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Implications of Spatial Distribution of Solid Waste Disposal Sites on Effective Solid Waste Management in Chuka Municipality, Tharaka Nithi County-Kenya

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Abstract: ***Technological advancements continue to make representation of the world's phenomena easy and a reality today especially by depicting patterns and distributions in a given area. Location of waste bins is a determinant to effective solid waste management in urban areas due to its influence on waste disposal and collection frequencies. In Chuka municipality, uneven geographical coverage of waste collection services through designation of formal disposal sites by the County solid waste management service has resulted into proliferation of informal disposal sites in unserved and unmapped areas. The objective of this study was to establish the spatial distribution of formal and informal solid waste disposal sites in Chuka Municipality. A field survey was conducted and the spatial data was acquired using a handheld GPS device inform of coordinates (latitude and longitude) for each solid waste disposal site in the study area. Neighbor Analysis in Arc GIS 9.3 (version) was used to analyze the data. The analysis revealed spatial clustering of both formal and informal disposal sites in the study area for areas covered and not covered by the county solid waste management service respectively. Relative Nearest Neighbor Analysis indicated a higher concentration of informal disposal sites than the formal disposal sites implying that the uncollected waste stream load will keep on increasing as the number of informal disposal sites increase within the CBD, Ndagani, Kibumbu and the suburbs of Rukindu, Kathituni, Mucwa and Kirege. Therefore, the study recommends more evenly distributed formal disposal sites in the medium population density areas with application of GIS tools in designating them for effective waste management.***

Keywords: Disposal sites, Spatial distribution, Nearest Neighbor Analysis, solid waste

1. Introduction

Waste management is a global environment issues, with solid waste management in urban areas being one of the major problems facing urban planners globally (Danbuzu, 2014) because the rapid urbanization currently taking place has undoubtedly made the world into a network of cities and towns dealing with comparable environmental difficulties, particularly those pertaining to solid waste management (UN – Habitat, 2019). Since waste production is typically predicted to rise along with both economic progress and population expansion, areas with a high concentration of developing and lower-income countries are likely to see the biggest increases in garbage output (Kaza et al., 2018). The challenge experienced by the urban entities in these countries is how to reconcile economic growth, population growth and infrastructural needs with environmental protection (Majale & Wekisa, 2020).

Waste collection is a key and important component of municpal solid waste management (Fuseini, 2021) because it determines the implementation of other actions in the hierarchy of waste management, yet it is the most challenging aspect due to the massive investment required in terms of personnel (capacity), and optimally located points (bins) (Majale & Wekisa, 2020). Therefore, distribution of solid waste collection containers to residential areas remains a key strategy to enhance waste collection with spatial equity in a municipality yet it is a herculean challenge to Municipal Waste Management Authorities (Fuseini, 2021). Victor (2016) observes that where disposal sites must be used, they should be carefully designed, supervised, and placed far from habitations, educational institutions, and other infrastructure facilities utilizing remote sensing and GIS. GIS (Geographical Information System) is a technology whose potential matches the need for the global solid waste management. Specifically, GIS can provide an opportunity to integrate field parameters with population and other relevant data or other associated features which will help in selection of suitable disposal sites, can provide ways for decision making during planning especially when it comes to solid waste collection and disposal, and its use in analysis especially when representing the real world phenomenon, helps in integrating and simplifying the interpretation of facilities distribution especially the visual analysis and interpretation (Danbuzu, 2014).

Most importantly, GIS helps managers in creation of databases that informs the stakeholders on the exact areas that

need more attention rather than concentrating on a particular area (Danbuzu, 2014).

Kenya like any other developing country, finds itself in a precarious position in addressing waste management due to urban population growth superseding general population growth rate (Majale & Wekisa, 2020) which explains why there is a growing challenge of illegal and indiscriminate dumping of waste in most of the urban areas in the country.

In this respect, Kenyan parliament passed the Sustainable Waste Management Act of 2022 with objectives to: promote environmentally sound infrastructure and systems for ensuring efficient solid waste service delivery, ensuring a clean and healthy environment for Kenyans to live in, reducing air, land, fresh water, and marine pollution, and improving waste management sustainability, establish an environment that is conducive to employment in the green economy for waste management, recycling, and recovery, promote sustainable manufacturing and consumption practices that emphasize resource efficiency, and educate the public on responsible waste and environmental behavior (Sustainable Waste Management Act, 2022).

