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Geospatial Analysis for Suitable Landfill Site Selection. A case of the City of Kigali.

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Abstract:

The most widely used technique for managing urban solid waste is sanitary landfilling. The landfill is a highly demanded public resource; it contributes significantly to enhancing the quality of life for residents and safeguarding urban ecology by preventing the negative effects of solid waste on the environment and people. Rwanda has poor and unstable systems for managing waste from its source to its final disposal (landfill), especially in the City of Kigali, which still experiences open landfills with inappropriate site management. This study applied the GIS-based suitability technique (MCDA) in landfill site selection in the City of Kigali, Rwanda. The research study used different methods using GIS-based MCDA in spatial data processing and analysis, Microsoft Excel for qualitative and quantitate data from a purposively sampled community for social consultation. These research findings noticed the importance of the application of Multiple criteria decision analysis (MCDA), a GIS technique suitability analysis in landfill site selection as urged by the primary researcher and confirmed by the results from the target population, where 95% of sampled respondents agreed that GIS is useful for spatial analysis, especially suitability study. Most of the requirements for landfill site selection are distance to Residential Areas/built-up, Wetlands, Rivers, Lakes, Roads, Soil Permeability, and Slope. This research found that Residential Areas, Wetland, and Slope are the most sensitive criteria to consider for landfill site selection. The result of the GIS-based landfill site suitability map produced using the Multi-Criteria Decision Analysis (MCDA) for the City of Kigali showed that some most suitable site landfill selection is indicated by (green colour in the map). It is clear to conclude that the GIS-based landfill site suitability map for the City of Kigali is more important, not only the policy-making but also the future researchers.

Key Words: Geographic Information System (GIS), Multi Criteria *Decision Analysis* (*MCDA*), Landfill, Suitability, City of Kigali

1. Introduction

The most widely used technique for managing urban solid waste is sanitary landfilling. Furthermore, a landfill site is a piece of land where trash is dumped, either directly onto the ground (land raising) or into an unintentional hole in the ground (filling) (Rebecca and Arhin, 2016). Globally, landfills are situated in areas that are not suitable for socioeconomic use locally(Chabuk, 2016). As a highly demanded public resource, a highly sought-after public resource, Landfills contribute significantly to enhancing the quality of life for residents and safeguarding urban ecology by preventing the negative effects of solid waste on the environment and people (Hajam et al., 2023).

Municipal solid waste (MSW) is the term used to describe the trash that natural people generate throughout their construction, business, and residential activities and that municipalities gather and manage. The growth of the social economy, exponential increases in population and urbanization, and growing living standards have all contributed to an increase in MSW creation worldwide (Babalola & Busu, 2011). Developed nations produce between 521.95 and 759.2 kg per person annually (kpc), while underdeveloped nations produce between 109.5 and 525.6 kpc (Karak, 2012). MSW presents a serious risk to both human health and the environment. Every person on the earth is impacted by the global issue of municipal solid waste management, or MSWM (Nukusheva et al., 2023). Effective waste management techniques rely on institutional capabilities as well as regional waste characteristics, which change depending on cultural, climatic, and socioeconomic factors (Vergaraand Tchobanoglous, 2012).

Rwanda is experiencing the poor and unstainable systems for managing waste from their source to their final disposal (landfill) (Rajashekar, 2019). It doesn't adhere to waste management best practices, where the solid waste management system in Kigali City is still an open landfill, with an estimated 800 tons of solid trash collected daily and 292,000 tons annually (Rajashekar, 2019). Dumping sites in Rwanda municipalities, particularly in Kigali City are a significant source of air, water, and land pollution due to inappropriate methods of waste collection, transportation, disposal, and treatment in Kigali City (Iraguha et al., 2022). Low-income communities typically dump their trash in uncollected locations at the nearest vacant lots, streams, rivers, public areas, or water channels (ruhurura), polluting the surrounding ecosystem. The use of best practices in landfill planning is crucial for socioeconomic, environmental, and safety reasons (Sano, 2012).

