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MUNICIPAL SOLID WASTE LANDFILL EFFICIENCY INDEX: DEVELOPMENT AND APPLICATION IN KUITO, CAPITAL OF BIÉ PROVINCE, REPUBLIC OF ANGOLA

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Abstract: The management of municipal solid waste (MSW) on the African continent has faced challenges, due to the urbanization process, population and economic growth, especially in sub-Saharan Africa. In this context, the development of methodological approaches to assess the MSW management system assumes importance for the elaboration of policy guidelines. The objective of the present work was to develop and apply an index to evaluate the efficiency of the landfill, based on landscape analysis, in Kuito, capital of the Province of Bié, in Angola. The methodology included field visits, survey of the physical structures and operational conditions of the municipal landfill. These surveys made it possible to calculate a landfill efficiency index (*IEA*), based on landscape analysis, integrating elements from the physical, biotic and anthropic dimensions. The structural and operational conditions of the landfill indicated environmental, social and human health risks, as it was an open-air dump. Such conditions led to the closure of the landfill by the provincial authorities, based on the results indicated by the *IEA*.
Keywords: Africa, environmental management, environmental impact

INTRODUCTION

The disposal of municipal solid waste (MSW) in landfills and dumps is the only alternative for several countries on the African continent (UNEP, 2018). Sanitary landfills are generally restricted to metropolitan areas of capital cities, as in the city of Kinchasa in the Democratic Republic of Congo (Kang et al., 2023), Cape Town in South Africa (Barnes et al., 2021), and Accra in Ghana (Oduro-Appiah et al., 2020).

Dumps are distributed across the African continent, especially in municipalities located inland, as recorded in Namibia and South Africa (Kadhila et al., 2023) and Rwanda (Squire & Nkurunziza, 2022). About 90% of the waste generated on this continent is disposed of in landfills (UNEP, 2018). In most cases, they are poorly managed and cause risks to human health and the environment, due to the presence of organic and inorganic pollutants (Afolabi et al., 2023).

Angola, the third largest country in Sub-Saharan Africa (SSA), only has one sanitary landfill in operation, in the capital Luanda, the Mulenvos landfill (Maria et al., 2020). This landfill receives about 2 million tons per year of MSW generated by 6.9 million people (27% of the population of Angola), residing in the Province of Luanda (INE, 2016a).

Kuito, capital of the Province of Bié, in Angola, is undergoing an urbanization process. In the period from 1990 to 2017, its urban area ranged from 1,139 ha to 7,342 ha, representing a growth of 544% in 27 years (UN Angola, 2018). The MSW management system corresponds to the daily collection of MSW generated by 65% of the urban population and 3.5% of the rural population, reaching 39,000 t $(year)^{-1}$ or 0.46 $kg.(hab.day)^{-1}$ (Cristovão et al., 2022). The per capita generation in Angola ranges from 0.46 $kg.(inhab.day)^{-1}$ (Kaza et al., 2018) to 0.48 $kg.(inhab.day)^{-1}$ (Scarlat et al., 2015). The collected waste was transported, until March 2020, to a landfill 18 km from Kuito, and disposed of without any sorting. The absence of a recycling industry in the region justifies this scenario, following the trend of several countries in Sub-Saharan Africa (Kaza et al., 2018). On the African continent, the average recycling rate was estimated at only 4% (UNEP, 2018), with a negative emphasis on ASS. According to Zaman & Swapan (2016), SSA countries, including Angola, are among those with the lowest recycling rates on the planet, less than 5 kg per capita per year, although the exceptions are South Africa, Namibia and Republic from Congo.

The landfill is an alternative for waste disposal that generates impacts and environmental damage, which require monitoring and control. even after the end of its activities. Thus, the continued assessment of its structural and operational conditions becomes relevant. An alternative is the development of indices or indicators that can address specific MSW management issues (Ferraz et al., 2021). However, for its application to the reality of the African continent, adaptations are necessary, due to the availability of information; the inclusion of qualitative and quantitative factors; the replicability and reliability of the results raised (Cervantes et al., 2018).