The Act goes further to charge with responsibility, the county governments of among other things, maintaining designated disposal sites and landfills; maintaining information on waste management initiatives; and dissemination of the data with the appropriate authorities. The above areas of focus by the Act are of particular interest to this study especially on the need to collect and manage data on waste collection, quantities and generation as well as on disposal sites at county levels of governments.

The county government of Tharaka Nithi cites poor waste management as one of the emerging issues in the TNC MTP IV of 2022 for the period 2023 – 2027 but has not proposed the action areas for mitigating the challenge. In the County Integrated Development Plan (CIDP) for the period 2021 – 2022, waste management and pollution control is one of the priority areas and whose strategy is to relocate the current dumpsite and provide litter bins. Provision of litter bins is a result of good planning and locating municipal litter bins conveniently so that one can collect the accumulating trash and emptying regularly is an important phase of waste management (Majale & Wekisa, 2020).

Of great interest in the study, is the spatial distribution of the litter bins currently within space in Chuka Municipality in consideration to the geographical coverage as required in the provisions of the Sustainable waste management Act of 2022 relating to functions of county governments in sustainable waste management.

Statement of the Problem

Chuka town, a medium-sized urban center, is urbanizing fast and faces the problem of unsustainable waste management coupled with inadequate waste collection. The increased urbanization has attracted increased human settlement even in areas not initially designated for residential land use, consequently leading to informal open disposal sites where waste is rarely collected because it exists outside the usual known waste collection sites currently served by the County Solid Waste Management Service. The current designated waste collection and disposal sites were arrived at in a discretionary manner and are inadequate taking into consideration the urban sprawl being witnessed that has led to the growth of both formal and informal settlements in the municipality. Significant improvement in Municipal Solid Waste Management has been realized in the municipality through increased waste collection frequencies and the allotment of large metal waste bins by the County Municipal Solid Waste Management Service but there is an increasing emergence of informal disposal sites in the township where waste collection is still scanty due to a lack of drop-in bins, and in other cases, some areas are not served by collection trucks, or the collection bins are not accessible to the new settlers for disposal of waste. Further, there is lack of public awareness and involvement, resulting in uncontrolled solid waste disposal; waste produced is not sorted or segregated at the source and is disposed of in its mixed state, complicating waste stream handling in the township. Consequently, most of the residents in these localities, comprising of low and middle-income families, suffer from waste-related environmental health nuisances and hazards. In case of floods from heavy rains, the waste flows into nearby channelized flows rendering them polluted yet, clean and safe urban human settlements is guaranteed in the 2010 Kenyan Constitution and SDG 11 and 12 on ensuring that urban areas and human habitations are inclusive, secure, robust, and sustainable while ensuring environmentally sound disposal of waste, reduction, and recycling. It would therefore be necessary to establish the spatial distribution of the current designated and undesignated disposal sites which may inturn inform on the inequalities and gaps in the provision of formal disposal and collection sites for an efficient solid waste management system that appreciates and utilizes available modern technology in achieving spatial equity in the distribution of formal disposal and collection sites. The study therefore intended to fill this gap of knowledge by applying GIS technology to establish the spatial distribution of the informal and formal disposal sites in the municipality and the implications it has on effective solid waste management.

1.3 Purpose of the Study

This study aimed at establish the spatial variations in distribution of the formal and informal disposal and collection sites in Chuka Municipality and the implications it has on effective solid waste management.

1.4 Objectives of the Study

The study was guided by the following specific objectives:

- To establish the spatial distribution of formal and informal waste disposal sites in the township.

1.5 Research Questions

The study was guided by the following research questions:

- How are the formal and informal disposal sites spatially distributed within the municipality?

1.6 Significance of the Study

The Constitution of Kenya (2010), specifically chapter 5 (69), obligates the government to provide a clean and healthy environment to the people while article 42 gives all citizens the right to a clean and healthy environment. Proper municipal solid waste management is a key activity towards the realization of this constitutional obligation.

The increase in commercial, residential, and infrastructural development within Chuka township environs has directly affected sustainable waste management due to the generation of more waste streams. Uncoordinated and lack of urban spatial plans compound the problem of unsustainable urban SWM, consequently affecting the safety of the human settlement. Therefore, the findings of the spatial distribution of the solid waste disposal and collection sites is significant in planning facility allocation, especially for waste collection services. The findings of this study are also expected to contribute to the enhancement of current knowledge on efficient integrated solid waste management in the fast growing urban areas of Kenya.