Geospatial technologies broadly include remote sensing photogrammetry, cartography, geographic information system (GIS), global positional system (GIS), and information technology (IT) (Pednekar,2017). Geospatial technologies have a far-reaching impact on mapping,

monitoring, and management of land resources on sustainable basis (Kumar, 2018). Multiple Criteria Decision Analysis (MCDA) is one among geospatial technologies tools, and MCDA is used to measure the relative importance weighing for each criterion from geospatial data (Kumar, 2018). MCDA technology is also useful for landfills site selection and suitability analysis. The two are integrated: GIS offers reliable data analysis and visualization, while MCDA offers a consistent evaluation of potential eligible candidates, such as landfill sites, based on a variety of criteria(Tims, 2009). The combination of MCDA and GIS in the creation of multi-criteria spatial decision support systems (MC-SDSS) not only improves accuracy but also significantly enhances the effectiveness of evaluating site suitability indexes (Imagery and Panđa, 2023).

2. Methods and Materials

2.1 Description of study area

Figure 1 shows the city of Kigali, the capital of Rwanda, specifically all its three districts namely Gasabo, Nyarugenge, and Kicukiro, in which the research will be conducted. Kigali is a capital and largest city of Rwanda. It is situated at -1°56'22.79" S 30°03'20.40" E, approximately located in central of Rwanda. It observes central Africa time, which is two hours ahead of coordinated Universal Time (UTC+02:00) and it is shares the same time with rest of the country. As part of the country's 2006 local government restructuring, Kigali city is one of the 5 provinces of Rwanda. It shares the boundary with northern province in north, Eastern province in East and south and Southern province in west. The city and province of Kigali divided into 3 administrative districts which Gasabo that occupies the big part of the city in north, Nyarugenge in east and Kicukiro in Eastern-south. According to Rwanda population and housing census 2022, Kigali is the most urbanized province with 86.9% and total population of 1,745,555. The total size of Kigali city is 730km^2. The city is situated in an area of undulating hills, with steep slopes connecting a number of valleys and ridges. Regarding the elevation compared to sea level, the highest point in Kigali city is at 1,853 meters and the lowest point is 1300 meters.

