

'Eco-Taka': An Efficient G.I.S based Solid Waste Management Solution

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Abstract: *Solid Waste Management has been and still remains one of the major challenges in most developing countries, including Kenya, with cross cutting effects on the environment, human health, and the road and drainage network among others. This study set out to take an analytical look into Nairobi's S.W.M model in a bid to identify its shortcomings. The 'ECO-TAKA' S.W.M model was then developed as a self sustaining model that shifts the cost burden from the waste producer (Consumer). G.I.S was used as a decision support tool in studying spatial characteristics of the existing solid waste management approach and coming up with objective S.W.M Zones.*

Keywords: Geographic Information System (G.I.S), Solid Waste Management (S.W.M), 4 R's (Recycle, Re-use, Reduce, Recover)

1. Introduction

'Taka' or 'Takataka' is a Swahili word which translates to garbage, waste or refuse. As an S.W.M approach the 'Eco-Taka' model seeks to extract economic value from consumer remains. It is an S.W.M model that was designed to motivate public participation in the 4 R's (Recycle, Re-use, Reduce and Recover) through economic reward schemes.

2. Background

Littered streets; flying polythene bags blown by the wind; clogged drainages and smelly garbage heaps are some of the demerits that characterize many neighborhoods across Nairobi. However, a trip down memory lane reveals that this was not always the case.

Pre and Post independence Nairobi was a clean City. Garbage collection services were fully provided by the Nairobi City Council to every household at a fee factored in the monthly water bill. The Council managed to achieve a 90% garbage collection rate.

In the mid 80's and 90's changes in the city By-laws saw this charge dropped with the council forced to fund garbage collection services from its other sources. This coupled with the rapidly growing population saw the council gradually become overwhelmed. Residents who had been used to weekly garbage collection by the council had to adapt to weeks of uncollected garbage. Illegal dumpsites became a common site even within the Central Business District. The private sector was brought in to help salvage the situation. Private garbage collection companies emerged.

Currently, Nairobi generates approximately 3500 tons per day of solid waste out of which roughly 50% is collected (City Council of Nairobi, 2010). This leaves close to 1750 tons being either burnt or illegally dumped every day.

While all this was happening, the City's dumpsite was slowly growing into the environmental nightmare it is today. Originally set on a 32 acre abandoned quarry site employing an open dumping landfill system, the Dandora Dumpsite has grown into a mountain of garbage run by illegal gangs who mint millions from it. Although it was declared full and hazardous in 2001, it still remains active with efforts to find a new dumpsite location proving futile.

This problem is not unique to Nairobi. Solid waste management is one of the major challenges facing many urban areas in developing countries. In Kenya for instance, the rapid urbanization has seen many towns and municipalities struggle to curb the continued mushrooming of illegal dumpsites. Nakuru Town, once considered the cleanest town in East and Central Africa is a pale shadow of its former self with a poorly maintained municipal dumpsite, littered streets and garbage heaps spread out all over. To add salt to the injury, the town's main dumpsite is set on a relatively high ground which sees runoff flow into the town with lots of floating materials. The dilapidated state of the 27 acre dumpsite has left it inaccessible during the rainy seasons forcing garbage trucks to offload by the roadside.

Mombasa, Kenya's second largest city has also fallen prey to the garbage menace. Generating approximately 700 to 800 tons of garbage daily, only 68% of this is collected with the rest ending up dumped or burnt (Tan, 2012).

According to Kenya's Vision 2030, the social strategy aims to make Kenya a clean, secure and sustainable environment with emphasis on reduced pollution and improved waste management. To achieve this, there is need to evaluate the current situation with regards to waste management and come up with a solution that best fits the local situation.

3. Study Area

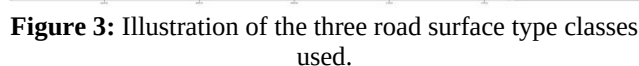
Nairobi County is Kenya's economic and administrative capital. Covering an area of approximately 695 KM², Nairobi

5.1 Data Acquisition & Manipulation



First, various existing Spatial and Non-spatial datasets were collected at the beginning of the study. The spatial datasets obtained in ESRI Shapefile format included Administrative Boundaries (County, Sub-location, Division and Constituency Boundaries), Road infrastructure, Buildings and Rivers.

The Road Network Shapefile was acquired as a single line dataset with various attributes such as the Road Name, Class, Surface Type and length. However the dataset happened to be too heavy for fast processing. I therefore opted to divide it into three separate datasets depending on the road surface type i.e. Tarmac Roads, Murram Roads and Tracks.