Further, most cities and towns in Kenya lack an updated database on solid waste management and the results of this study are therefore expected to make a significant contribution towards the establishment of such a database for Chuka town. Further, the study findings are expected to provide baseline information for appropriate waste policy development for Chuka Municipality and the larger county as well as forming a basis further research.

Scope of the Study

The study was carried out within Chuka Municipality in Tharaka Nithi County, encompassing all the waste collection points currently serviced by the county municipal waste management department and the informal disposal sites not accessible or served by the County Municipal Solid Waste Management Service.

Conceptual Framework

The researcher sought to establish the implications of spatial distribution of solid waste disposal sites on effective solid waste management in Chuka Municipality. Figure 3 gives a model showing the relationship among the study varaibles which include the dependent variables, the intervening variable and the independent variable.

Mugenda and Mugenda (1999) defines the indepenent variable as that which the researcher manipulates inorder to determine the effects or influence on other variables, while the dependent variable refers to that which attempts to indicate the total influence from the effect of the independent variable. Further, an intervening variable is that which is recognized as being caused by the independent variable and as being a determinant of the dependent variable (Mugenda & Mugenda, 1999).

For this study, the independent variable was the spatial distribution of disposal sites while the dependent variable was the effectiveness of the solid waste management. The intervening variable was the stakeholders participation.

That the spatial distribution of waste disposal sites determines geographical coverage and frequency of waste collection, waste minimization, waste segregation, waste storage and resource recovery which are indicators of effective municipal solid waste management.

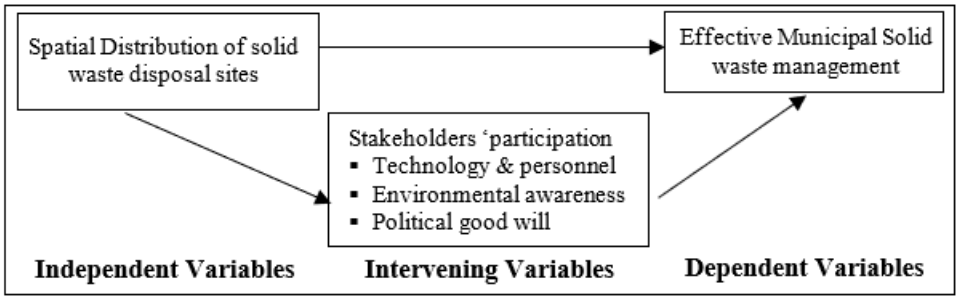

Figure 1: Conceptual Representation of Variables

How well the disposal sites will be planned and distributed in consideration to environmental health protection will require stakeholders' participation such as GIS experts in applications of technology, political good will and environmental awareness among others to properly and adequately site them.

The effectiveness of municipal solid waste management on the other hand will also be determined by how well stakeholders' are involved, their environmental awareness, their technology, political goodwill, consumer education, incentives, and related facilities.

2. Methodology

Study Area

The study area comprised of Kibumbu, Ndagani and Chuka town CBD in Chuka Municipality. Chuka Municipality is situated in Chuka Division, Karingani ward, Chuka Sub – county of Tharaka Nithi County. It is on the eastern slopes of the towering Mt. Kenya, 70 km from Meru town and approximately 175kms North East of Nairobi in Kenya. It extends from River Tungu on the North through Ndagani and Chuka Central Business District to River Naka on the Southern side, and from Kibumbu on the West to Kathigiririni on the East through the CBD. The municipality is bound by northings 0.2888094^0 S and 0.345586^0 S and Eastings

37.689555^0 E and 37.632063^0 E. It has an elevation of 1397 m and an area of 169.6 Km^2.

