is expected to be generated in 2023 [1]. Based on this estimation about 800 tons will be generated daily thus exceeding the current capacities of the two transfer stations including Fiamah about 80 tons and Stockton Creek about 180 tons (425 design capacity) in the study area [2] , [3]. The projected increase in municipal solid waste generation, combined with the inadequate capacities of the two (2) municipal solid waste transfer stations, make it impossible for waste to be collected from designated collection points on time, resulting to the indiscriminately disposal of waste into open spaces, along roadside, and waterways, posing significant health risks to residents [4]. This situation has also led to environmental degradation, economic losses, and a decline in the quality of life of the resident [5]. Solid wastes are non-liquid and non-gaseous by-products of human operations that are deemed unproductive. It includes biodegradable (paper, textiles, food waste, straw, and yard trash), partially biodegradable (wood, disposable napkins, and sludge), and non-biodegradable items (leather, plastics, rubbers, metals, glass, ash from coal, briquettes, or woods burning, dust, and electronic waste). Improper solid waste disposal can have major environmental and health repercussions, such as air pollution, water pollution, soil contamination, and disease spread [6]. The government of Liberia together with its international partners are working together to improve solid waste collection, transportation and disposal through the construction of a well-designed municipal solid waste transfer station. However, and given the topographic complexities of the study area, the identification of a suitable site for municipal solid waste transfer station has been a major challenge. This research is aimed at using GIS and multicriteria analysis to locate potential sites for municipal solid waste transfer station.

I. MATERIALS AND METHODS

1.1 Study Area

Greater Monrovia lies between latitude 6°18′48″N and longitude 10°48′5″W in Montserrado County and it located on the coast of Liberia and has a tropical climate with high temperatures and humidity throughout the year (Figure 1). The study area experiences two distinct seasons: the rainy season and the dry season. The rainy season lasts from May to October and is characterized by heavy rainfall. During this season, the area receives an average of 3,800 mm (150 inches) of rain annually. The dry season runs from November to April and is characterized by lower humidity and temperatures. However, temperatures can still be quite high, reaching up to 32°C (90°F) in some areas. The harmattan wind, which is a hot, dry wind blows from the Sahara Desert during the months of December to February. Additionally, the area also experiences high humidity, averaging around 80% throughout the year. The area is characterized by a high level of informality, with many people engaging in street vending, small-scale entrepreneurship, and other informal economic activities. Services including banks, insurance companies, and microfinance institutions, telecommunications, hospitality, agriculture government and NGOs and transportation are sectors that provide employment a minority of the residents in the area. Access to basic services such as healthcare, education, and sanitation remains a significant challenge for many residents of the area. The area's infrastructure is underdeveloped, with limited access to safe drinking water, reliable electricity, and adequate transport infrastructure. Many (70%) residents live in informal settlements without access to basic services or legal protection. The area has a population of 1.5 million people and is divided into thirteen zones (wards) namely Paynesville, Gardnersville, Bardnesville, New Georgia, New Krutown, Logan Town, Clara Town, Central Monrovia A, Central Monrovia B, West Point, Sinkor, Old Road, Larkparzee, Congo Town (Figure 1) under ten electoral districts according to Liberia Institute of Statistics and Geo-Information Services [6]. Figure 1 shows the Study Area (Greater Monrovia).