Therefore, landfill efficiency indices under African conditions must allow for a quick diagnosis, with information that does not require long-term and costly studies, in terms of monitoring and human resources. In this context, the landscape analysis technique and its adaptations are inserted as a fundamental element for environmental studies, since the landscape is configured in the perceptible space and a common cultural asset, with a holistic, relativistic and dynamic character (Marques et al., 2021) .

The study of the landscape has been disseminated through the use of techniques such as geoprocessing and remote sensing tools. Applications of this technique have been used in studies of land use and occupation in watersheds (Marques et al., 2021; Medeiros et al., 2016) and evaluation of technological performance in agricultural areas (Marques et al., 2020).

The objective of this research was to develop and apply a municipal solid waste landfill efficiency index, based on landscape analysis, applied to the African continent. The study was carried out in the municipality of Kuito, capital of the Province of Bié, in Angola.

METHODOLOGY

STUDY REGION

Kuito (coordinates 12° 24' 23" S, 16° 55' 56" E; 1600 m altitude) has an area of 4,814 km^2 and 430,000 inhabitants (INE, 2018). The climate of this municipality corresponds to subtropical altitude (Cwb), according to the Köppen classification, with average annual precipitation ranging from 1,200 mm to 1,300 mm and a dry period between June and September, with average annual temperatures ranging from 18 to 20 °C (Huntley, 2019).

DIAGNOSIS OF THE MUNICIPAL LANDFILL AND DESCRIPTION OF THE LANDFILL EFFICIENCY INDEX (LEI)

In the diagnosis of the municipal landfill, three visits were carried out, in July and December 2019 and March 2020, to contemplate the dry and rainy seasons of the municipality. In the field surveys, prominent elements of the landscape were evaluated, in the physical, biotic and anthropic dimensions, according to the methodology described by Medeiros et al. (2016) and Marques et al. (2021). In this assessment, the observer walks through the internal and external area of the landfill and lists the elements that stand out in the landscape and are related to risks of environmental contamination, in addition to vulnerabilities to the health of the population in its geographical area.

The physical environment included analysis items related to potential environmental impacts caused by interactions involving soil, water and atmosphere. This dimension includes aspects such as risk of erosion, formation and flow of leachate, fires and proximity of the landfill to environmental protection areas. The biotic factor comprised the perceived relationships involving flora and fauna, their biological diversity and the quality of the forest fragments around the landfill. The

anthropic factor considered the quality of the engineering works, the operational conditions of the landfill, the safety conditions of the employees, the social impacts related to the waste pickers inside and around the landfill area.

The following grades were attributed to each highlighted element evaluated: 5.0 (most favorable condition), 3.0 (intermediate condition) and 1.0 (most adverse condition). The grades were assigned on the spot, in accordance with the consensus of technicians from the National Institute for Territory and Urban Planning (INOTU) of the Province of Bié. Thus, an efficiency index for the landfill and its surroundings (IEA) was obtained through the following equation:

$$LEI = \frac{\sum_{i=1}^{n} x_i}{\sum_{i=1}^{n} y_i} . 100$$

where LEI corresponds to the landfill efficiency index (%); n the number of highlighted elements of the landscape; xi the score obtained in the evaluation process (dimensionless); yi the maximum score on the rating scale (dimensionless).

RESULTS

Table 1 presents the results of the landfill efficiency index considering the dimension related to the physical environment. The index presented a minimum score in the highlighted elements evaluated, with the exception of the evidence of erosion process, as it was not observed in its surroundings.

The location of the landfill was the main factor of environmental vulnerability, as it was close to springs. Manure flow to its surroundings was observed and the possibility of reaching the water network that supplies the downstream population, evidencing health risks. This was the main reason for the closure of the landfill by the city of Kuito, in March 2020, after the municipal administrator had access to the information collected in loco. The presence of leachate on the surface enhances soil and groundwater contamination. Landfill areas have shown a high potential for environmental contamination of anthropogenic origin, both inside and around them, according to results collected in Nigeria by Afolabi et al. (2023) and Omeiza et al. (2023).