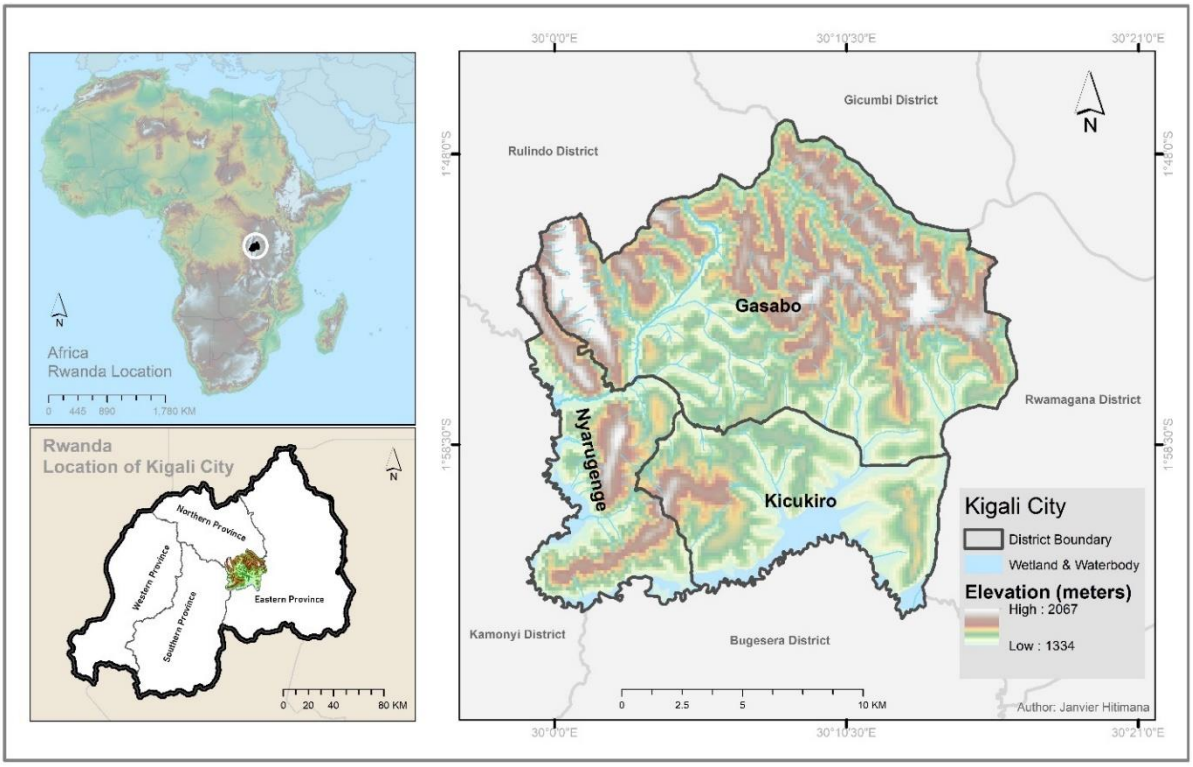

Figure 1: Map indicating the location of research area

2.2 Data collection

During data collection, both qualitative and quantitative research techniques were applied. The qualitative research relied on the use of interview which generated primary data on the application GIS spatial techniques particularly the multidimensional Multi criteria decision analysis (MCDA) from different respondents selected from several institutions and occupations. The study also applied quantitative research design since through secondary data mainly the statistics of respondents' views were computed in tabular form and analysed then decided the standards used in multidimensional Multi criteria decision to generate various maps.

2.2.1 Primary data

For the primary data collection, the authors employed a structured interview to local readers from institutional regulatory bodies in charge of environmental inspection and climate change mitigation in City of Kigali such as: the Ministry of Environment (MoE); Rwanda Environment Management Authority (REMA); Rwanda Development

Board (RDB); Directorate of Motor Vehicle Inspection Centre; Rwanda Association of Professional Environmental Practitioners (RAPEP); and the Directorate of Environment and Natural Resources Management in districts of Kigali City. In addition, various respondent from various occupations like surveyors, architects, urban planner and others stakeholders contributed to the research by filling questionnaires.

The table 1 below shows the type and total number of selected respondents used in this study. A total number of 110 respondents were selected as purposive sampling.

Table 1: Type and number of selected respondents

S/N	Occupation of respondents	Total Number	Percentage (%)
1	Land surveyor	35	32
2	Urban planner	10	9
3	Architect	5	4
4	Civil engineer	5	4
5	Building owners	30	28
6	Local authority/Government	25	23
Total		**110**	**100**

Source: Authors, 2024

Both interviews and questionnaire survey were administered face to face and took place in the respondents respective living areas or working offices. Using a questionnaire, the researcher assessed respondents' knowledge of the application of geographic information systems, or GIS, in landfill site selection and suitability analyses. According to the results, 95 percent of the 110 respondents in the survey agreed that GIS is helpful for spatial analysis. The researcher arrived at the conclusion that the appropriateness analysis approach for selecting landfill sites was Multiple Criteria Decision Analysis (MCDA), based on his experience with Geographic Information Systems (GIS) in study. As a result of this study, the City of Kigali employed multiple criterion decision analysis (MCDA) to determine the feasibility of potential landfill sites.

Furthermore, respondents were further asked to rank EIA effectiveness on climate change mitigation in Gasabo district, ranking them as very highly effective, highly effective, moderate/effective, and not effective. Each respondent then provided the explanation on their EIA ranking.

2.2.2 Method for Selecting Suitable Site for a Landfill

The landfill suitability analysis was determined through using Geographical information system (GIS) and Multi Criteria Decision Analysis (MCDA). To select the suitable site for landfill, 5 factors which are slope, settlement, road, river and lake have been selected for analysis and as they have different contribution to the selection of suitable site of landfill, each factor will have its unique weighting criteria, all these will be finally analyzed through weighted overlay from spatial analyst tool under ArcGIS.