A high resolution Aerial Image of Nairobi from the year 2012 was also acquired. This was used to countercheck the various spatial datasets for any currency issues that may have required updating. The image was also used as a base map in the digitization of various datasets of interest such as the Railway network and Protected Areas like Forest, Airports, National Park, Military Bases and the Ruai Sewerage treatment plant.



4. Objectives of the Study

- To map the existing waste management state in a bid to identify emerging issues, patterns, gaps or opportunities.
- To develop a self sustaining S.W.M Workflow.
- To develop objective waste management zones



Demographic data from the 2009 National census was obtained from the Kenya Open Data Initiative website. The Nairobi Sub-locations census data was extracted from the

national dataset. A Join was then created between the excel sheet and the Sub-locations Shapefile taking the Sub-location name as the common field. The join was validated and inconsistencies that arose from the field matching corrected.

The data collection exercise also involved a Socio-economic Survey. This involved questionnaire based interviews conducted in various sample sites. The sample sites were chosen based on the various income levels with fifteen randomly selected households interviewed per sampled site. The key questions sought to find out the waste collection method, quantity collected, collection frequency and the monthly rent.

The waste quantity data for the Dandora Dumpsite was extracted from the weigh bridge log sheets obtained from The Nairobi County Government Environment Department. The Daily Waste Quantity received into the dumpsite was calculated by averaging the total received over three days. This total was then used to estimate the waste composition with percentages sourced from secondary data i.e. The Preparatory Survey for integrated solid waste management (NCC, 2010). A GPS Survey was also carried out to map the existing illegal dumpsites in a bid to visualize any weak points of the existing S.W.M model. This survey was focused mainly on Nairobi's Eastlands area due to time and financial constraints.

6. Results

6.1 Illegal Dumpsite Survey

The Illegal Dumpsite mapping exercise was successfully completed yielding the results shown below.

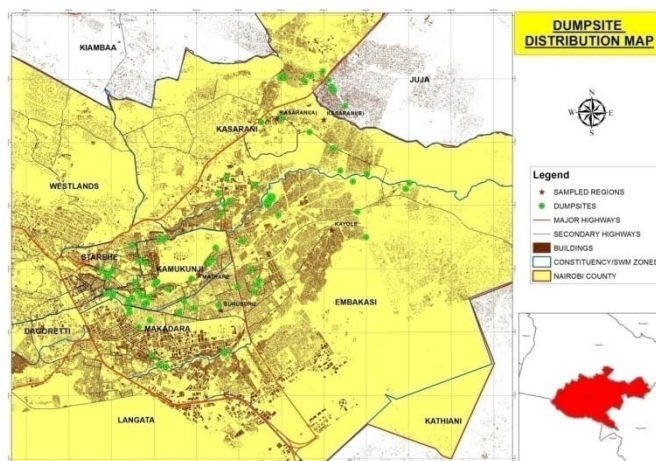


Figure 5: The distribution of illegal dumpsites.

The results from this survey indicated a high concentration of illegal dumpsites in Low Income level areas and slums as well as market places and areas with poor accessibility. The illegal dumping in low income areas and slums could be explained as resulting from low income levels meaning, either most people cannot afford the garbage collection fees or there are no service providers in the area because it is not economically attractive.

For market areas, the main issue was that common dumping sites are used and collected by the County Government garbage trucks or burnt. This method lacks efficiency and is

not environment friendly. Some of the low income areas and slums plus areas with poor accessibility were found to be served by Community Based Organizations (C.B.O's). However most of the CBO's were ill equipped to collect garbage opting to use handcarts to collect the garbage and transporting it to illegal dumpsites.

6.2 Socio-Economic Survey

The Socio-economic survey was based in six sampling sites namely:

- Karen (High Income area)
- Buruburu (Middle Income area)
- Kayole (Low Income area)
- Mathare (Slum area)
- Kasarani [A] (Middle Income area)
- Kasarani [B] (High Income area)

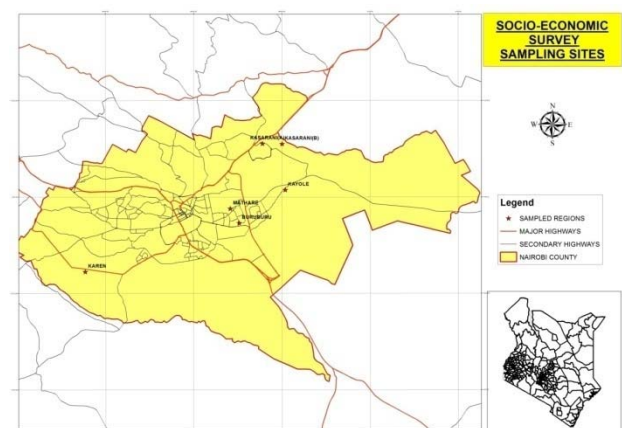


Figure 6: The distribution of socio-economic survey sampling sites.