Atmospheric pollution was perceived by the odors of the decomposition of organic matter and the emission of gases from the natural combustion of the mass of waste exposed to the open sky (Figure 1A). Gaseous emissions from landfills have been perceived by populations living close to these areas, causing respiratory and allergic problems, as recorded in South Africa (Njoku et al., 2015), Namibia (Kadhila et al., 2023) and Ghana (Peprah et al., 2022).

Table 2 shows the results of the analysis of the biotic dimension of the landfill efficiency index. The area around the landfill was degraded, with reduced potential for natural regeneration, due to the suppression of vegetation and exposed soil. However, shrubs and native species were seen in its surroundings (Figure 1B). The presence of these forest fragments positively impacted the evaluators' perception and allowed the biotic dimension to reach 40%. On the African continent, research has pointed to the loss of land value due to the presence of landfills and the costs for their decontamination, as in Egypt, with estimates of economic losses in the order of US$ 350 million (Sarhan, 2022)

Table 3 presents the results of the anthropic dimension of the landfill efficiency index. This dimension is related to the landfill's engineering structure and social vulnerability, expressed by the proximity to populated areas and the presence of waste pickers. This dimension achieved the same score as the biotic dimension (40%), due to access

Standout elements	Description	Note
Environmental Protection area	Proximity to areas of environmental vulnerability, such as nearby streams and springs	1
Erosive process inside and around the landfill	Evidence of erosion and the formation of grooves and ravines inside and around the landfill	3
Soil and water contamination	Perception of risk of leachate infiltration and runoff inside the landfill.	1
Surface runoff	Presence or possibility of formation of surface runoff from the landfill to its surroundings.	1
Odor perception	Perceived odors around the landfill	1
Perception of gas formation	Formation of gases and particulate matter inside the landfill, due to the combustion of waste	1
Risk of fire	Spontaneous natural combustion of waste	1
Sub Total	Somatória das notas atribuídas ao meio físico	9
LEI meio físico	Landfill efficiency index considering the physical environment	26%

Table 1. Efficiency index of the Kuito landfill, Angola, considering the physical environment.

Figure 1. View of the Kuito municipal landfill, Bié Province, Angola: (A) spontaneous combustion of solid waste; (B) open-air solid waste and surrounding vegetation.

Standout elements	Description	Note
Biological diversity	Presence of native species of trees and shrubs in the surrounding landscape.	3
Scenic beauty	Maintenance of natural landscape features around the landfill	1
Biologic contamination	Presence of exotic and aggressive species such as *Leucaena leucocephala* in the surroundings	3
Natural regeneration	Capacity of environmental resilience in the surroundings.	1
Soil vegetation cover	Surrounding land covered with vegetation	
Presence of fauna inside the landfill	Presence of birds or mammals during the operation inside the landfill	3
Presence of fauna around the landfill	Presence or evidence of insects, birds and mammals in the surroundings	1
Sub Total	Sum of scores assigned to the biotic environment	12
LEI half biotic	Landfill efficiency index considering the biotic environment	40%

Table 2. Efficiency index of the Kuito landfill, Angola, considering the biotic environment.

conditions, the location of the landfill in an isolated area, with no buildings around it, the absence of collectors and the presence of machines for compacting and grounding waste.

The exposure of solid waste allowed concluding that the grounding operation is not carried out periodically, as observed in all visits. Compaction and grounding operations were carried out only when a considerable volume was accumulated, using a bulldozer model tractor and backhoe. Contributing to this scenario is the lack of structures to accommodate workers and guards at the landfill, such as sanitary and electrical installations, access to drinking water, kitchen and changing room. Such conditions prevented the permanence of workers and made their presence sporadic. Thus, the waste was exposed to the open air for several days (Figure 1B).

Organic waste predominated in the landfill, as glass bottles and metals (lead, iron and aluminum cans) were collected by waste pickers in the urban area before being sent to the landfill. Subsequently, recyclable materials were sold in factories on the Angolan coast and Luanda, 700 km from Kuito. For this reason, the presence of collectors was not observed inside the landfill, in the three visits carried out, despite the absence of guards or structures to limit the access of people or vehicles (guardhouse and fence).