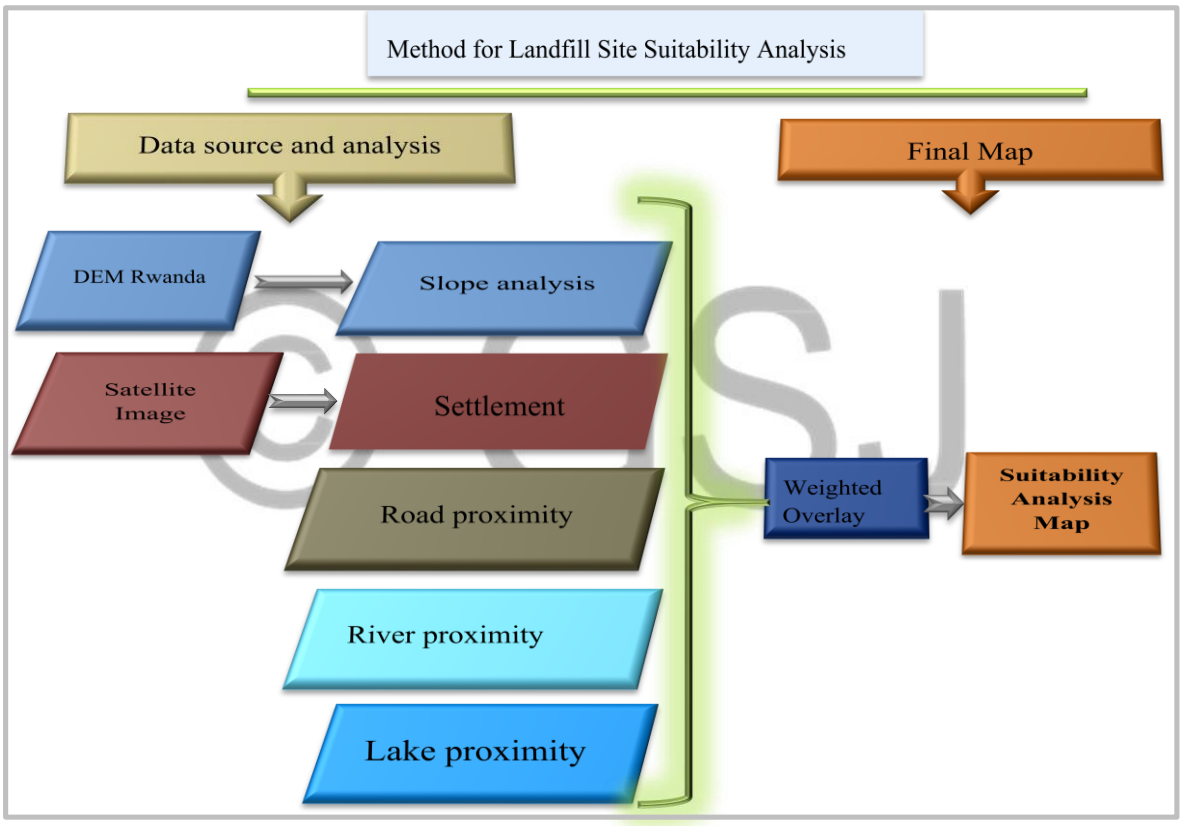

Figure 2: Methods for landfill suitability analysis using MCDA

2.3 Data analysis and software

Data analysis was done with the help of MS Office software (Word, Excel, PowerPoint). Respondents' opinions were transformed through data processing into a useful format. The information gathered through surveys is already available in the form of percentages, tabulated statistics, and frequency distribution. The following

methods were utilized to process the obtained data: coding, editing, and tabulation (Shukla, 2018) To achieve to this objective, the field visit was conducted in Kigali city through an oral interview to sector and district officials in charge of city planning from Gasabo, Kicukiro, and Nyarugenge district. The researcher integrated the information of respondents to GIS through multi-criteria decision analysis to develop various map. After conducting interview, the researcher processed the revealed standard of respondents in various tables using Multi criteria decision analysis (MCDA).

3. Results

3.1 Results on the Identified Types of Spatial Analysis Techniques

Using a questionnaire, the researcher assessed respondents' knowledge of the application of geographic information systems, or GIS, in landfill site selection and suitability analyses. According to the results, 95 percent of the 110 respondents in the survey agreed that GIS is helpful for spatial analysis. The researcher arrived at the conclusion that the appropriateness analysis approach for selecting landfill sites was Multiple Criteria Decision Analysis (MCDA), based on his experience with Geographic Information Systems (GIS) in study. As a result of this study, the City of Kigali employed multiple criterion decision analysis (MCDA) to determine the feasibility of potential landfill sites.

3.2 Result on Landfill Suitability Site by Slope

Table 2: Result on Landfill Suitability Site by Slope

Criteria	Percentage	Landfill Suitability	Ranking	Percentage (%)
Slope	<2%	Most suitable	4	68
	2 – 10%	Moderate suitable	3	17
	10 – 15%	Less suitable	2	13
	>15%	Not suitable	1	2

According to the table above, 68 % of 110 respondents revealed that the most suitable slope for suitable landfill site selection should be less than two per cent with ranking 4. Therefore, the research used the slope which is less than 2% in MCDA-GIS Software to determine the location of landfill in in City of Kigali and this map were overlayed to other maps to get the final location of landfill sites location in the city of Kigali.

