Original Paper

Socio-environmental impacts of landfill site in Nduba sector, Kigali, Rwanda

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Abstract. *Currently, solid disposal is a significant challenge in urban cities. In particular, Kigali City generates thousands of tons of solid waste to be transported and discarded in one city's landfill on a daily basis. It has contributed to the rise of social and environmental problems near the Nduba landfill. Previous studies have emphasized types of waste (liquid and solid) but have been unable to demonstrate land use and cover change because of solid waste disposal since its establishment in 2012. The study aimed to evaluate spatiotemporal changes vis a vis the social and environmental implications of solid waste disposal in the Nduba sector. Primary data were collected within a defined study area, whereas secondary data relied on remote sensing and geographic information system (GIS) data. Images of land use/cover were used for spatial analysis and changes before and after landfill establishment. The findings of this study indicate that land use/cover has changed considerably in the last decade. For instance, the built-up area increased within the study area from 69.21 ha to 187.56 ha in 2001 and 2019, respectively. The change detection of land use/cover indicates that the size of the landfill increased by 18.79 ha in 2019. Forest land has reduced from 199.8 ha in 2001 to 104.49 ha in 2019. Even though authorities around the landfill have established a buffer of 400 m, it remains evident that the socio-environment impacts are likely to happen 1,000 m from the current landfill's boundary. Despite public and private efforts to handle solid waste on-site, residents of Nduba claimed that the landfill had substantial social and environmental impacts.*

1. Introduction

In this era of escalating impacts of climate change and global warming, waste management has become a central issue of priority for environmental protection in several countries worldwide (Khan & Faisal, 2007). However, some do not adequately plan for solid waste management in terms of collection, transportation, recycling, and suitable disposal sites (McDougall et al., 2008). Particularly developing countries lack the human and financial capital to conduct adequate studies that handle solid waste-related issues (Buenrostro et al., 2001).

It is estimated that 3.19 billion tons of solid waste are produced annually (Kaza et al., 2018). Nevertheless, the quantity of solid waste generated in developed countries is relatively high compared with that in developing countries (Ahsan et al., 2014). A global solid waste management study conducted by the World Bank in 2018 revealed that high-income countries such as the United States, Canada, and European Union member states generate approximately 34% of global waste, with only 16% of the world's population. In contrast, low-income countries account for only 5% of global waste, with only 9% of the total population (Kaza et al., 2018).

Poor solid waste practices have undermined Rwanda's sustainable development in the last decades. For instance, From 1983 to 2012, Solid Waste was disposed of in the Nyanza landfill and replaced by the Nduba landfill, currently the only city's landfill site. (Rajashekar, Bowers, & Gatoni, 2019). But, the country's target is to reach an effective waste management system with major investment projects, including the construction of the Kigali Centralized Sewerage System (KCSS) and modern landfills in all districts by 2024 (NST1, 2017).

The Nduba landfill has been described as an open dumping site (Iraguha, Remalan, & Setyono, 2022) with a lack of modern waste treatment facilities, which is causing harmful chemicals and environmental problems, including leachate and vermin (Rajashekar, Bowers, & Gatoni, 2019). Contrary to sanitary dumpsites, the facilities are designed so that waste is secluded from the environment and residential areas (Idowu et al., 2019). There is little precision in a daily estimation of the volume of waste generated in the capital city of Kigali. The previous research suggested that the landfill could accommodate 400 to 800 tons per day and reach 1,300 tons in 2030 (Rajashekar, Bowers, & Gatoni, 2019).

Kigali's rapid population and economic growth have been seen as a major cause of the increase in solid waste production (Rajashekar, Bowers, & Gatoni, 2019) and also needs infrastructure and institution capacity for proper management (Iraguha, Remalan, & Setyono, 2022). Though the City of Kigali(CoK) and sanitation body WASAC(Water and Sanitation Corporation) took a central role in Nduba landfill management, Rwanda Utilities and Regulator Authority (RURA) set guidelines, issued license and requirements for private waste collection companies. It also sets out the household's tariff for collection (Rajashekar, Bowers, & Gatoni, 2019).

There are several companies licensed to collect and transport solid waste, including for instance; Agruni, Coped, Ubumwe Cleaning, ISUKU Kinyinya, etc. (Uwajambo et al., 2017; Mukamana, 2021). Prior to solid waste collection, there was a lack of separating households' waste from biodegradable and non-biodegradable(Akimanizanye et al., 2020). It is ideal for sorting it at the source for recycling to minimize waste disposed at the site (Gahima & Bizuhoraho, 2021). The latest study suggests a potential for rising health issues such as respiratory problems, cancer, and skin disorders in landfill vicinity (Mukamana, 2021). The facility is associated with an increased risk of diseases related to poor sanitation, such as cholera, intestinal worms, and typhoid (Kabera, 2020). The same study reveals that the key issue is the safe disposal of solid waste which can affect landslides and end up contaminating groundwater.

To enhance solid waste management and decision-making processes, GIS has been an appropriate tool for setting up new landfills using multi-criteria and suitability analysis (Jimoh et al., 2019). In contrast, remote sensing is applicable to the changing detection of land use/cover over a certain period (Mugiraneza, Ban, & Haas, 2018).

Yet, in previous studies, GIS and remote sensing have not been applied to evaluate the spatiotemporal impacts of solid waste disposal. Some scholars identified and assessed challenges related to solid waste management in Kigali and quantified the volume produced daily. However, little is known about the site's suitability and potential socio-environment impacts. The study used mixed spatial analysis methods such as Geographical Information System (GIS), ERIDAS software, interviews, and questionnaire survey. Thus, this paper aims to assess the social and environmental impact of the landfill.

2. Materials and Methods

2.1. Scope of the study area

The study evaluates the socio-environmental impacts of solid waste disposal in the Nduba sector and its implications on residents and the environment. The area of the site and 1 km buffer of the site were selected as the study area. The study used the methods of Nas et al. (2009) for the four criteria, such as residential area, road networks, slope, and the combination of rivers, streams, and wetlands, as one criterion. This method is based on the boolean operation model in GIS, which enables each criterion to be weighted and ranked/scored. Criteria weights were calculated using Analtyic Hierarchical Process(AHP) method (Nas et al., 2009). Each criterion was assessed based on weight, scoring, and distance (Table 1). It was indicated that a 0 score has no constraint, a score of 5 has a strong constraint, a score of 9 is an extreme constraint, whereas a score of 10 is an extreme constraint. The score 0-4 are positive compared to those ranging from 5-10, which are negative.

Criteria	Distance	Scoring	Weight
Residential area	<1 km	10	0.20
	>1 km	0	
Road networks	<0.2 km	10	0.10
	0.2-1 km	9	
	>1 km	0	
Streams, rivers, and wetlands	<0.3 km	10	0.15
	0.3-0.5 km	5	
	>0.5 km	0	
Slope	>15%	10	0.10
	<15%	0	

Table 1: Alternative criteria for ideal landfill site. Source: Nas et al., 2009, page 496.