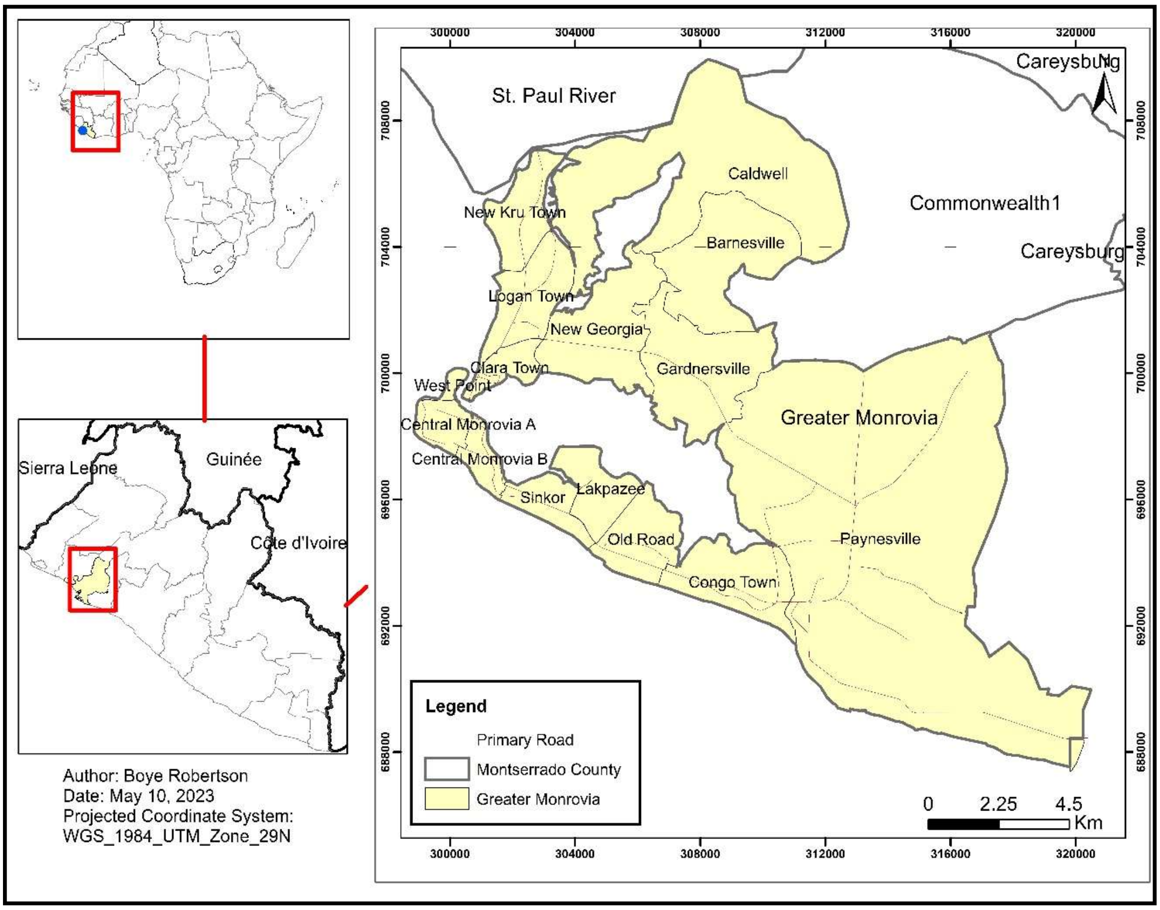

Figure 1: Study Area

1.2 Mythology Approaches

The data for lithology and land use for the study area was obtained from the Liberia Institute of Statistics and Geo-Information Services (LIGIS). The agency is responsible for data collection and management in Liberia. The SRTM data used to generate the slope and drainage density maps was downloaded from USGS.

1.2.1 Generation of factors' maps

Lithology

The lithology data was loaded in ArcGIS software application and used to generate lithology map of Greater Monrovia [7] .

Slope

The slope map was developed from the SRTM image in ArcGIS software application using spatial analyst tool and filled using fill tool to replace the depressions or low points in the digital elevation model (DEM) with interpolated values that are higher than the surrounding terrain. The slope was converted to degree to create a slope map. After the slope was reclassified into five (5) classes with between 0 ° - 1.194° degree classified as zero slope, 1.194° – 2.786° low slope, 2.2786° -5.373° moderate slope, 5.373° - 9.852° strong slope and 9.852° - 25.373° as steep slope [8], [9].

Drainage density

The drainage density map of the study area was generated from the STRM image in the ArcGIS software application. The image was filled using the fill spatial tool to replace the gaps/ depression in the image. And it was generated from several steps including the use of flow accumulation tool to identify the areas where water is likely to accumulate based on the slope of the terrain, the raster calculation tool and apply a threshold value of 500 to flow accumulation raster to identify the areas with the highest accumulation values which are indicative of stream channels within the study area; the stream link was used to identify the main channel network and calculate the total length of stream channels within the study area; used the stream order tool to assign a hierarchical order to the stream network and to calculate the stream order for each segment of the stream network; followed by the stream to feature tool to convert the stream network in a raster format to a vector format so as to do further analysis of the stream network and to calculate the length of the stream segments that contributes to each stream segment within the study area. Then the line density was used to calculate the density of stream channels within the study area. The drainage density was furthered reclassified into five (5) classes including 0-1.105 as the lowest; 1.105 – 2.210 as low; 3.315 as moderate; 3.315-4.420 as high and 4.420 as very high [10]. [7].

Land use/ land cover

The land use data was load in ArcGIS software application and used to create a buffer distance of 150, 200, 250,300 and 350m around the residential areas The residential areas with 150 meters – 250 meter's buffer was considered as not safe areas for placement of a transfer station, while areas with 300 meters' buffer considered safe and 350 meters' as the most safe or preferable areas to place a municipal solid waste transfer station [11].

1.2.2 Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP). The method used in the AHP process consists of the identification of the criteria / factors involved in the study of identifying a suitable site for municipal solid waste transfer, the classification and standardization of the criteria / factors, the weighting of the criteria, and the aggregation.

Classification and standardization of criteria

The criteria selected were classified according to their degree of influence on identifying suitable sites for municipal solid waste transfer station in the study area. In the standardization, the factors were assigned by weights according to their degree of influence.

Table 1: Factors in the analysis of site suitability for municipal transfer station

Factor	Classification	Rank
Lithology	Beach Deposit Unit 1, Beach Deposit Unit 2, Monocratic Gneiss-Relatively high permeability	3
	Diabase-Extremely low permeability	9
	Edina Sandstone, Paynesville sandstone-Relatively low permeability	6
	Fluvial and Deltaic Deposit-High permeability	2
	Lagoonal and Beach Deposit- Quite high permeability	1
	Water	Restricted
Slope	0-1.194209	1
	1.194209-2.786487	3
	2.786487-5.373939	9
	5.373939-9.85221	7
	9.85221-25.376934	2
`	0-0.433	9

Drainage Density	0.433-1.105	7
	1.105-2.015	3
	2.015-3.228	2
	3.228-5.526	1
Land use	150	1
	200	1
	250	2
	300	7
	350	9

Weighting of criteria

This step is based on a pairwise comparison series, it was developed by Satty, 1997.The Pairwise comparison makes it possible to transform a complex decision problem into a series of simple judgments concerning the meaning of each of the indicators. In order to determine its relative importance, each indicator is successively compared with the other indicators of this same criterion [12].