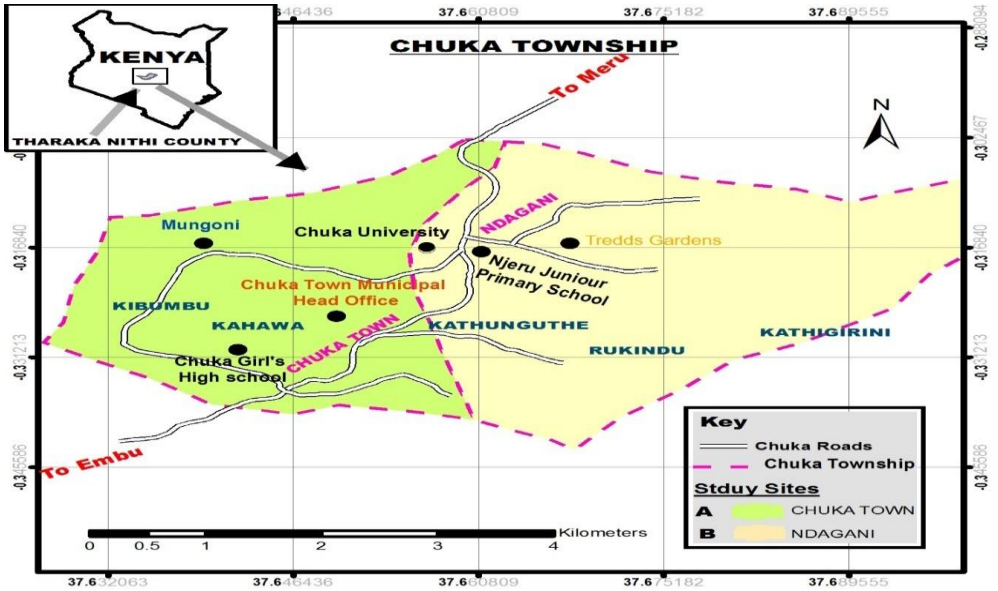

Figure 1: Map of Chuka Township

Source: Galaxy Geoservices Consultants Inc.

Research Design

The research design for the study was explanatory. Usually, it is carried out in order to identify and report some correlations between various components of the phenomenon being studied (Lellisa, 2018) and for this reason; it helped in describing the distribution of MSW disposal sites in Chuka Municipality. It seeks to explain and account for the descriptive data by identifying causes and contributing evidence to support or disprove any hypotheses or predictions (Lellisa, 2018).

Data Collection

A handheld GPS device was used to capture locational co-ordinates of the formal and informal disposal sites. These were catured as waypoints inform of latitudes and longitudes in the format of DD (Decimal Degrees) in the UTM projected co-ordinate system zone 375 with a local datum of Arc1960. The captured GPS co-ordinates were then transferred to the MS-Excel spreadsheet where they were converted into GIS-acceptable format of CSV files. The raw data was then transferred into ArcGis software version 9.3 for nearest neighbor analysis. A satellite image was used as the basemap onto which the GPS co-ordinates were overlaid through geo-coding, for generating maps showing the distribution of the formal and informal disposal sites in the municipality.

Data Analysis

The Nearest Neighborhood Analysis was used in order to examine the spatial distribution of the solid waste dump sites in town. The analysis was done by the ArcGIS 9.3 computer application. The NNA is a technique for investigating patterns in locational information that can be visualized through the comparison of the observed patterns of event-to-event or random point-to-event nearest neighbor distances with those that are hypothetically anticipated from a number of hypothesized models, in particular those of spatial randomization. (Upton, G & Fingleton, B., 1985)

3. Results and Discussion

Analysis of Spatial Distribution of Formal and Informal Waste Disposal Sites

A survey of all disposal sites revealed a total of 47 formal disposal sites in the municipality representing 24.4% of the total disposal sites observed in the municipality, and a total of 146 informal disposal sites representing 75.6% of the total disposal sites observed in the municipality. These findings agree with those of Danbuzu (2014) that found out that out of the 741 Solid Waste Collection Points only 96 (12.96%) are legal (authorized), while all the other 645 (87.04%) are illegal (unauthorized) in Urban Katsina – Nigeria. This implies that the formal disposal sites are not meeting the need for the waste disposal and collection and hence are inadequate and unsustainable to address geographical coverage in waste collection.

Spatial locations of waste disposal sites in the study area was then explored to examine the nature of their distribution and to what probability was the distribution by random chance. To get spatial distribution pattern of the disposal sites, computed nearest neighbor ratio (R – Value) was compared with standard index value. To make distinction between the two categories of disposal sites, analysis was done for formal disposal sites independently.