Residential proximity to the location of the landfill should be considered a priority when setting up a facility. A buffer distance of 1 km from the landfill to the nearest residential area. Given the sensitivity of the landfill issue, the highest weighting score of 0.20 was calculated and assigned to the residential area. Landfills are effective because of the accessibility of road networks. However, the distance from the main road should be assessed not only to indicate the accessibility of the site but also to ensure the wellness of road users. A minimum distance of 200 m is a very extreme constraint, whereas beyond such a buffer, it does not affect the surroundings.

Streams, rivers, wetlands, or other water sources near landfill facilities are exposed to the risk of water contamination. A distance of fewer than 300 m scored a very extreme constraint, whereas those above 300 m had no constraint.

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Given the significance of the risk, a weight of 0.15 was assigned for the criteria. The slope of the landfill terrain was also chosen as one of the criteria for the assessment. The slope of the facility of 15% or higher increases the speed of rainwater runoff, causing the risk of waste moving from designated landfills to unsafe places (Nas et al., 2009). Therefore, less than 15% of the slope of Nduba has no constraint. Nduba is geographically located in the Gasabo district, and one of the three districts forms Kigali City. In Gasabo, the facility is located in Nduba, Gasanze, and Muremure villages, as shown in Figure 1 below.

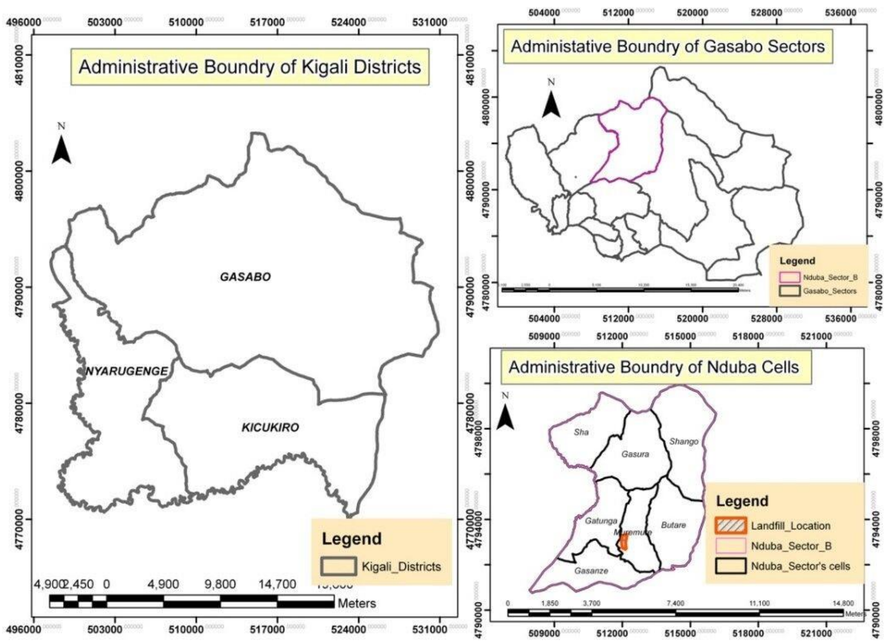

Figure 1: Geographical location of the Nduba landfill

2.2 Study design

This work consisted of data collected from various sources, both secondary and primary. Data on existing literature were used in this research. Data were also collected from public institutions in charge of utilities regulations, environment, and sanitation, including local government entities, for their direct involvement and to understand the management and operation of the landfill fully. But, the City of Kigali and sanitation body WASAC has taken a central role in Nduba landfill management. Therefore, the primary data method used key informant interviews from WASAC, COK, and DPMM-KALISIMBI. Key informants are Mr. John Mugabo from the City of Kigali (CoK), Mr. Amos Kazora Shyaka from WASAC(Water and Sanitation Corporation), and Mr. Ildebland Urayeneza from Depot Pharmacetique et Materiel Medicales-KALISIMBI were interviewed separately. Eventually, a survey questionnaire was used to gather data on the perception and feelings of residents living in the landfill vicinity (appendix).

This survey research aimed to collect Nduba residents' thoughts and feelings about the landfill. From a target population of 2,996 people residing 1 km from the site, 85 respondents were selected using a random sampling method because of their location and population distribution. The sample size was computed using the following formula (Daniel, 1999):

$$n = \frac{N*X}{(X+N-1)} \quad (1)$$

where, $X = Z_{a/2}{}^{2} * p * (1-p) / MOE^{2}$ *and* $a = 0.05$

In Equations (1), *n* is the sample size, *N* is the population size, *Z* is the critical value for a confidence level of 95% in the normal distribution, *MOE* equals the margin of error, and *p* represents sample proportion.

A sample size of 341 was calculated from the estimated population of the Nduba sector, and the population size in the study area was 25,370. An interview included 341 households within 1km from the landfill, the average size of a household is 4.0 (NISR, 2012), and the number of heads of households (HH) to be interviewed was obtained by taking the sample size and dividing it by the average size of household (341/4=85 HH).

All the participants were interviewed from their homes and provided answers to the questions listed in the questionnaire. Respondents were selected based on the population distribution and assigned criteria. All of them were located in three cells: Muremure, Gasanze, and Gatunga. Geographic coordinates were used to provide the physical boundary of the site and the precise location of other geographical features to ensure the accuracy of the survey. Moreover, a group of public and private experts was interviewed to collect relevant information on their responsibilities in the management of the Nduba landfill. One professional staff member from CoK was interviewed in his office, and an email interview was used for an employee at the Water and Sanitation Corporation (WASAC) to respond to the questions sent to his email.

The study also used secondary data to analyze spatial features using ArcGIS 10 and ERDAS Imagine 14 in the description, mapping out, and change detection of the site to evaluate the spatial and temporal implications of solid waste disposal in eight years of its operation. Secondary data were collected based on the year of publication and image resolution (Table 2). Landsat images, orthophotos, and other spatial data of the site were used for better visualization and interpretation. Landsat images were freely downloaded from the USGS website with a resolution of 30m, whereas 10m and 25cm resolutions were used for the digital elevation model (DEM) and orthophoto, respectively. Other spatial data are accessed by public institutions such as the National Land Authority (former National Land Center), the National Institute of Statistics Rwanda, and the CoK.

2.3 Data collection

Primary and secondary data were used in this study. For the primary data, the focus was to acquire relevant field data from residents of Nduba and the authorities responsible for managing the Nduba landfill. A survey questionnaire (Appendix) was used to gather data about the attitude of government officials and Nduba residents vis-à-vis the landfill. The researcher helped respondents complete the questionnaire to ensure that all questions were responded well. Additionally, a face-to-face interview was conducted with a senior official in the (CoK), and a set of questions was sent to the email of the staff of the WASAC to make it easier to understand the entire operation of the Nduba landfill.

The study used different secondary data collected from various sources (Table 2), which allowed the authors to understand the spatial and temporal changes in the Nduba landfill over a certain period and the social-environmental implications in the vicinity.