Consistency ratio

The calculated priorities have a meaning only if the pairwise comparison matrices are coherent (respect of transitivity), it would then be necessary to apply a respect of coherence. If RC is less than 10%, then the matrix is considered acceptable otherwise the comparisons must be reviewed according to Satty, 1997.

The consistency indicator and the consistency rate are calculated as follows for checking the accuracy:

CR = Consistency index (CI)/Random Consistency Index (RI)

• CI = $(\lambda max - n)/n - 1$

- λmax is the Principal Eigen Value; n is the number of factors

• $\lambda max = \Sigma$ of the products between each element of the priority vector and column totals.

Table 2: Saaty random consistency indices

• n -	1	2	3	4	5	6	7	8	9	10
• RI -	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Random Consistency Index (RI) [13].

Aggregation of criteria

The aggregation step is done following the assessment of the factors and the calculation of the weighting coefficient to be assigned to each factor. Thus, the lithology of the area, the slope, the density of drainage, and the type of soil were combined to give the map of the suitable site in Greater Monrovia. These factors were combined in ArcGIS with the Weighted Overlay Tool.

$S = \Sigma W_i X_i$, With S the result of the combination, Wi the weight of factor *i*, Xi the value of the criterion of factor *i*.

II. Results And Conclusions

2.1 Results

2.1.1 Lithology

Lithology refers to the physical and chemical characteristics of the rocks and soils that make up a watershed. The lithology of a watershed affects the rate at which water infiltrates into the ground, the capacity of the subsurface to store and transmit water, and the chemical composition of the water that flows through the watershed. For example, watersheds with permeable lithology such as sandstone or limestone may have higher rates of groundwater recharge and storage, while watersheds with impermeable lithology such as shale or clay may have lower rates of infiltration and groundwater storage [14].

Figure 2a and 2b show the lithology formation and permeability for each lithology within Greater Monrovia.

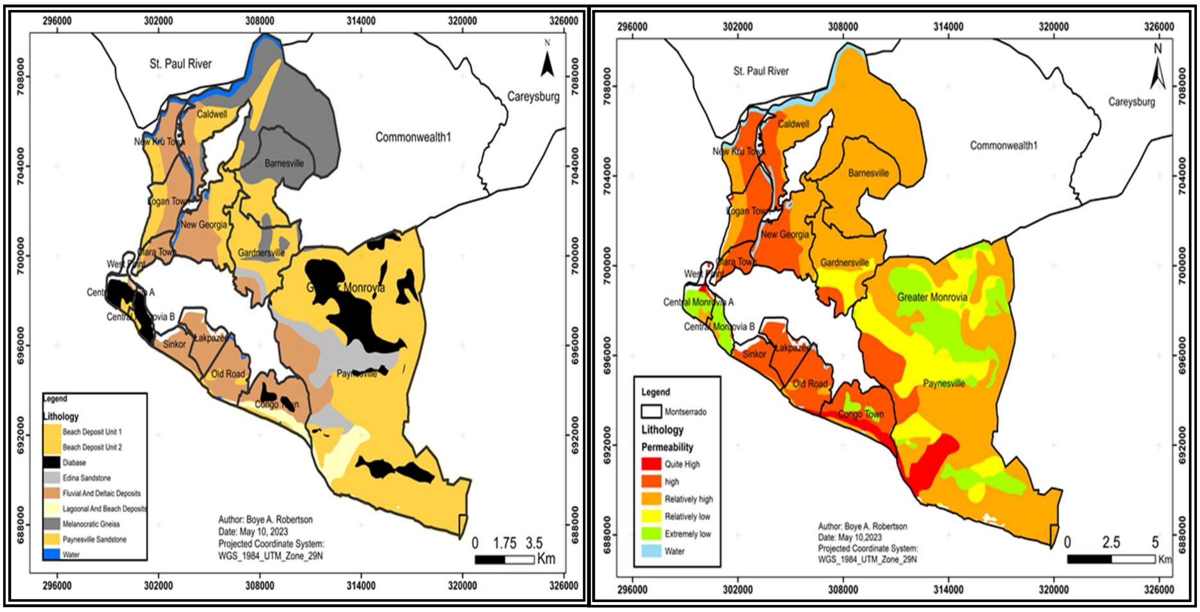

Figure 2: Lithology on the left and permeability of lithology on the right

According to the maps, there are eight (8) lithological formations in Greater Monrovia in which 5% of the area of Greater Monrovia comprising Beach Deposit Unit 1 and 32% Beach Deposit Unit with both having relatively high permeability. Greater Monrovia also contained 10% of Diabase which has an extremely low permeability. Additionally, Greater Monrovia contained 6% of Edina Sandstone which has relatively low permeability, 21% of Fluvial and Deltaic Deposit with high permeability, 3% of Lagoonal and Beach Deposit containing quite high permeability, 16% of Macronotic Gneiss containing a relatively high permeability and 7% of Paynesville Sandstone which has relatively low permeability.

2.1.2 Slope

Slope is the inclination or steepness of the surface of an area; it is used for the analysis of the surface considered in this project to determine which area may be prone to erosion. It has been specified that waste site should be situated on surface with slope less than twenty degrees (20º). Therefore, a slope map was created from digital elevation model (DEM), and the DEM was converted to raster data format before it was used for spatial analysis. Figure 3a and 3b present the slope within Greater Monrovia.