Nearest Neighbour Analysis of Formal Disposal Sites

Plate 1: Formal Disposal sites in Chuka Municipality
Source: Author (Field survey 2021)

Plate 1 shows formal disposal sites which are the designated or authorized sites for waste disposal and collection by the county solid waste management service through the County Government of Tharaka Nithi. Table 1 shows the results of the Nearest Neighbour Analysis of the 47 formal disposal sites in Chuka Municipality.

Table 1: Nearest Neighbour Analysis of Formal Disposal Sites

Description Value	Description Value
Number of (Formal disposal sites) 47	47
Observed Mean Distance 134.65 meters	134.65 meters
Expected Mean Distance 172.69 meters	172.69 meters
Nearest Neighbour Index (Ratio) 0.780	0.780
Z-score	-2.889
P value 0.0000	P value 0.0000

The analysis of the spatial distribution pattern of formal disposal sites revealed that the observed mean distance of the 47 disposal sites across Ndagani, Kibumbu and Chuka CBD in the study area was 134.65 meters while the expected mean distance stood at 172.69 meters. This implied that the formal disposal sites were closer to each other than normal.

Further, the Nearest Neighbour Index (R – Value) was then computed to establish the pattern of the distribution. According to Esri, (2018) values of nearest neighbour index, an index of 0 implies exclusively clustered distribution, an index value 1.0 shows absolute random distribution and then an index value above 1.0 indicates a tendency to disperse.

For the case of formal disposal sites, computed nearest neighbour index was 0.780 (Rn = 0.780) indicating a clustered distribution pattern. Location of formal disposal sites had a deviation of -2.889 (Z score) below the mean distance at a significance level of 0.01. A z-score of -2.889 implied that there is less than 1% likelihood that the clustered pattern of formal disposal sites could be the result of random Chance. This means that there is concentration of the formal disposal sites in the study area than normal which can be attributed to the concentration of high- density population in the urban areas of the municipality, high economic activity that leads to high waste generation, and the accessibility provided by the road network. These findings agree with those of Naibbi & Umar (2017) and Fuseini (2021) that the pattern of distribution of disposal and collection containers was clustered due to the urbanizing form with high population concentration in Kano Metropolis – Nigeria and Ejisu Municipality – Ghana respectively, just like Majale& wekisa (2020) found out that the communal waste collection points are clustered in the densely populated area of Mombasa City.

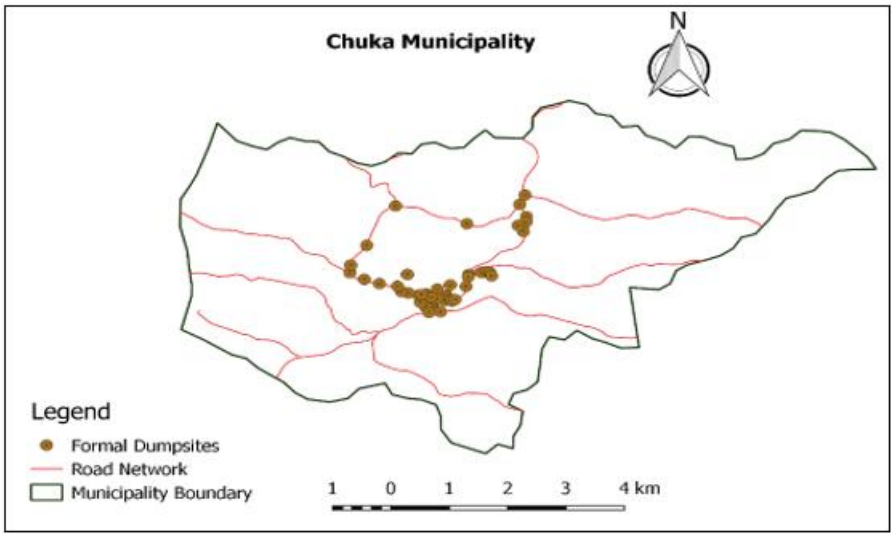

Figure 2: Spatial Distribution of the Formal Disposal Sites.
Source: Galaxy Geoservices Consultants Inc.

It is clearly observable in Figure 2 that there is more clustering at Chuka Town CBD in the south, as compared to Ndagani in the North and Kibumbu in the west. All the above case studies observe that the clustering of formal disposal sites causes proliferation of informal disposal sites in unserved areas that threaten the environmental health in those areas. Infact, Majale & wekisa, 2020 observed that a close inspection of the pattern of densities of both informal and formal collection points in Mombasa, shows that areas with high density of collection points are the same areas experiencing low quality of life.