Research techniques and methods were formulated based on the research objectives. Different methods were applied because this study has three potential research objectives. The first objective was to emphasize spatial changes during the eight years of the Nduba landfill operation. Landsat images were manipulated to reveal land use and land-cover changes. The image classification method provides a precise change in the area of interest.

The other point is that the Nduba landfill should have a systematic method of handling solid waste disposal. Therefore, the second objective was to compare the Nduba site with the ideal landfill site. The criteria for an effective landfill compared to the Nduba site were elaborated. Building on this, several spatial data, namely, building footprints, agricultural land use, elevation, and hydrological and road networks, were used and processed in ArcGIS 10 to examine the suitability of the site. Moreover, interview and observation techniques were used to collect qualitative data from the target population within 1 km of the site.

Data Type	Year	Resolution / Accuracy	Source
Landsat images	2001, 2015, 2019	30 m	Earth explorer-United State Geographical Survey
Digital elevation model	2009	10 m	National Land Authority
Ortho-photo	2009	25 cm	National Land Authority and National Institute of Statistics Rwanda
Administrative boundary	2006	-	National Institute of Statistics Rwanda
Slope, roads, and rivers	2012-2020	-	National Land Authority National Institute of Statistics Rwanda
Site boundary	2018	-	City of Kigali

Table 2: Summary of the secondary data source used in this study

Face-to-face interviews were also conducted with the CoK and WASAC employees and site workers in charge of managing the Nduba landfill to assess where the landfill has all the potential attributes of a sanitary landfill. The third objective is the handling process and socio-environmental impact. The study collected and assessed respondents' opinions using a Likert scale method. The rating scale ranged from 1 to 5 (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree.

2.4 Data analysis

The data analysis included ArcGIS, ERDAS Imagine software, and other statistical analyses. All spatial data were analyzed using ArcGIS 10 by creating specific layers for each feature, such as slopes, road networks, hydrology, and environmentally protected areas (in shapefile format). Moreover, overlaying maps using the weighted overlay method for each criterion provides a detailed site suitability analysis. Spatial indicators of an effective landfill in comparison with the Nduba status were examined using a spatial multi-criteria analysis technique. Qualitative data were collected using interview and observation methods, and the analysis involved investigating similarities and differences regarding all defined criteria. Through research observations, notes were taken from the respondents' reactions and views.

The analysis of change detection at the site involved comparative analysis. The technique ensures that the images are classified into specific classes using the same projection system (Maina et al., 2020). In the process of change detection using ERDAS Imagine 14, at least four major steps, such as; image preprocessing, classification of an image, land use/cover, and eventually change detection, were followed (Hegazy & Kaloop, 2015). First, Landsat images were classified using an unsupervised image classification technique. The land cover and use of the study area were classified into five classes: built-up areas, trash lands, bare lands, forest lands, and grasslands. Each class shows a variation in percentage. The image types were classified using Landsat 8 OLI/TIRS C2 Level-2.

3. Results

3.1 Characterization of the Nduba site

As introduced in previous chapters, the site is located in the Gasabo District of Nduba. It is also hundreds of meters from the Nduba head office sector. The area of the landfill was 14.4 ha (1.54 km^2). However, the future site was set to extend 400 m from the actual site (Figure 2). Nearly the entire area was designated for solid waste disposal. All types of solid waste are brought in using waste trucks operated by private companies commonly known as "cooperatives." Site workers separated degradable solid waste from non-degradable solid waste at discharge points. In all three districts of Kigali, 14 private companies were responsible for transporting solid waste to the site using garbage trucks. However, the precise estimation of waste produced and transported by those companies remains unknown.

The separation of waste at the site is done not only to reduce the volume of waste but also to increase its recyclability. Construction machineries, such as excavators and bulldozers, squeeze up garbage materials simultaneously to make way for garbage truck operations.

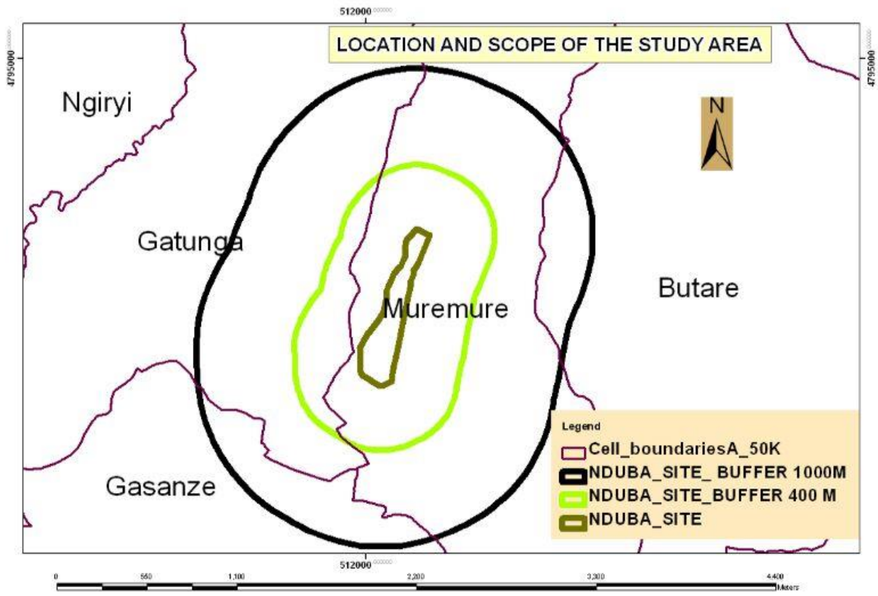

Figure 2: The Nduba landfill boundary and scope of the study

It was reported that the site was initially used as an open dumping site, similar to the same way as previous landfill in Nyanza. Subsequently, it became overloaded with the amount of waste generated in Kigali. The CoK decided to call private companies to manage and enhance sanitation and safety. In Figure 2, the site is designed with components such as main and access roads, wastewater and fecal sludge ponds, filled ponds, a stock of sorted materials, a landfill for solid wastes, leachate drains, and leachate pits.

3.2 Past and current status of the study area

3.2.1 Land use and cover

Over the past few years, land cover in the study area has changed because of the increase in human activities and the amount of waste produced in the city. Such a change can be observed when comparing its previous satellite images. Generally, the land within the study area was previously used for agricultural and residential purposes. As a countryside place, land prices seem low for low- and middle-income earners.

The land cover of the study area using Landsat images from 2001, 2015, and 2019 indicated built-up areas, forests, open land, and bare land in colors of red, dark green, green, and yellow, respectively, as shown in Figures 3, 4, and 5. The gray color indicates the trash land in the images from 2015 and 2019. It is clear that there is no trash land in the area. Instead, the land was bare in 2001. Moreover, the built-up area was relatively small compared to the years after 2001.

Three years after the establishment of the site, the 2015 satellite image shows a large garbage area. Such changes in land cover can also be seen in Gasanze and Gatunga (southwest of the study area). Forest and bare land largely changed into built-up area use of land (top left). Furthermore, between 2001 and 2015, a considerable decline occurred in the land used as forests.