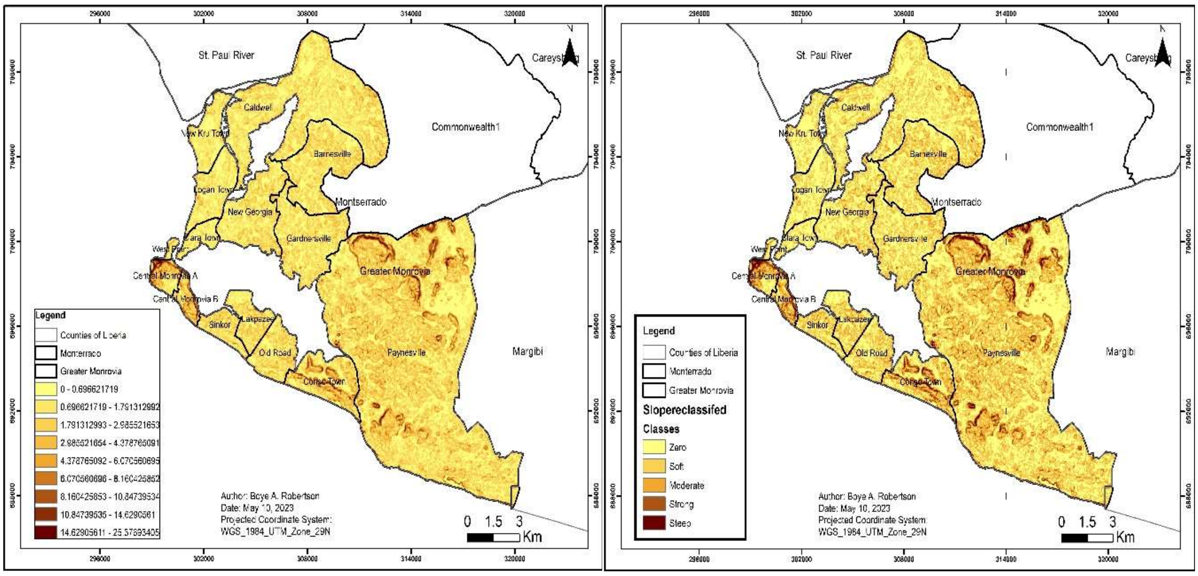

Figure 3: Slope on the left and reclassified right on the right

According to the figure 3a and 3b, Bardenesville, Gardenesville, New Georgia and Caldwell have a slope between 0 to 2.292-degree which are classified as zero to moderate slope, while Central Monrovia A and part of Central Monrovia B in the Southwestern part of Greater Monrovia have slope between 5.397 to 25.367 degree which are classied as strong to steep slope.

2.1.3 Drainage density

Drainage density refers to the amount of stream length per unit area in a watershed. Watersheds with higher drainage densities generally have more streams and higher streamflow, which can affect water quality and quantity. Drainage density can also affect the potential for flooding and erosion. Figure 4a and 4b showed the drainage density within Greater Monrovia.

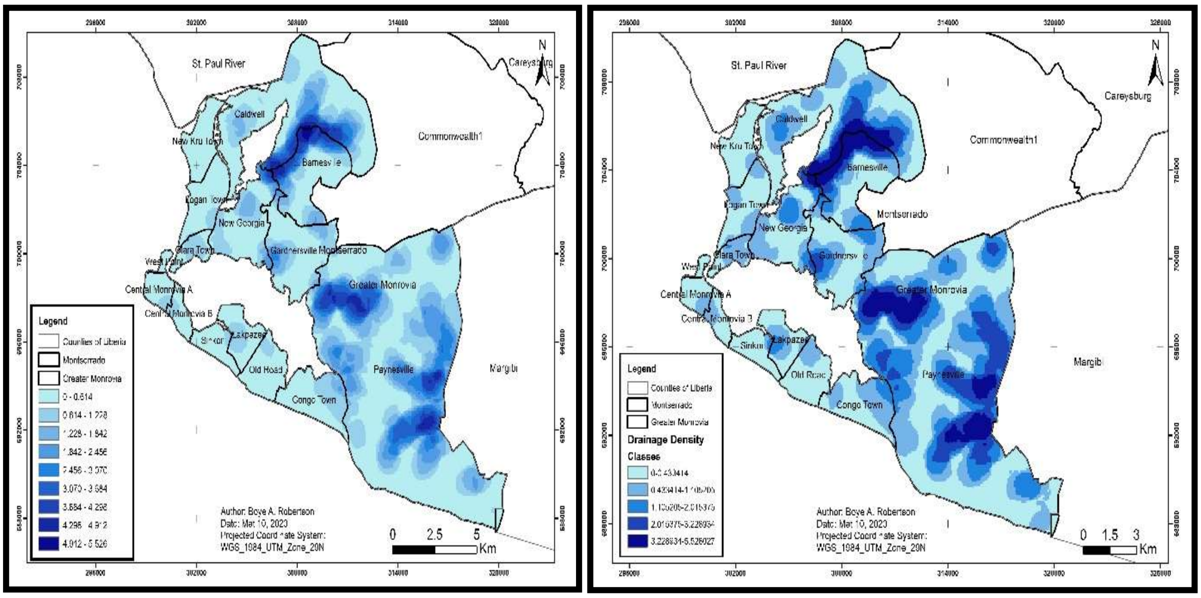

Figure 4: Drainage density on the left and reclassified drainage density on the right

According to figure 4a and 4b, the Northern part of Greater Monrovia especially in Caldwell and the Northwestern and Southeastern part contained a drainage density between 2.211 to 5.926 constituting the highest level of drainage density. The Southwestern part contained drainage density between 0 to 2.210 representing the areas with the lowest drainage density area.