3.3 Result on Landfill Suitability Site by Settlement/Residential Area

Table 3: Result on Landfill Suitability Site by Settlement/Residential Area

Criteria	Distance (Meters)	Landfill Suitability	Ranking	%
Settlement/ Residential	>1000m	Most suitable	4	95
	600 – 1000 m	Moderate suitable	3	3
	300 – 600 m	Less suitable	2	1
	<300 m	Not suitable	1	1

95 % of the 110 respondents to the surveys stated that a minimum of 100 meters should separate a settlement from the landfill site with ranking number 4. This information is seen in table 4.7 above. As a result, the researcher used this distance to create a map of appropriate dump site locations that only took into account the settlement model. This map was then further superimposed over other maps to create the final suitable landfill site location map for the City of Kigali.

3.4 Result on Landfill Suitability Site by Road Location

Table 4: Result on Landfill Suitability Site by Road Location

Criteria	Distance (Meters)	Landfill Suitability	Ranking	%
Roads	>2000m	Most suitable	4	79
	1000 – 2000 m	Moderate suitable	3	14
	500 – 1000 m	Less suitable	2	6
	<500 m	Not suitable	1	1

Table 4.8 shows that, according to 79% of the 110 respondents, land fills' most suitable distance from a river should be greater than 200 meters. In order to create the final map of appropriate landfill site selection, the researcher used this information to create a map in GIS using MCDA methodologies. This map was then overlaid with other maps for overall suitable locations of landfill sites in City of Kigali.

3.5 Result on Landfill Suitability Site by River Location

Table 4: Result on Landfill Suitability Site by River Location

Criteria	Distance (Meters)	Landfill Suitability	Ranking	%
Rivers	>200m	Most suitable	4	89
	150 – 200 m	Moderate suitable	3	8
	100 – 150 m	Less suitable	2	3
	<100 m	Not suitable	1	0

The above table shows the choice of 89% of 110 respondents that the most suitable standard distance between landfill sites and rivers should be greater than 200 meters, with a ranking of 4. This gave a guidance for the researcher to set the distance between landfill sites and rivers in GIS using MCDA methods to generate a map. Thus, the obtained map was overlayed with other maps to determine the final suitable landfill site's location in the City of Kigali.

3.6. Result on Landfill Suitability Site by Wetland Location

Table 5: Result on Landfill Suitability Site by Wetland Location

Criteria	Distance (Meters)	Landfill Suitability	Ranking	%
Wetlands/Floodplain	>300m	Most suitable	4	57
	200 – 300 m	Moderate suitable	3	36
	100 – 200 m	Less suitable	2	2
	<100 m	Not suitable	1	1

Table 4.11 reveals that 57% of 110 respondents reported the most suitable distance from wetland location to landfill to be greater than 300 meter in order to not harm the wetland with a ranking 4. The researcher used this information to generate a partial map for land fill site location which was overlayed with other maps to determine the final map of suitable landfill site's location in city of Kigali

.3.7 Result on Landfill Suitability Site by Lakes

Table 6: Result on Landfill Suitability Site by Lakes

Criteria	Distance (Meters)	Landfill Suitability	Ranking	%
Lakes	>300m	Most suitable	4	72
	200 – 300 m	Moderate suitable	3	20

	100 – 200 m	Less suitable	2	7
	<100 m	Not suitable	1	1

The above table shows that 72 % of 110 respondents revealed that the most suitable landfill should be located in distance >300m from the lakes. The researcher used distance >300m in GIS using MCDA technique to locate landfill sites considering the lake. And the obtained map was overplayed with other maps to determine the final map for suitable landfill site's locations.

3.8 Result on Landfill Suitability Site by Soil Permeability

Table 7: Result on Landfill Suitability Site by Soil Permeability

Criteria	Percentage (%)	Landfill Suitability	Ranking	%
Soil Permeability	>35%	Most suitable	4	93
	20 – 35%	Not suitable	1	7

The above table shows that 93% of 110 respondents revealed that the most suitable percentage of soil permeability should be greater 35% with ranking 4. The researcher used the slope of greater than 35% in GIS using MCDA technique to locate landfill sites considering the soil permeability. And the obtained map was overlayed with other maps to determine the final map for suitable landfill site's locations.

3.9 Results on the Overall Weighting rate (%) for each Criterion.

Table 8: Results on the Overall Weighting rate (%) for each criterion.