For the land cover in 2019, the size of the landfill site did not change significantly compared to that in 2015. However, what is seen in the eastern part as trash land (gray color) is liquid waste disposal located outside the official boundary of solid waste. The figure for 2019 indicates that the forest zone (green) is quite close to the built-up area (red). However, a few non-residential housing units (also in red) can be seen in landfill sites used by landfill management companies.

3.2.2 Accuracy assessment of classified images

Deferential GPS was used to collect ground data for evaluation accuracy. All five physical land types were taken with their respective ground positions for comparison with the refracted colors of the image after classification. The overall classification accuracies of the images from 2001, 2015, and 2019 reached 86.00%, 87.33%, and 89.33%, respectively (Tables 3). The built-up area is highly reflected with an accuracy of more than 90%, whereas trash land remained consistent at 80% in 2015 and 2019.

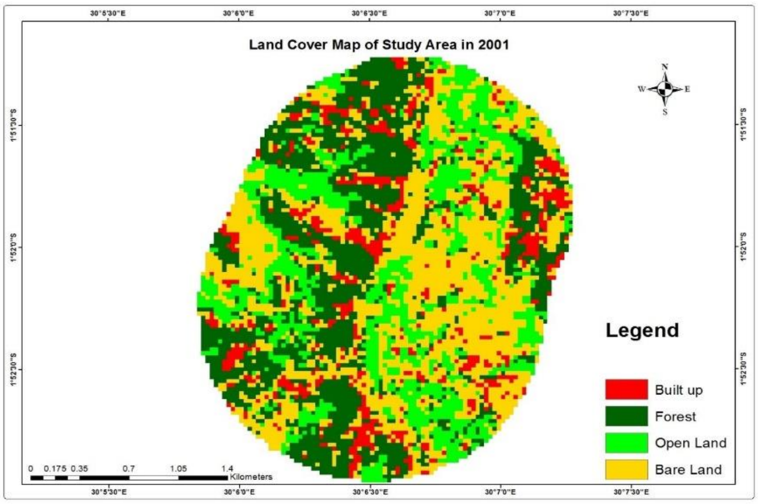

Figure 3: Land cover of the study area in 2001.

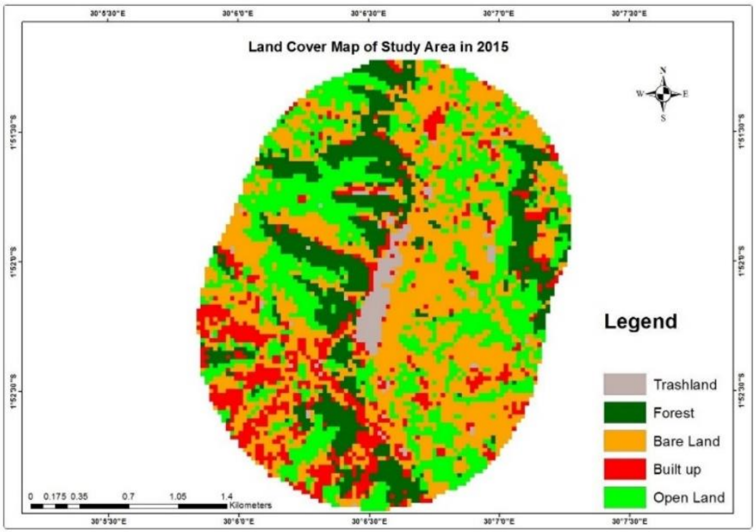

Figure 3: Land cover of the study area in 2015

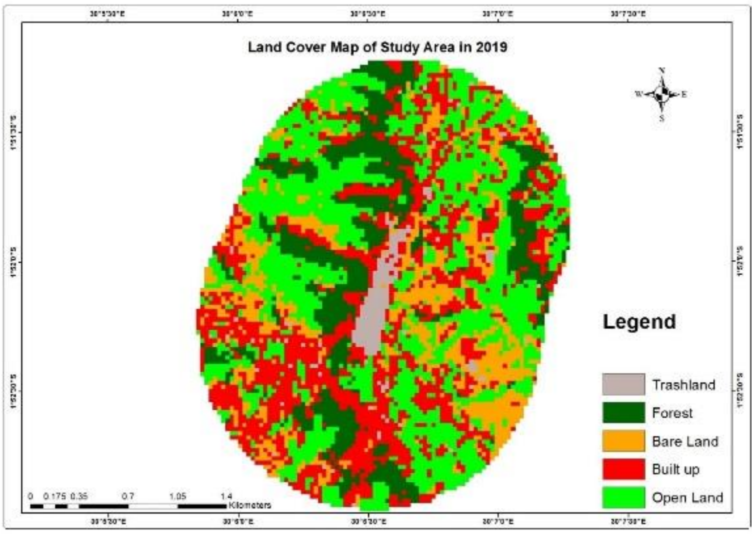

Figure 4: Land cover of the study area in 2019

3.3 Change detection of the Nduba site

Land use/cover change was assessed using the combined Landsat images of 2001, 2015, and 2019, as shown in Figures 6, 7, and 8. The technique involved changing one class to another and unchanged four land cover types. The results in Table 4 show that the land use/cover categories changed in terms of area and percentage. Trash land changed from 16.45 ha in 2015 to 18.79 ha in 2019 (a surplus of 4 ha of the actual size). The possible source of this error is more likely due to the accuracy of the image reflection. The reason for this growth is that there is no proper way to control the situation. There was a massive increase in built-up area from 69.21 ha to 187.56 ha, from 10.58% to 28.69% of the entire study area. Forests were one of the most affected land use/cover types in the study area. The reduction in the area of forest was 199.89 ha in 2001 to 104.49 ha in 2019, from 30.58% to 15.98 % of the entire area. The change in open land could be seen as an increase of 14% in the area from 2001 to 2019, whereas bare land reduced considerably by approximately 20% in the same period. During the survey, agricultural activities occupied a large area. It could be justified by the increased open land owing to fertile land.

year	Class name	Reference total	Classified total	Number corrected	Producers accuracy (%)	Users accuracy (%)	
2001	Unclassified	31	30	30	-	-	Overall Classification Accuracy = 86.00%; Overall Kappa Statistics = 0.8253
	Built-up area	28	30	24	85.71%	80.00%	
	Forest	29	30	25	86.21%	83.33%	
	Open land	28	30	24	85.71%	80.00%	
	Bare land	33	30	26	78.79%	86.67%	
	Totals	150	150	129			
2015	Unclassified	25	25	25	-	-	Overall Classification Accuracy = 87.33%; Overall Kappa Statistics = 0.8480
	Trash land	22	25	20	90.91%	80.00%	
	Forest	23	25	21	91.30%	84.00%	
	Bare land	24	25	20	83.33%	80.00%	
	Built-up area	32	25	24	75.00%	96.00%	
	Open land	24	25	21	87.50%	84.00%	
	Totals	150	150	131			
2019	Unclassified	25	25	25	-	-	Overall Classification Accuracy = 89.33%; Overall Kappa Statistics = 0.8720
	Trash land	22	25	20	90.91%	80.00%	
	Forest	25	25	23	92.00%	92.00%	
	Bare land	24	25	21	87.50%	84.00%	
	Built-up area	32	25	24	75.00%	96.00%	
	Open land	22	25	21	95.45%	84.00%	
	Totals	150	150	134			