2.1.4 Land use/land cover (2021)

The land use / land cover map of Greater Monrovia (see figure 5) shows the residential land use / land cover type in Greater Monrovia. Buffers of 150, 200, 250, 300 and 350-meters' distance was generated around each residential area in Greater Monrovia to so as to avoid pollution and other health issues. Figure 5 represents the residential area within Greater Monrovia.

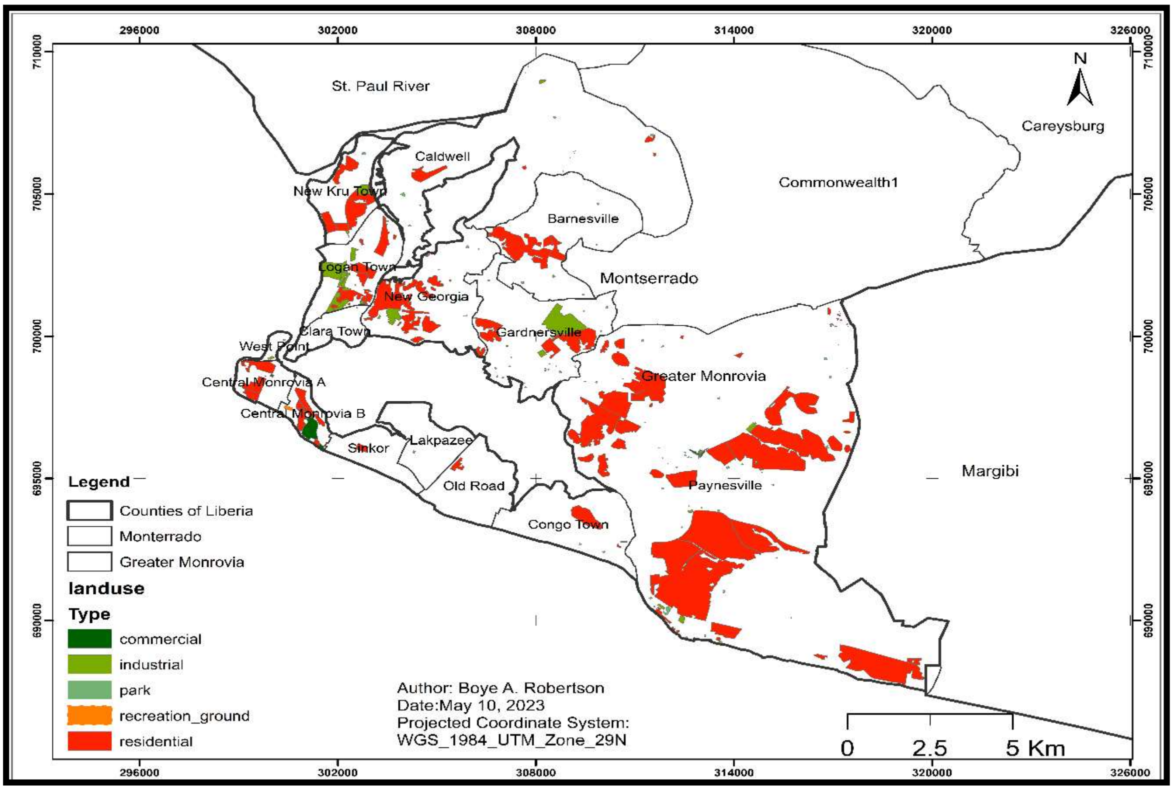

Figure 5: Land use /land cover (2021)

A buffer of 350 meters was considered as most preferable buffer to prevent potential heal hazard and other health issues.

2.1.5 The weights assigned to each factor

Table 2 presents the weights assigned to each factor.

Table 2: The weights assigned to each factor

Matrix		Lithology	Slope	Drainage density	Land use	normalized principal Eigenvector
		1	2	3	4	
Lithology	1	1	5	7	9	68.69%
Slope	2	1/5	1	1	2	13.13%
Drainage density	3	1/7	1	1	1	10.17%
Land use	4	1/9	1/2	1	1	8.01%

The four (4) selected factors are assigned the following weights 68.13% for the lithology which represents the most influential and important criterion. The slope has a weight of 13.1% followed by drainage density with a weight of 10.2% and land use with 8.0% assigned weight.