Nearest Neighbour Analysis of Informal Disposal Sites

Plate 2: Informal Disposal sites in Chuka Municipality
Source: Author (Field Survey, 2021)

Informal disposal sites are waste drop points where people just dump household refuse and which often are not officially designated for dumping. Table 2 shows the results of the analysis of 146 informal disposal sites.

Table 2: Nearest Neighbour Analysis of Informal Disposal Sites

Description	Value
Number of informal disposal sites	146
Observed Mean Distance	77.53 meters
Expected Mean Distance	130.711 meters
Nearest Neighbour Index (Ratio)	0.593
Z-score -9.306	Z-score -9.306
P value 0.0000	P value 0.0000

The analysis of the spatial distribution pattern of all informal disposal sites by the nearest neighbour analysis for all the 146 dumpsites mapped in the area, the observed mean distance was 77.53 meters with an expected mean of 130.71 meters, implying that they were very close to each other and meaning that there was disposal of waste at areas of convenience by residents without any guidelines or considerations of any threats.

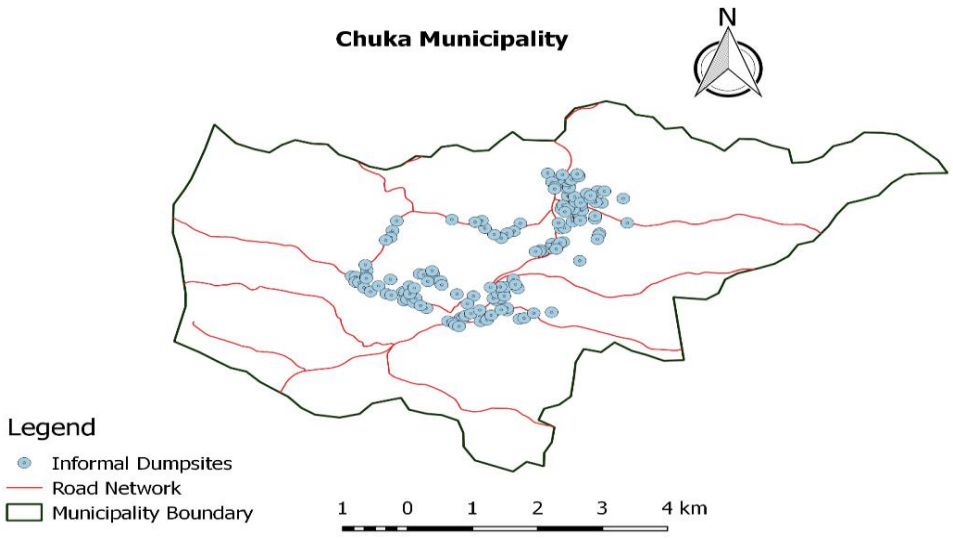

Figure 3: Spatial Distribution of Informal Disposal Sites.
Source: Galaxy Geoservices Consultants Inc.

From the Nearest Neighbour Analysis, the computed Nearest Neighbour Index (Rn = 0.59) indicated that the distribution of informal disposal sites was clustered, having a Z score of -9.30 when the critical values was -2.58 at the significant level

of 0.01. Given the z-score of -9.30, there is a less than 1% likelihood that the clustered pattern of informal disposal sites could be the result of random chance. It means that informal disposal sites are close to each other and that residents are likely to cover about 78 meters to the reach any nearest informal disposal site from the first encountered one at their premises. These findings agree with those of Danbuzu, (2014) and Manjale & Wekisa (2020) that if there are no designated sites for waste disposal an urbanizing area, there is a tendency of people disposing off their waste at their convenience, which leads to emergence of uncontrolled disposal sites even in places that are inaccessible by the Municipal Solid Waste Management service trucks for collection. This can lead to environmental degradation, health risks, and hinder the effectiveness of waste management systems

Comparison of Spatial Randomness of Disposal Sites Distribution

The nearest neighborhood analysis showed that the distribution of both formal and informal disposal sites in the study area was spatially clustered. There was a need to compare the spatial distribution of formal disposal sites to the informal ones. Further analysis was done using Relative Nearest Neighbour Index as shown:

$$\text{Relative NNI} = \frac{\text{NNI of Informal Disposal sites}}{\text{NNI of Formal Disposal Sites}}$$

$$= \frac{0.593}{0.780}$$

$$= 0.76$$

From the above, distribution of informal dumpsites relative to an expected random distribution appears to be more concentrated than that of formal sites relative to an expected random distribution.