Table 3: The accuracy assessment of the classified image of 2001,2015 and 2019

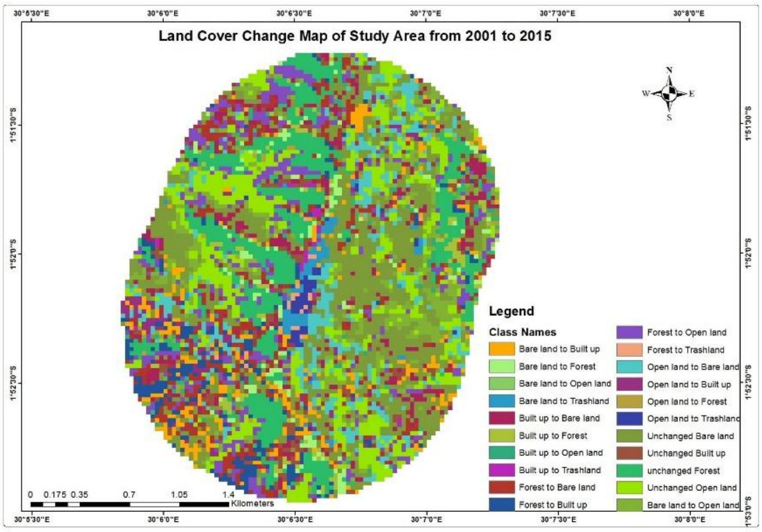

Figure 5: Land use and cover change from 2001 to 2015

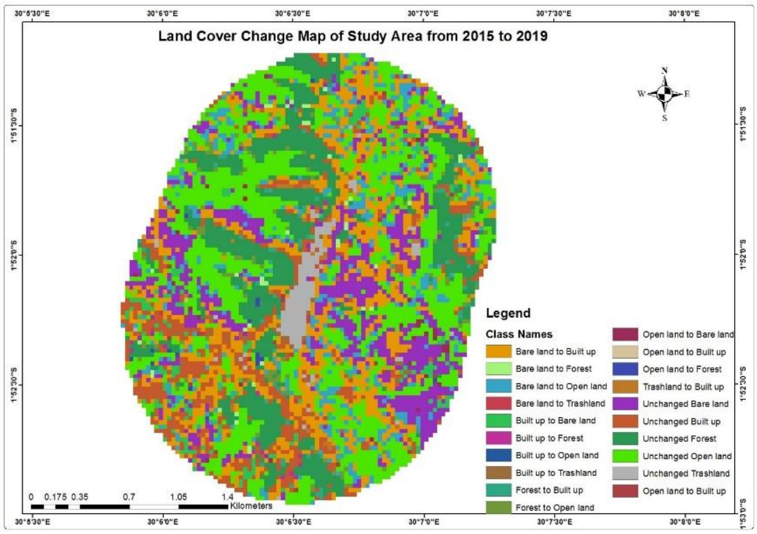

Figure 6: Land use and cover change from 2015 to 2019

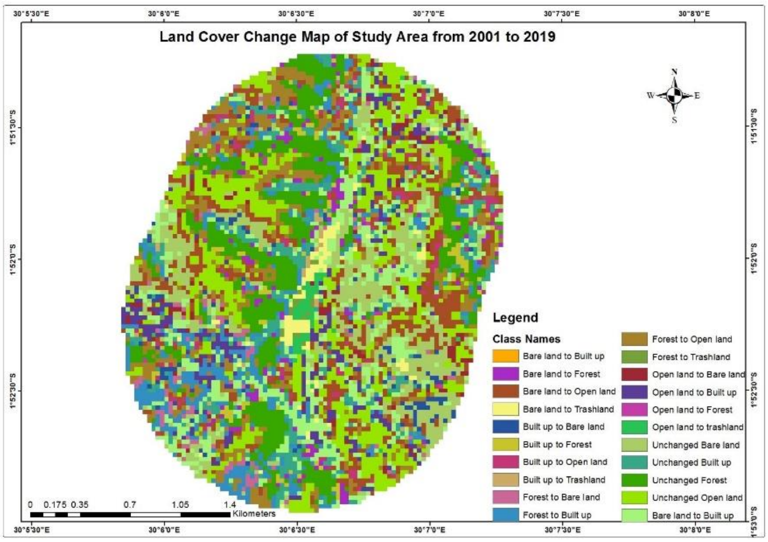

Figure 7: Land use and cover change from 2001 to 2019

Land use Categories	2001		2015		2019	
	Hectares	%	Hectares	%	Hectares	%
Trash land	-	-	16.45	2.82	18.79	3.18
Built-up area	69.21	10.58	81.9	12.53	187.56	28.69
Forest	199.89	30.58	114.48	17.51	104.49	15.98
Open land	143.55	21.95	179.28	27.42	234.54	35.87
Bare land	241.2	36.89	259.74	39.72	106.47	16.28
Totals	653.85	100	653.85	100	653.85	100

Table 4: Change detection of the study area

3.4 Spatial multi-criteria assessment of the Nduba landfill

3.4.1 Residential area

The study identified the housing units within the study area. Large concentrations of these units were identified on the east and west sides of the site, while others were scattered. Most interviewees reported that houses have three to four bedrooms in single-family housing units. Most of the respondents indicated that their land and properties were situated in the official delineation of the landfill.

Few stay there for occupational reasons. Although the site is located on the outskirts of the city, the land is used for a mix of residential and agricultural activities. Ongoing expropriation within 400 m has started since the establishment of the site. The CoK promised them to be relocated to the remaining cities in the near future.

3.4.2 Road networks and accessibility

Each waste truck took one main road passing through the Gasanze center to the Nduba landfill. A road with a width of 5 to 6 m is insufficient to allow a smooth flow of trucks and other vehicles. It has been reported that during heavy rainy seasons, some company vehicles, particularly those in old conditions, cannot be used because of poor road conditions. Another concern of the road is the heavy dust blown out toward housing units alongside the roads. Inadequate roads and safety are other concerns for pedestrians and Nduba residents. One of the interviewees stated that a number of accidents occurred because of the absence of road enforcement regulations and a lack of improved road conditions. No road accessing the site had a sewage system, as shown in Figure 9 below.

Figure 8: Garbage truck transporting solid waste to the Nduba landfill site

3.4.3 Distance to environmentally sensitive areas

Water sources were identified in the surroundings of the site. These elements present the potential and uniqueness of an area for mitigating environmental impacts. Several trees were identified near the site, and the distance from the site was ≤ 20 m. Respondents argued that old trees used as traditional medicine were cut off during site extension from 2014 to 2016 (Figure 10).