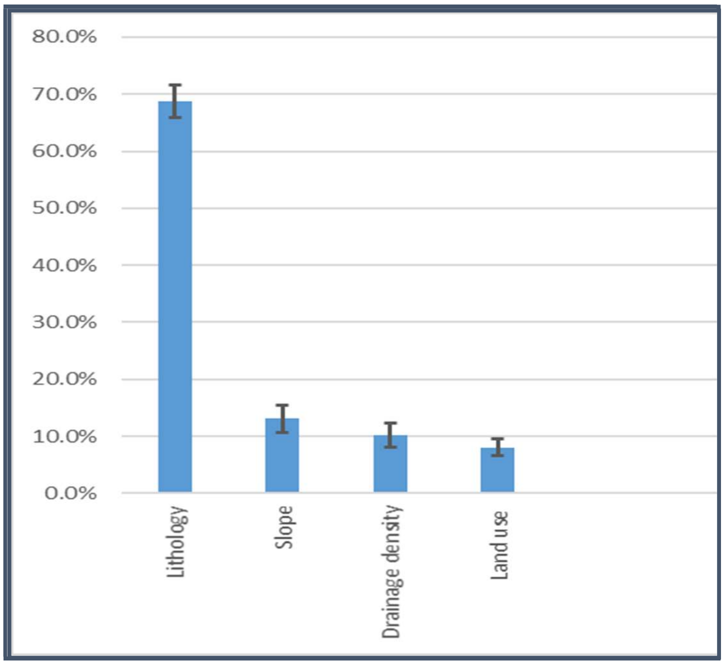

Figure 8: Histogram of the weight of the factor

Table 3: Weight of factor

Factor		Comment	Weights	+/-
1	Lithology		68.7%	2.9%
2	Slope		13.1%	2.4%
3	Drainage density		10.2%	2.1%
4	Land use		8.0%	1.5%

2.1.6 Suitable site for Municipal Solid Waste Transfer Station in Greater Monrovia

The suitability site map for municipal solid waste transfer station (see figure 7) shows five (5) classes which are depicted in green, yellow and red. The green are depicted in two values and the red depicted in two value. The high value green color are areas that highly suitable site for municipal solid waste transfer station, while the low value green color are areas that are suitable. Additionally, the high value red color depicts areas that are not suitable, while the low value red color are areas least suitable for municipal solid waste transfer station.

Figure 7 presents the suitable site for municipal solid waste transfer stations in Greater Monrovia.

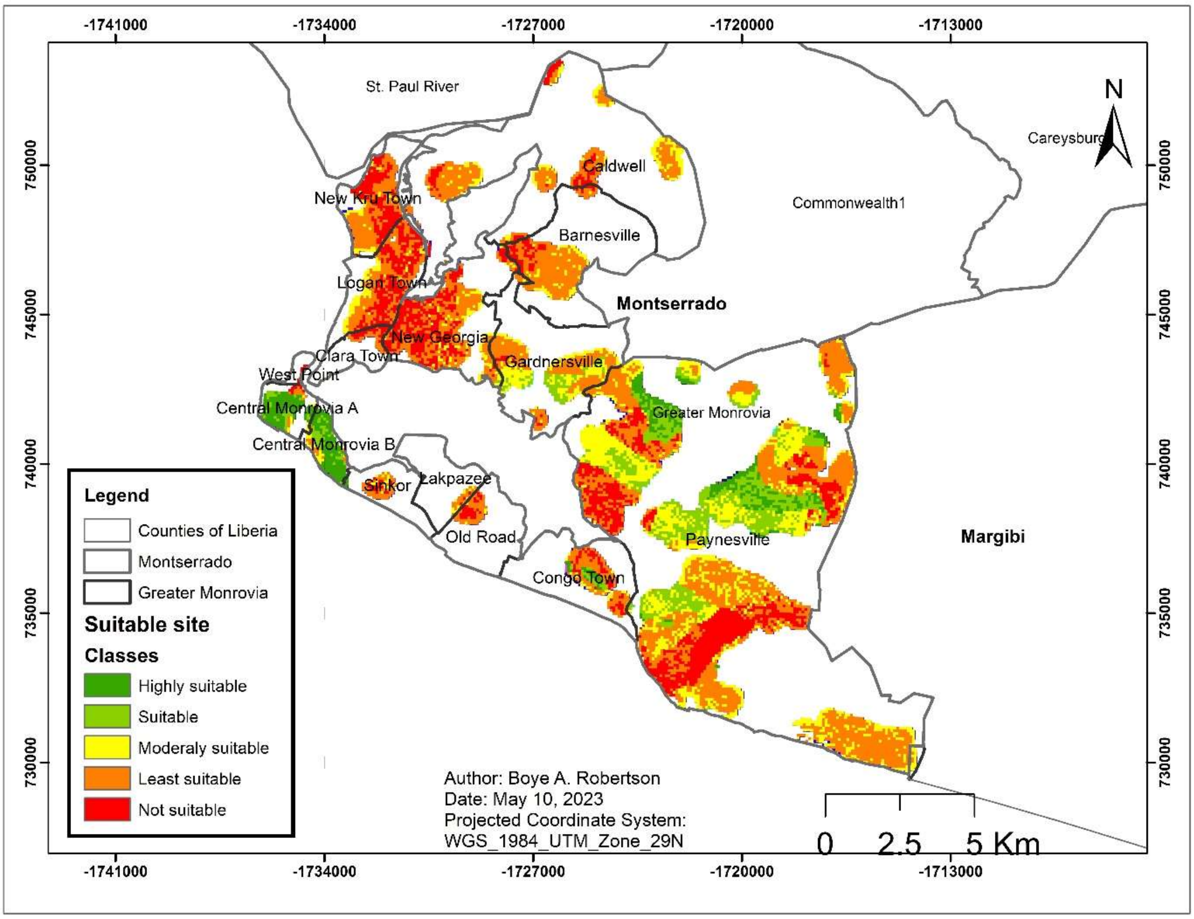

Figure 7: Suitable site for municipal solid waste transfer station in Greater Monrovia

As per Figure 5, Greater Monrovia is classified into five (5) classes. Of the total area of Greater Monrovia, 43% is considered as least suitable, 21% as not suitable, 20% as moderately suitable, 11% as suitable and 6% is highly suitable for the siting of municipal solid waste transfer stations.