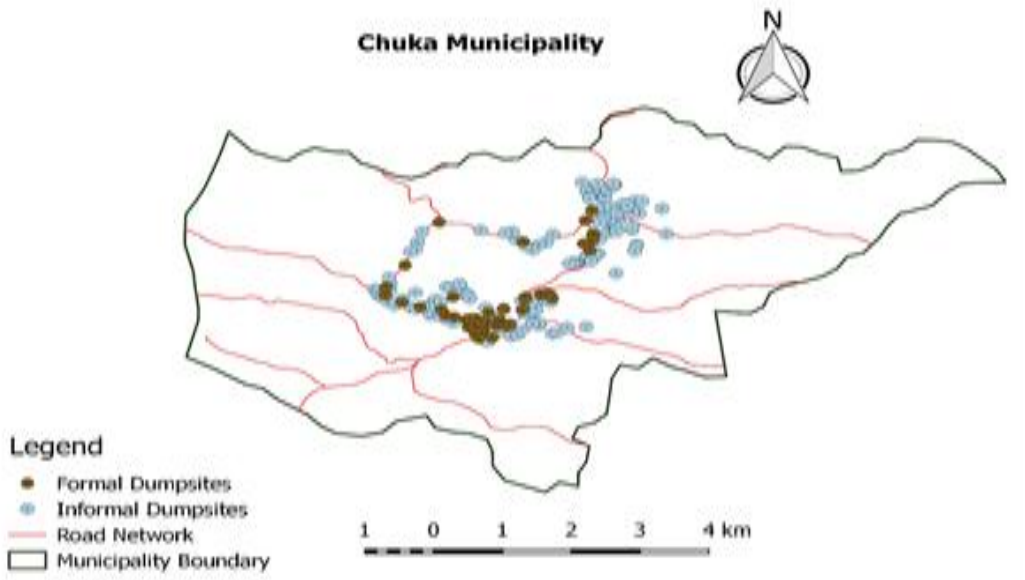

Figure 4: Spatial Distribution of Formal and Informal Disposal Sites.
Source: Galaxy Geoservices Consultants Inc.

The relative index showed that informal disposal sites are more concentrated than the formal disposal sites therefore there is a higher concentration of informal disposal sites than the formal disposal sites. The implication is that uncollected waste stream load will keep on increasing as the number of informal dumpsites increase within the CBD, Ndagani, Kibumbu and the suburbs of Rukindu, Kirege and Mucwa fringe areas of the township. This is exemplified by ground dumping of wastes in both formal and informal disposals.

4. Conclusion and Recommendation

4.1 Conclusion

The study aimed at establishing the spatial distribution of the solid waste disposal sites and its implications on effective solid waste management in Chuka Municipality – Tharaka Nithi County, Kenya. Based on the results of the Nearest Neighbour Analysis on spatial distribution of the disposal sites, formal disposal sites were clustered and hence not evenly distributed, leaving a substantial population to resort to informal disposal points, which were also clustered indicating a section of the population underserved by the Municipal Solid Waste Management Service.

The clustered spatial distribution of both formal and informal disposal sites can also hinder even solid waste disposal management. For example, the close proximity of formal and informal disposal sites can result in confusion and overlap of responsibilities between government agencies and waste pickers, leading to inadequate waste collection and disposal (Mati & Ng'ang'a, 2021). Moreover, the clustered spatial distribution of informal disposal sites can make it challenging for formal waste management systems to reach and collect waste from these areas (Liu et al., 2019).

A spatially even distribution of the formal disposal sites would significantly redress solid waste management while stakeholder involvement would be a critical component in its effectiveness.

Therefore, clustered spatial distribution of both formal and informal disposal sites is a significant challenge in even solid waste disposal management. Addressing this issue will require a holistic approach that considers environmental justice, community involvement, and effective waste management practices.

4.2 Recommendations

The following are recommendations made by the study to enhance the current waste management system:

1) Even distribution of the formal disposal sites even in medium populated areas to enhance effective solid waste collection and overall management.
2) Involvement of all stakeholders in waste management.
3) Application of GIS technology in site selection for formal disposal sites.

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