Waste was not separated, nor was any control carried out on the amount disposed of in the open. The landfill also lacked engineering structures to control gaseous emissions, rainwater drainage, leachate collection and treatment, control of the amount of MSW deposited.

Three cleaning companies hired by the city hall officially deposited waste in this place, but there were other clandestine ones.

In the compartmentalized analysis of the landfill efficiency index, which reached 36%, the worst condition is observed in the physical environment. The possibility of worsening a series of environmental impact categories, such as the intensification of climate change, fires and the export of contaminants to the water network, contributed to this assessment. Thus, the absence of engineering structures to control environmental impacts, the precarious operating conditions and the risks of environmental contamination allowed classifying the Kuito municipal landfill as a dump, justifying its closure.

It must be added that in the Province of Bié municipal solid waste is deposited in landfills in all its municipalities, an issue that challenges the provincial government. Therefore, the management of solid waste in Kuito and, to a greater extent, in the Province of Bié, involves the development of strategies that reduce the sending of solid waste to landfills. In this bias, it is recommended the development of environmental education programs contextualized to the reality of Kuito, and supported by the Municipal Administration. Priority must be given to disseminating concepts on preventing the generation of MSW, associated with the sorting of recyclable materials and sending them to Luanda, in addition to the implementation of a municipal composting plant, with use in agriculture, a relevant economic activity in the Province of Bié, (Cristóvão & Medeiros, 2022).

The construction and operation of a sanitary landfill has high costs for the African context. For this reason, it is recommended to create an inter-municipal consortium for the construction and management of a sanitary landfill in Kuito, due to its geographical position and road structure. The municipalities of Kuito, Kunhinga, Chinguar, Kamacupa and Catabola, which have around one and a half million inhabitants, could participate (INE, 2016b). Such a model has been adopted

Standout elements	Description	Note
Risk to the population	Proximity to the landfill in the urban area, buildings, rural properties.	5
Landfill access road	Signaling, paving, accident risk, erosive process and drainage	3
Waste pickers	Presence of pickers at the landfill	5
Triage	Presence of structure for sorting waste in the landfill.	1
Access control	Access restriction, presence of guards, fences, guardhouse and lighting in the landfill	1
administrative structure and sanitary	Presence of kitchen, bathroom, dressing room, furniture, computers, internet access, telephone, electricity and drinking water	1
landfill operation	Presence of machines, materials and employees for compaction and daily grounding of waste.	3
Waste control	Scale to quantify the input of waste, assessment of the presence of hospital, industrial and construction and demolition waste	1
Groundwater control	Physical structure and human resources for monitoring groundwater quality	1
Gas emission control	Physical structure and human resources for monitoring, capturing and burning gases.	1
Leachate control	Physical structure and human resources for soil sealing, drainage, accumulation, treatment and disposal of leachate.	1
Surface runoff control	Drainage structure for the collection and conduction of rain water	1
Subtotal	Sum of scores attributed to the anthropic environment	24
LEI half anthropic	Landfill efficiency index considering the anthropic environment	40%
LEI	Landfill efficiency index	36%

Table 3. Efficiency index of the Kuito landfill, Angola, considering the anthropic environment.

in municipalities in the Brazilian Amazon, with social and economic realities similar to those of the African continent, as reported by Oliveira et al. (2021).

FINAL CONSIDERATIONS

The efficiency index identified the main vulnerabilities of the Kuito municipal landfill, such as operating conditions and the absence of engineering structures to control the environmental impacts generated. In addition to actions aimed at the landfill, it will be necessary to organize a recycling chain, reverse logistics, waste valuation and a reduction in the generation of organic waste, through environmental education programs.

An alternative would be the creation of an inter-municipal consortium involving municipalities in the Kuito region to build and manage a sanitary landfill. The results of the present study led to the closure of the Kuito landfill area.

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