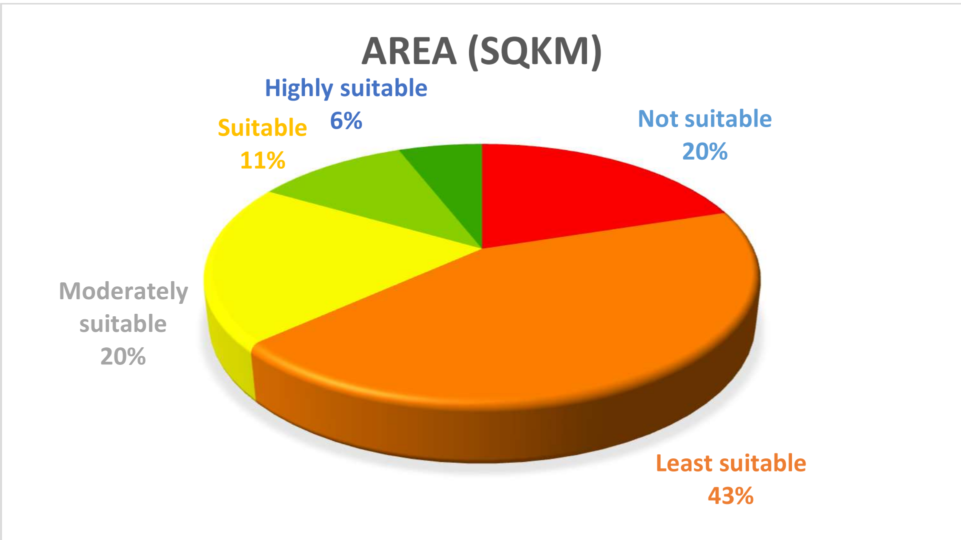

Fig. 8: Proportion of suitable site for transfer station

Table 3: Suitable site for municipal solid waste transfer station

This table summarizes the area (square kilometers) per each class of suitable site within Greater Monrovia.

Classes	Area (sqkm)	Percentage
Not suitable	16.6031	20%
Least suitable	35.7927	43%
Moderately suitable	16.6296	20%
Suitable	8.87391	11%
Highly suitable	4.89112	6%

The result showed that 16.7 square kilometers about 20% of Greater Monrovia is not suitable for a municipal solid waste transfer station, 35.8 square kilometers about 43% is least suitable, 16.6 square kilometers about 20% is moderately suitable, 8.9 square kilometers about 11% is suitable and 4.9 square kilometers about 6% is highly suitable.

2.1.7 Comparison with existing municipal solid waste transfer stations' locations

There are two transfer station in Greater Monrovia. They include Stockton Creek which is located in the North and Fiamah in the South. These two (2) have a capacity of about 250 tons including Stock Creek 425 ton (design capacity but smaller than that, about 180 tons) and Fiamah 80 tons. The two transfer station have the capacity to accommodate only 33 percent of the waste generated daily in Greater Monrovia.

Figure 8a presents the result on the comparison between results from the research and current transfer stations locations.

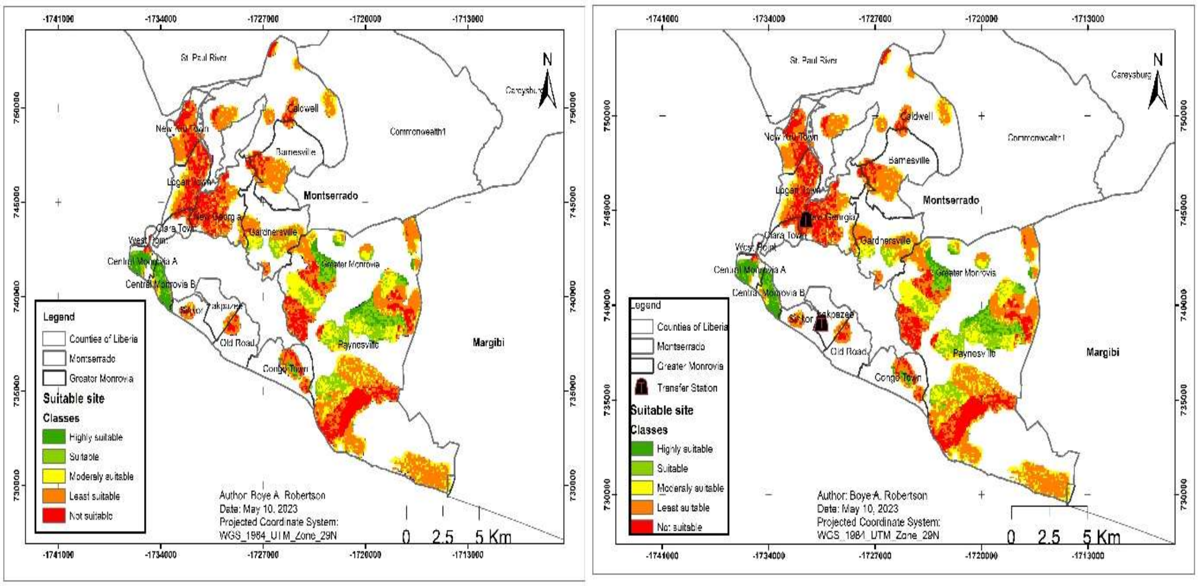

Figure 8: Suitable site on the left and existing transfer stations on the right

Figure 8b showed that the Stock Creek Transfer Station is sited in a not suitable site, while Fiamah Transfer was constructed in an area which might have high population concentration, high slope, high drainage density or in a lithological area with high permeability. This showed that a proper environmental assessment analysis was not implemented prior to the siting of the two stations thus putting the water sources in Greater Monrovia at risk of being polluted from leachate [15].