Figure 9: Trees and grassland surrounding the site

3.4.4 Slope of the Nduba landfill

The Nduba landfill is located at the top of Muremure Mountain. The slope of the study area ranges from 0.7% to 68% (Figure 11). However, the sensitivity of landfill smell and water runoff greatly impacts the Nduba community. Residents located on high slopes suffer from bad smells than those located on low slopes.

Therefore, those located in the eastern part of the site are less likely to experience bad smells and truck noise because the wind direction is east to west.

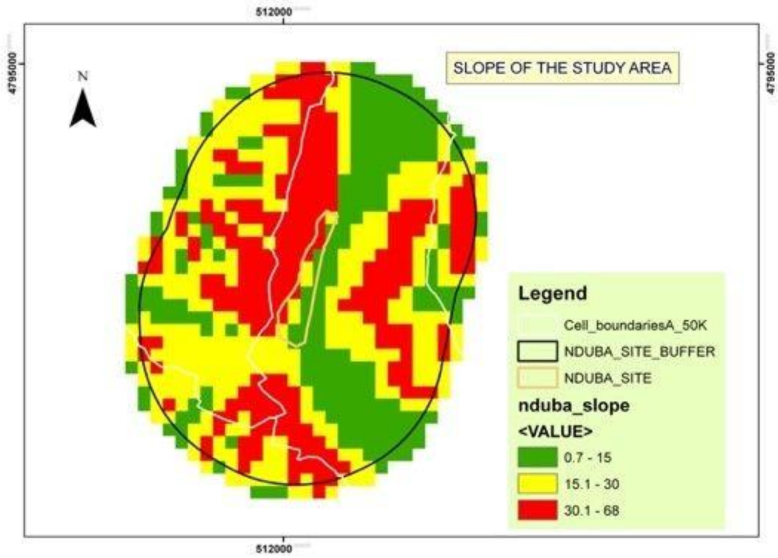

Figure 10: Slope map of the study area

The interviewees located on the western side of the landfill urged that the situation became unhealthier during the rainy season. Those identified were found in the Gasanze and Gatunga cells. Water runoff often carries solid waste from a site to its neighborhood. Precipitation also presents other challenges for accelerating waste leakage toward residential compounds. Despite this concern, landfills have no retaining facilities to block solid waste leakage and other materials (Figure 12). The sloping terrain of the view side of the Gasanze and Gatunga cells is steep compared with any other side of the landfill. During the rainy period, the soil covering the dumped material could slide downward, leaving garbage uncovered.

Figure 11: Layer of laterite soil covering the solid waste

3.5 Suitability analysis of the site

Different spatial criteria were investigated to determine the suitability of the site. The spatial attributes presented in Table 1 were used with weighted overlay methods. The produced suitability maps reveal the interconnection between criteria ranging from unsuitable to most suitable within the study area (Figures 13 through 16). The findings showed that almost the entire site boundary was located in the least suitable area. However, additional attributes could be important for the analysis and indicate that the site is not suitable for its location.