S/N	Criteria	Sensitivity/Weighting rate (%)
1	Settlement/ Residential	45
2	Wetlands/Floodplain	20

3	Slope	11
4	Rivers	8
5	Lakes	7
6	Roads	5
7	Soil Permeability	4
	Total	***100***

Table 4.13 The above table showed that Settlement/ Residential with 45 % is the highest sensitive, followed by wetlands/floodplain weighs 20%, and slope with 11 %, from among other criteria.

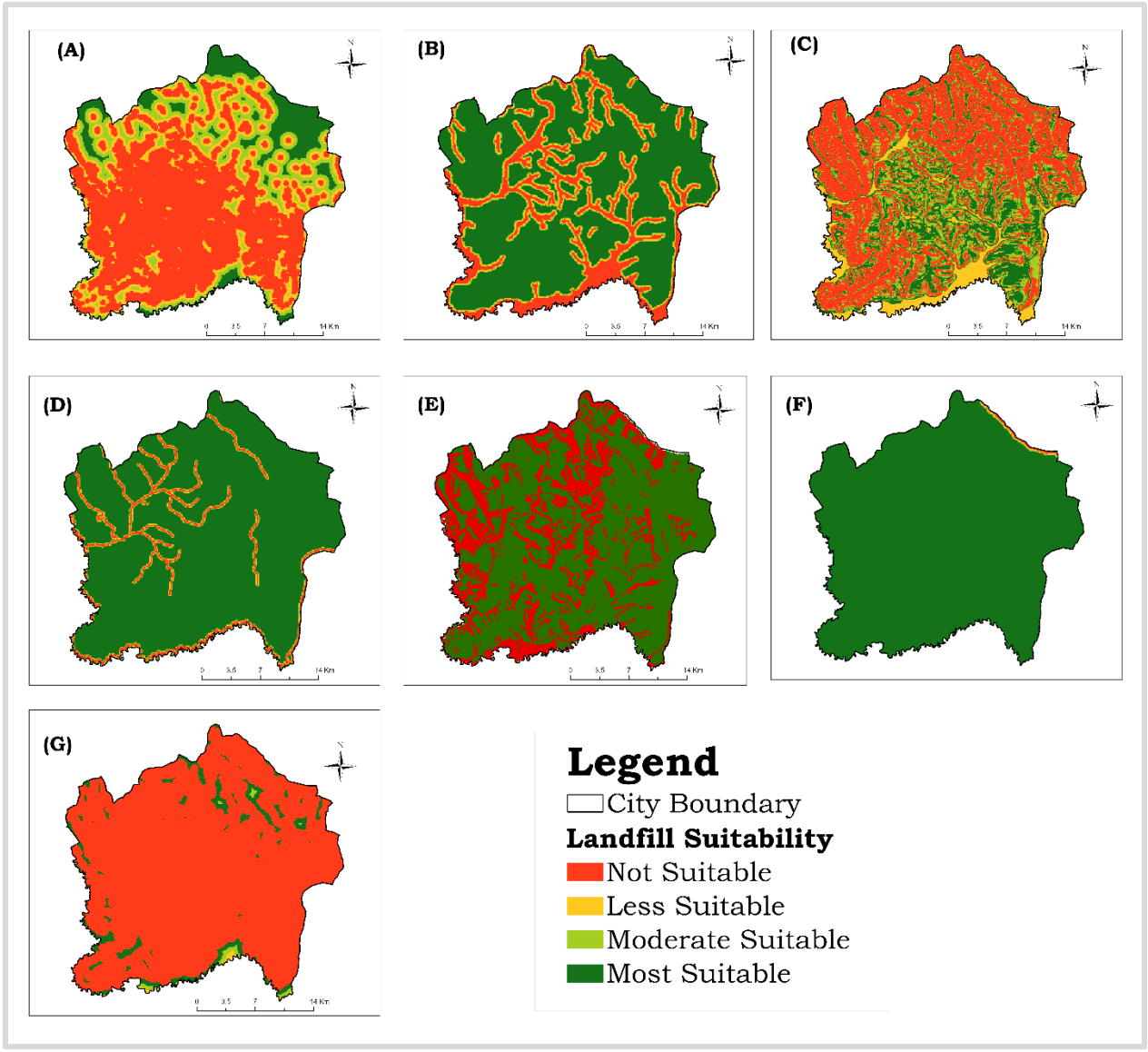

Figure 3: Map showing landfill suitability sites by each criterion

(A): Settlement/Residential, (B): Wetland, (C): Slope, (D): Rivers, (E): Soil Permeability, (F): Lake, (G): Road