2.2 Discussions

2.2.1 Importance of the selected factors for the identification of suitable site for municipal solid waste transfer station construction

Greater Monrovia lies in a flood plain area thus making the area venerable to flooding [16]. The area experiences two distinct seasons including rainy season and the dry season. The rainy season lasts from May to October and is characterized by heavy rainfall (3,800 mm of rain annually. Siting a municipal solid waste transfer station requires an intensive analysis to identify factors that could ensure the protection of primarily the surface and ground water so as to avoid leachate (wastewater generated from water mixing with waste). Locating a site for municipal solid waste transfer stations in Greater Monrovia, Liberia, faces various environmental and climatic challenges. One of the most significant challenges is the high rainfall intensity, which results in flooding and soil erosion in some parts of the city. This can pose a significant risk to the transfer station's infrastructure, leading to damage and loss of functionality. Another challenge is the presence of sensitive environmental features such as wetlands, forests, and water bodies that need to be protected to avoid the degradation of the ecosystem services they provide (WSP Environmental, a global consultancy firm & Liberian Environmental Protection Agency (2013). This research which focuses on the use of GIS and MCA to identify suitable site for municipal solid waste transfer station considered four (4) criteria including lithology, slope, drainage density and land use.

The results from the research showed several potential sites which were classified into five classes including not suitable (43%), least suitable (20%), moderately (20%), suitable (11%) and highly suitable (6%). As per figure 7, the highly suitable sites (6%) are mainly located in Northern part of Paynesville and Central Monrovia A and B in Greater Monrovia. The not suitable sites (43%) are mainly located in New Georgia, Bardnesville, New Krutown, Logan Town and Southwestern part of Paynesville in Greater Monrovia.

2.2.2 Importance of Saaty's Multi-Criteria Analysis in site suitability assessment

The use of geospatial tools and Saaty's AHP multi-criteria analysis in the analysis and identification of suitable sites for municipal solid waste transfer stations. This method has shown its effectiveness in several works and it results are similar to other research work globally [17],[18],[19],[20],[21] .

2.2.3 Importance of Lithology in the siting of Municipal Solid Waste Transfer Station

Lithology refers to the physical characteristics and composition of rocks and soils in an area. It affects the permeability and stability of the subsurface, which can have significant implications for MSW siting. For instance, areas with highly permeable lithology, such as sandy or fractured rocks, may facilitate the movement of contaminants into groundwater. Conversely, impermeable lithology, such as clay or bedrock, can act as a barrier and reduce the risk of pollution. Understanding the lithology of a site is crucial for assessing the potential for waste migration and selecting appropriate locations for MSW facilities [22].

2.2.4 Importance of Drainage density in the siting of Municipal Solid Waste Transfer Station

Drainage density refers to the amount and pattern of natural or artificial watercourses in a given area. It plays a crucial role in MSW siting due to the potential for contamination and pollution. High drainage density can increase the risk of leachate (liquid that seeps through waste) reaching groundwater or nearby surface water bodies. Therefore, areas with low drainage density are generally preferred for siting MSW facilities to minimize the potential for water pollution [23].

2.2.5 Importance of Slope in the siting of Municipal Solid Waste Transfer Station

Slope is an important factor in MSW siting as it affects the surface runoff and the potential for erosion. Steep slopes can enhance the erosion of exposed waste and increase the likelihood of surface water runoff carrying contaminants downstream. Additionally, landslides can occur in areas with unstable slopes, posing a risk to both the environment and human safety. Siting MSW facilities on gentle slopes or relatively flat terrain can help minimize erosion and the associated risks [24].

III. CONCLUSION

The identification of a suitable site for municipal solid waste transfer station in Grater Monrovia, an area which is witnessing a sharp increase in municipal solid waste generation, is very crucial. This increase is posing a serious challenge to the local authorities. However, resolving this challenge requires identifying suitable to construct a municipal solid waste transfer station to collect waste that is currently being left abandoned due to the inadequate capacities of the existing transfer stations (2) in Greater Monrovia. The two transfer stations were built following the end of the 14 years' civil war in Liberia. According to Howard and Irwin, as cited by Anifowose, Omole and Akingbade, "an ideal waste disposal site is the one that is located reasonably close to the source of the waste, has convenient transportation access, is not situated in a low lying area or floodplain, and is underlain by geologically stable, strong and competent rock materia [25]. The findings from this research have shown the capability of GIS and multicriteria analysis as an authentic tool for analyzing the criteria for decision support. The analysis uses lithology, slope, drainage density and land use as determining factors in order to find the most suitable sites for municipal solid waste transfer station in Greater Monrovia. The results have shown that 6% of the total area of Greater Monrovia were identified as highly suitable, 11% as suitable, 20 % as moderately suitable 20% as least suitable and 43 % as not suitable site for municipal solid waste transfer station.

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