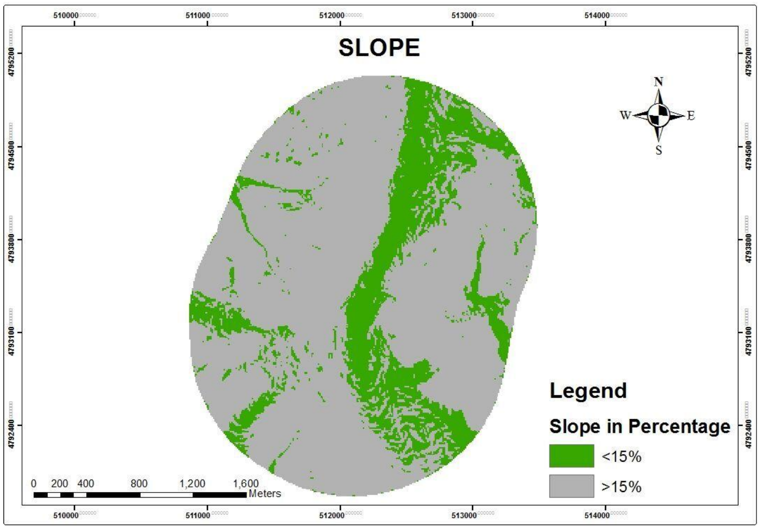

Figure 12: Slope analysis of the landfill

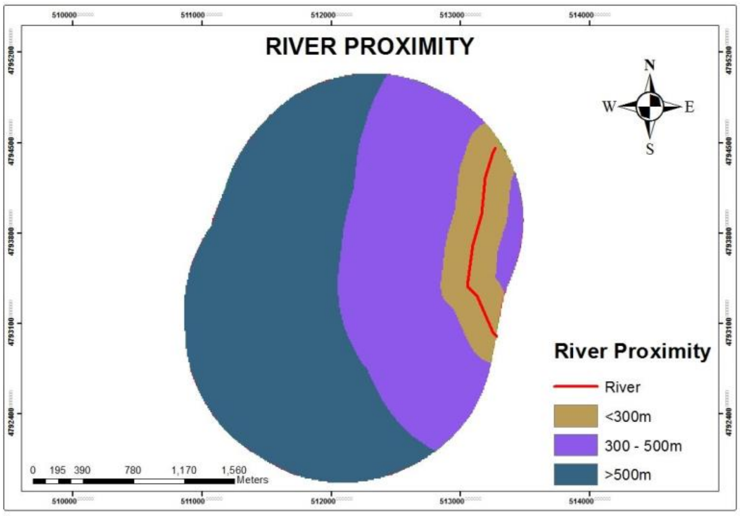

Figure 13: Suitability analysis of the river vis-à-vis the landfill

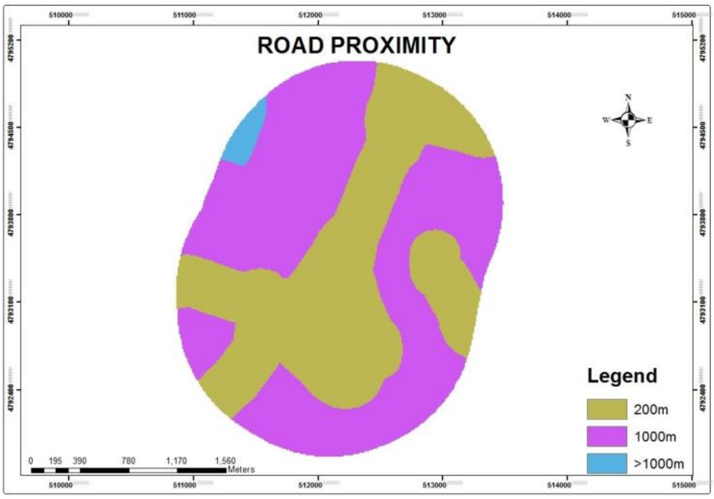

Figure 14: Suitability analysis of the road vis-à-vis the landfill

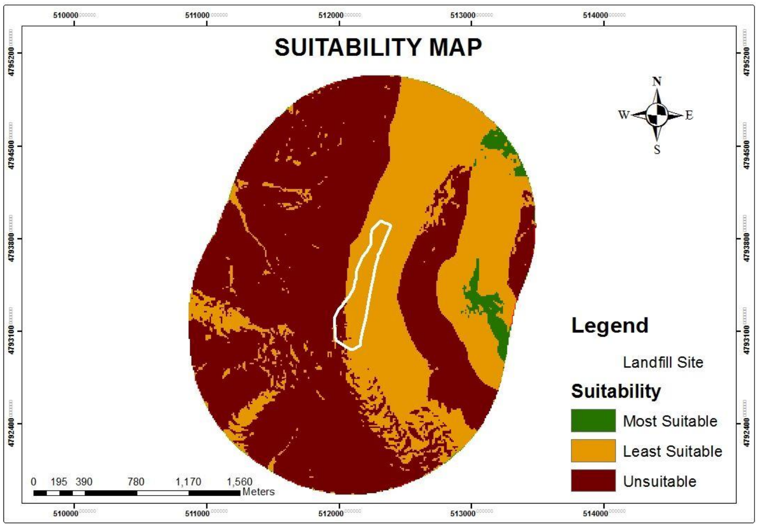

Figure 15: Suitability analysis map of slopes, rivers, and roads

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3.6 Summary of the overall results from the interview and field survey

3.6.1 Solid waste handling process in the Nduba site

The study aimed to determine the process used to handle solid waste in a Nduba landfill. Depot Pharmaceutique et Materiel Medical Kalisimbi(DPMMK) is a company in contact with the CoK, which manages solid waste on-site. A semi-structured interview with Urayeneza Ildebrand, an employee of the company, reported that 70 to 100 garbage trucks discharge solid waste daily. All trucks came from different private companies transporting waste. More than 165 people are employed on-site, five are permanent, and the others are responsible for sorting solid waste.

In practice, the sorting process starts when garbage trucks offload waste. The bulldozer pushes solid waste into discharge zones that are specified on-site. The workforce starts sorting out the garbage for further use, mostly organic waste. Materials, such as plastic bags, bottles, and non-degradable items, are stored in the designed area. The other materials were separated for recycling purposes. The remaining materials are flattened under the laterite soil when sorting is performed using bulldozers and compactors. Each vehicle must be recorded and directed to a discharging point to avoid inappropriate disposal and facilitate garbage trucks at the landfill entry point. Poor waste management appears to be associated with waste collection companies, particularly services that are sometimes irregular due to limited trucks(Akimanizanye et al., 2020).

3.6.2 Role and responsibility of the CoK and WASAC

As mentioned earlier, the CoK and WASAC are public institutions responsible for managing landfills. However, CoK (which authorized this study was responsible for managing solid waste). Among them are contract management and regular on-site inspections. Mugabo John, an employee in the CoK in charge of solid and liquid waste management, stated that the site has a periodic inspection plan conducted by an inspection team working daily on site, and the CoK and WASAC coordinate it. The inspection team evaluated its performance using the daily reporting system for solid waste disposal. However, because of the confidentiality of these reports, such data were unavailable for this study. These results reflect those of Rajashekar, Bowers, & Gatoni(2019), who also found that the whole system of SWM operations remained challenging to be understood, especially in the public institutions listed above and private waste collectors who work together. Little access to data on-site also remains an issue. The contracted company that operates the facility would first request approval from the City of Kigali to collect or share data.

The CoK is also in charge of awarding a contract to a private company to operate all site work. However, the company's responsibility was limited to the internal activities of the landfill site. The expropriation of residents located 400 m from the site was an ongoing activity before the establishment of the site. It is estimated that approximately 500 households and landowners have been expropriated to date.

3.6.3 Ideal landfill attributes compared to the Nduba site

Another objective of this study was to compare typical sanitary landfills and the Nduba landfill. The interview was conducted in the WASAC, the institution in charge of sanitation in the Nduba landfill. Assessment using several indicators includes the following: master plan and zoning regulations, weather conditions, water quality, accessibility of covering materials, impact on environmentally sensitive areas, and future expansion plan of the site (Walsh & O'Leary, 2002).

To compare the Nduba site with an ideal landfill site, Amos, a WASAC staff member, was interviewed on May 15, 2021, via his email. He revealed that the facility complied with the current master plan and zoning regulations. He also affirmed that the site was accessible to waste trucks under different weather conditions. However, it has been suggested that there is potential contamination of groundwater quality, and the landfill smell is uncontrollable. The interviewee strongly affirmed whether the site had access to soil-covering materials. He further confirmed that the site strongly impacts environmentally sensitive areas. However, he strongly agrees that there is space for the future expansion plan of the site.

Despite the score of each of the seven indicators assessed, five met the criteria, whereas three failed to meet the conditions of an ideal solid waste disposal facility. Thus, it is evident that the performance of the Nduba landfill is relatively high in accessing soil, which is used to cover the landfill's solid waste. With the newly revised Kigali Master Plan of 2020, the site respects its regulations. However, this document does not indicate the future expansion zone. The results also suggest that the odor of the landfill was controlled and did not reach nearby residents. However, the performance in protecting environmentally sensitive areas, providing sufficient site space for future expansion, and avoiding groundwater contamination are deficient in the Nduba landfill.

3.6.4 Community perspectives on the Nduba landfill

Nduba residents raised several issues that need to be addressed by the authorities and companies in charge of managing the site. Most informants responded that it is unpleasant to inhabit close to the site, with 91% saying that it is uncomfortable to live near the landfill. Landfill smell is inevitable for a community reach; according to the respondents, it goes beyond the study area. Residents residing in Kibungo Village in Muremure reported experiencing a bad smell and immense flies, locally known as "*amasazi*" from the site. Moreover, 89% of the respondents confirmed the same issue. In accordance with the present results, a previous study has demonstrated that accumulation and poor waste management affect rats, flies, and other insects, likely to cause infectious diseases (Kabera, 2020). Gatunga residents, who were most exposed to waste leachates, expressed concerns about the possible contamination of Nyabagendwa stream water sources.

The lack of a secure fence at the site has been regarded as another critical challenge to retaining garbage on-site. The intruders, looking at whether they could find valuable items on-site, played an essential role in scattering waste out of the official boundary. Without being precocious, some waste materials can harm human health when they are not appropriately handled.

The site has also become a feeding site for wild dogs, endangering the safety of Nduba residents and their livestock. According to the respondents, several cases have been identified of dogs that attack and kill farmers' livestock. Despite local government efforts to resolve these issues, they have been hunted down and killed. However, the approach is far from successful because the problem has not been resolved.

When asked whether residents in the vicinity of the site were being relocated for their willingness, they responded that they had never known anyone who left their neighborhood to go and live in other places because of the landfill issue. No one has left for such a reason; however, few people are coming to dwell in the area, as confirmed by six respondents. As presented in Table 7, the built-up area has remarkably increased around trash land in the past years. The study found that more than 70% of the respondents have been living in Nduba for the last four to seven years.