From the data analysis it was clear that monthly rent was directly proportional to the household head's income level. This question was used as a gauge of how comfortable or able one was to pay the existing garbage collection fees.

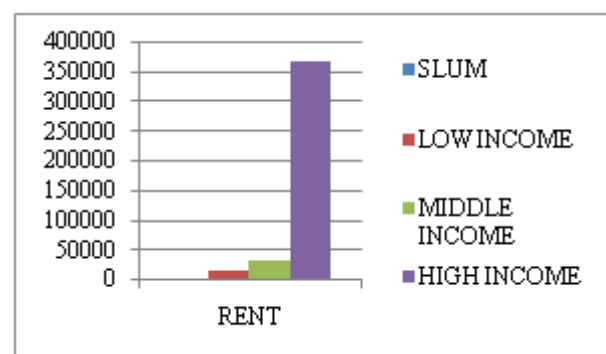


Chart 1: The variation of rent across the different income levels.

The collection fee levied was also directly proportional to the income levels.

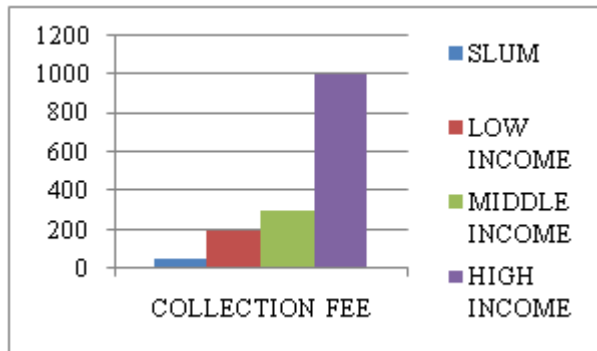


Chart 02: The variation of garbage collection fee levied across the different income levels.

However the High Income level area surveyed in Kasarani lacked the garbage collection services due to the poor road conditions unsuitable for truck navigation. Despite this predicament, no dumping was evident in the area with all households resulting to burning and self composting of waste. This was different from the slums and low income areas where the services were provided mainly by Community Based Organizations e.g. Youth Groups with companies shying off due to either poor accessibility or low returns. Most of the CBO's were ill equipped to provide these services mainly relying on handcarts as there means of transport and moving the waste to illegal dumpsites. The weekly collection frequency was also analyzed with the results showing higher collection frequencies of two times a week in High and Middle Income areas while the low income areas and slums' collection stood at once a week.

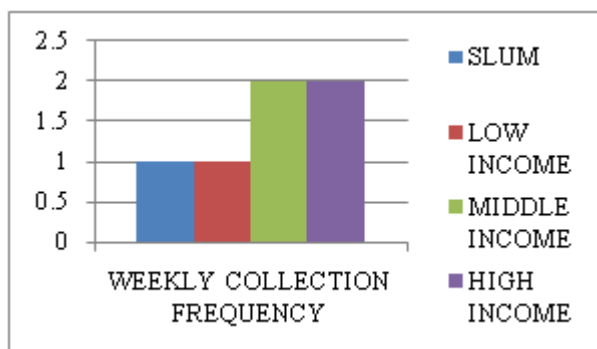


Chart 03: The weekly garbage collection frequencies.

The quantity of waste generated for every household per collection was also measured for the sampled sites and the results summarized as follows:

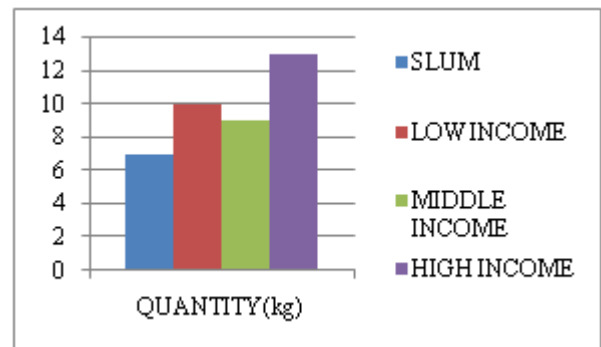


Chart 04: The waste quantity generated per household per collection

From the findings, it was observed that the quantity of waste generated is also directly proportional to the income level. Although the average weight of the generated waste per collection for the low income areas was slightly higher than that recorded for the middle income, the middle income still generated more waste considering the collection frequency. For purposes of coming up with a waste recovery plan, it was deemed necessary to analyze the waste composition. However due to the magnitude of resources such an exercise would require, this study relied heavily on secondary data sources. First, the weighbridge log sheets at the Dandora Dumpsite for three days were acquired from the Nairobi County Government Environment Department. They were as follows:

Table 1: Shows the daily waste quantities at the Dandora Dumpsite for the sampled days.