The above figure shows the landfill site suitability status by each criterion from the research. The suitability was analyzed using qualitative data where results is shown by category as here: Green color stands for the most suitable, while red color stands for not suitable sites

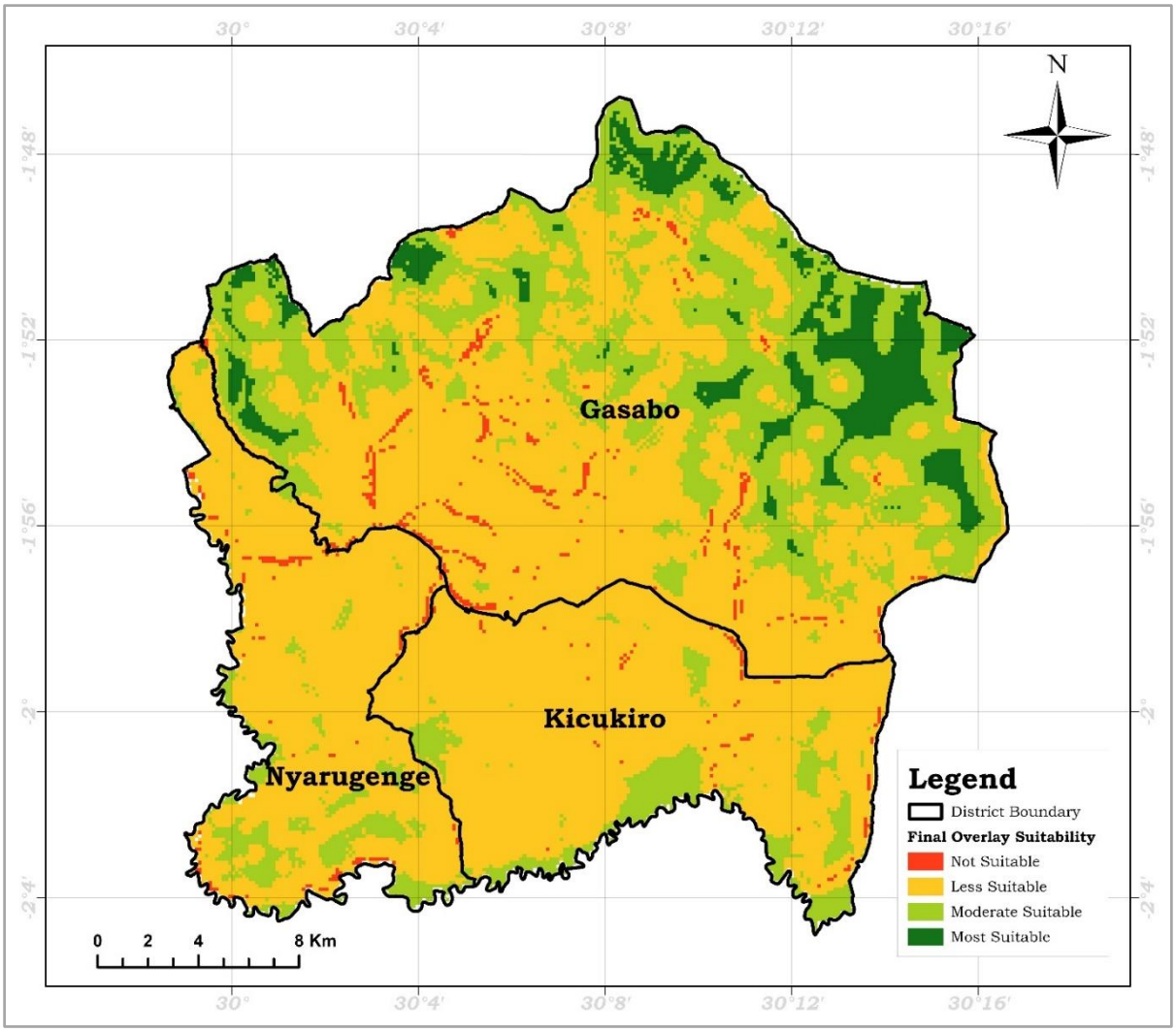

Figure 4: The Map showing o suitable landfill sites location in City of Kigali using GIS-MCDA

Figure 4 The above map shows the suitable sites for landfills in the City of Kigali, the map produced by considering overall criteria (Settlement, Wetland, Slope, Rivers, Soil Permeability, Lake, and Road) used for landfill suitability site analysis. The suitability was analyzed using qualitative data where results is shown by category as here: Green color stands for the most suitable, while red color stands for not suitable sites

3.10 Discussion

Objective1: Results on identifying GIS technique used for suitability analysis for landfill site selection.