They pointed out several reasons for the pulling factors. One explanation is that land is cheap compared to inner-city land. Second, the land was acquired for mixed-use (residential and agriculture), reasonably practicable in peri-urban areas, and in some cases, for commercial purposes (buying and selling), houses, and land. Another reason highlighted is that before 2013, Kigali had no master plan, which was somehow an opportunity for many, mostly with low income, to construct their house without any requirement or restriction. The suggested solutions from Nduba residents to prevent this situation are more oriented toward reinforcing government regulations. Others suggested that the case will be complicated if nothing is done soon because relocating people is not a long-lasting solution without considering groundwater contamination and air pollution.

Regarding how they perceive the landfill, nearly 60% felt it was not good and did not bring anything good to them apart from being hindered by its presence. Others suggest that the facility contributes to their livelihood, with 20% urging that it provides employment opportunities for low-income earners. Previous spatial analysis indicates that many people have moved within a few kilometers of the landfill decade. This growth is another concern in safety and planning. These results suggest that those who live at 400 m and outside tend to be exposed to landfill impacts. A comparison of the findings with those of Akimanizanye et al. (2020) confirms that rain contributes to solid waste slides toward residential areas located 400 m from the landfill. These results also match those observed by Tumwizere et al. (2017) suggested that the leachate generated from the landfill site ended up in the surrounding environment and could contaminate groundwater quality.

What emerges from the results reported here is that;

a. Using satellite images, the landfill site has grown in size over the last decades.

b. Even though authorities around the landfill have established a buffer of 400 m, it remains evident that the socio-environment impacts are likely to happen 1000 m from the current landfill's boundary.

c. The results indicated poor waste handling at the site, from waste collection to disposal.

d. The survey results indicated that residents nearby the site are more exposed to health risks and consequences.

4. Conclusion and Recommendations

The study mainly investigated the spatial changes in a landfill site that occurred before and after its establishment. However, such changes have led to social and environmental impacts on the surroundings of the site. These impacts were assessed using multiple criteria and Landsat imagery. The change detection findings provide insights into land use and cover changes. The overall results of the change detection show that forests and bare lands dramatically decreased, whereas trash land, built-up areas, and open land increased until 2019.

Dumping useless material underground is seen as an "*inefficient*" way of handling solid waste (McDougall et al., 2008). It is a common method of solid waste disposal in Nduba facilities. Three potential objectives of this study were considered in the data analysis. The primary objective was to focus on spatial changes before and after landfill establishment. The results indicate that there has been a significant change in trash land, built-up areas, forests, open land, and bare land in recent years.

The second objective of this study was to assess solid disposal based on the attributes of an ideal landfill. The findings demonstrate that the site scored low in affecting groundwater quality and environmentally sensitive areas. Regarding spatial attributes, the results revealed that the site leachates downward the Gatunga and Gatunga cells in the slope area. Accessibility to the site is narrow, and road conditions are poor. The lack of a drainage system for rainwater runoff can damage the site's main road and lead to road accidents. In addition, the report provides comprehensive suitability of combined criteria, such as road and river proximity, as well as the slope of the Nduba site. Given the limited resources, data availability, and scope of the study, it is worthwhile to investigate the suitability of the site. Additional attributes from different datasets, such as temperature, weather conditions, and soil type, are critical in landfill suitability analysis.

The third objective of this study was to focus on the handling process, human resources, and equipment used after the on-site discharge of solid waste. The findings indicate that waste is separated using human hands, and heavy construction machines assist in covering the remaining materials with laterite soil. Eventually, this mechanism was found to be inappropriate. For instance, in the rainy season, the leaching of protected materials occurs downward in residential areas.

Before this study, it was difficult to identify who was more or less affected by landfills. Therefore, this study suggests that a buffer of 400 m from the landfill to the residential area is insufficient. The buffer could be extended above 400 m, considering the significance of socio-environmental implications. Some residents consider landfills a source of financial opportunity for their livelihood. However, the implications of landfills can lead to socio-environmental damage. The CoK had affirmed that there was a plan to improve the facility to a modern level.

The interview results from the CoK, WASAC, and perceptions of Nduba residents demonstrated that solid waste disposal poses risks and challenges for the people of Nduba. The distance between landfills and residential areas is not sufficient to avoid harm. Much effort from public institutions is required to maintain waste inside landfills. Considering the significance of this issue, the safety of waste materials should be a priority in landfill management.

The physical boundary between the current and future expansion of the site needs to be demarcated to ensure the sustainability of the site. For instance, the outflows of waste material need to be retained, particularly on the side of the Gasanze and Gatunga cells, to avoid landfill leachates. The increase in built-up areas surrounding landfills could lead to environmental degradation. Trees must be protected because they are more exposed to waste chemicals. A buffer zone between the landfill and other land use activities was established to ensure the safety of materials from landfills. A new fence enclosing the site could prevent intruders and wild animals from penetrating the landfill.

It is essential to invite public participation at an earlier stage of any project that significantly impacts their lives. It is not the case for the Nduba residents. Before setting up a landfill site, a feasibility study could be a decisive tool in deciding whether to go with the project. In the case of the Nduba landfill, regulatory agencies should provide cost and benefit analysis, considering the cost related to expropriation and environmental costs to avoid a costly project. The lack of projection and data availability on landfill lifespan is crucial and can lead to underestimating socio-environmental consequences. Based on the CoK projection, the Nduba landfill is at 80% of its total capacity. It demonstrates that the available space is to continue creating layers of solid waste dumped inside the existing boundary.

Regarding landfill odor, WASAC affirmed that it was controlled; however, it was not disagreed with by some respondents in Nduba. It draws more attention to investigating this matter to explore the cause and who is affected in the area. It provides a safe working environment for site workers. An emergency preparedness office is required at the site to react in the event of an accident. The office could also be equipped with health experts and medical tools to examine the health effects of the landfill and those who are exposed to risks.

To increase the well-being of people residing near landfills, planting trees in the buffer zone decreases air pollution and the risk of respiratory diseases and increases clean air. Another advantage of afforestation is that it protects the soil in slope areas from land sliding during the rainy season.

Ongoing expropriation at 400 m from the site boundary started before landfill establishment. It means that some people did not receive compensation. As one respondent mentioned, since the expropriation started, he did not have the right to use his land, nor did he receive his promised money for his immovable properties. Fair and equitable compensation of residents' properties is recommended to ensure that resettled people will continue to improve their living conditions.

This study has found that, generally, a 400 m buffer is not enough for the safest of the community of Nduba. It is recommended to conduct research on which extent would be suitable for any human activities and environment to avoid landfill impacts in the near future. Since the landfill is considered an open dump site, furth work is needed to understand the implications of air pollution and leachates fully. The findings of this study have a number of important implications for future practice when selecting a landfill site. A further study could quantify the amount of waste produced, separated and non-separated, and assess the landfill site's long-term effects.

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