This research findings noticed the important of the application of Multiple criteria decision analysis (MCDA), a GIS technique suitability analysis in landfill sites selection as urged by the primary researcher, and confirmed by the results from target population, where 95% from sampled respondents agreed that GIS is useful for spatial analysis, especially suitability study. This effectiveness of MCDA in suitability analysis maybe it is due to, MCDA has capacity to consider various criteria simultaneously to enhance the analysis's comprehensiveness (Pearman & Phillips, 2014). Utilizing Geographic Information Systems (GIS) alongside MCDA enhances the analysis by providing spatial data, facilitating visualization and interpretation of suitability results (Greene et al., 2011), where MCDA offers decision support by quantitatively evaluating criteria and their relationships, aiding in identifying the most suitable locations or options. Therefore, it is clear to confirm that MCDA has the capacity to handle complexity and provide systematic decision support makes it a valuable tool for suitability analysis in various fields, including land use planning (Tims, 2009).

Objective 2: Results on the requirements for landfill sites selection

Most of the requirements for landfill sites selection are distance to **Residential Area/built-up, Wetlands, Rivers, Lakes, Roads**, **Soil Permeability**, and **Slope.** This research found that Residential Area, Wetland, Slope are the most sensitive criteria to take into consideration for landfill site selection. It clear to say the landfill should be far from residential area and wetland (Ngwijabagabo et al., 2020), to mitigate health hazards by ensuring adequate distance from residential areas and adhering to safety regulations. Slope grade consideration is also essential in landfill site selection, due to, slope ensures the stability of the landfill, preventing potential failures due to heavy rainfall, optimizing leachate management, as well as support in the effectiveness of waste containment and long-term environmental protection (Colomer-Mendoza, 2013).

Objective 3: Results on suitable landfill site's location in City of Kigali selected by using GIS technique (MCDA).

The result on GIS-based landfill site suitability map produced by using the Multi Criteria *Decision Analysis* (*MCDA*) for the City of Kigali showed that green color indicates the most suitable, and red color stand for not suitable landfill sites. This map produced by considering overall criteria (Settlement, Wetland, Slope, Rivers, Soil Permeability, Lake, and Road) used for landfill suitability site analysis. From the results, it clear to confirm that GIS-based landfill site suitability map for City of Kigali in careful consideration of multiple factors, may support landfill site location to ensure sustainability (environmentally, economically, and socially acceptable), where all these conditions satisfied the scientific and environmental criteria adopted in this study (Shrestha et al., 2019).

4. Conclusion

The researcher has identified that Multi Criteria *Decision Analysis* (*MCDA*) is the best effective techniques to apply for GIS-based landfill site suitability map production. Referring to the findings, it is time to conclude that GIS based MCDA is most the useful techniques in suitability analyses as urged by practitioner consulted during this research and also confirmed by the literatures. For landfill site selection, the research confirmed settlement/residential area, wetland, rivers, lakes, road and soil permeability are essential criteria to consider during landfill site selection planning, and management. Therefore, there is more suitable location for landfill sites in City of Kigali, and conclude that the produced GIS-based landfill site suitability map of City of Kigali will guide further studies and decision and policy making in the context of solid waste management via establishment of sustainable landfill management.

5. Recommendations

After conducting this research, the researcher drawn some recommendations to the City of Kigali and to the future researchers.

.To the City of Kigali

The researcher recommends the following to the City of Kigali:

- To consider the findings of this research in selecting suitable landfills site selection,
- The City of Kigali to improve awareness master plan implementation across the whole districts.
- Policy makers to review and update the standards and regulations of solid waste management and sustainable landfill management.

To the Future Researchers

It is recommended to the future researcher to deepen this topic of application spatial analysis to locate suitable site location of landfills in other city of Rwanda, particularly Secondary and satellite city of Rwanda. It is also recommended to update landfill selection criteria like wind direction.

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