Day	Date	Waste Amt (Kgs)
Day 1	12/05/2014	1,416,880
Day 2	13/05/2014	1,359,000
Day 3	17/05/2014	1,731,290

The average weight was calculated as:

$$(1,416,880 + 1,359,000 + 1,731,290) / 3 = 1,502,390 \text{ Kg.}$$

The waste composition percentages were borrowed from the *Preparatory Survey for Integrated Solid Waste Management in Nairobi City (NCC, 2010)*.

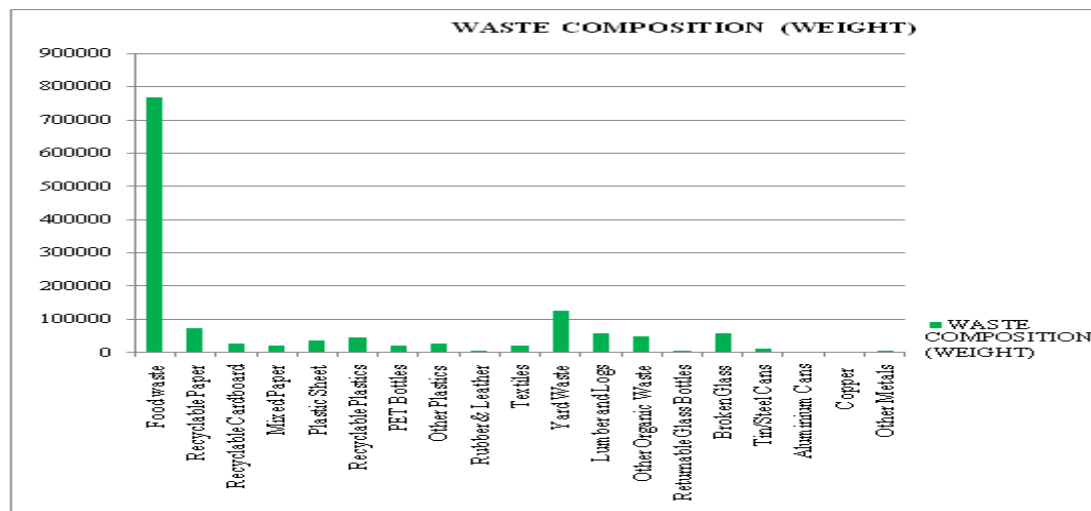


Chart 05: Estimated Waste stream composition in kilograms

From the waste composition analysis it was observed that of all the garbage coming into the dumpsite, food waste was the highest component taking up about 51%. The second highest component was plastics which took up about 8.4% of the total closely followed by paper at 7.93%. Glass was next at 4.04% with the least being metals which took up 1.16%.

The high relative proportion of food waste compared to the other components could be explained by the value of the various waste components i.e. the higher the value of the waste stream component, the lesser its chance of being hauled to the municipal dumpsite. The valuable waste is either not introduced to the waste stream at the source or it is removed from the waste stream by scavengers at illegal dumpsites and litter bins or recovered by the garbage collection team for sale to recyclers. For instance Nairobi's lucrative scrap metal business explains the very low metallic waste coming into the dumpsite.

From the analysis discussed above, various issues emerged that must be considered in the formulation of an effective S.W.M Plan for Nairobi County. First, it was clear that the 'Producer Pays' S.W.M system had failed since it locked out most of the slum and low income residents. This was evident in the distribution of illegal dumpsites either as a result of the areas not being economically attractive to garbage collection service providers or most residents not affording the services available.

It was also observed that the value of various components of the waste stream determined the probability of being recovered before reaching the dumpsite. There is need for an S.W.M model that objectively values waste and sets out to achieve early and effective recovery so that the least possible waste is hauled to the landfill thus increasing the landfills life cycle.

The high amount of food waste is an environmental hazard since dumping it in the open is bound to lead to uncontrolled methane gas emissions. Methane being a green house gas twenty times more potent than carbon dioxide, mitigation measures are necessary. Other emerging issues identified from literature reviewed in the course of this study include:

- Poor separation of waste.
- Uncontrolled open dumping at the already full Dandora Dumpsite.
- Shortage of funds to sustain the S.W.M plan.
- Lack of a clear S.W.M reward scheme.
- Operation of Garbage collection companies outside their designated zones.
- S.W.M zones tied to administrative boundaries.
- Overloading of garbage trucks.

6.3 ECO-TAKA S.W.M Model

The Eco-taka S.W.M model is a self sustaining model with its main focus being value recovery and producer participation. The model can be summarized into the following flow diagram.

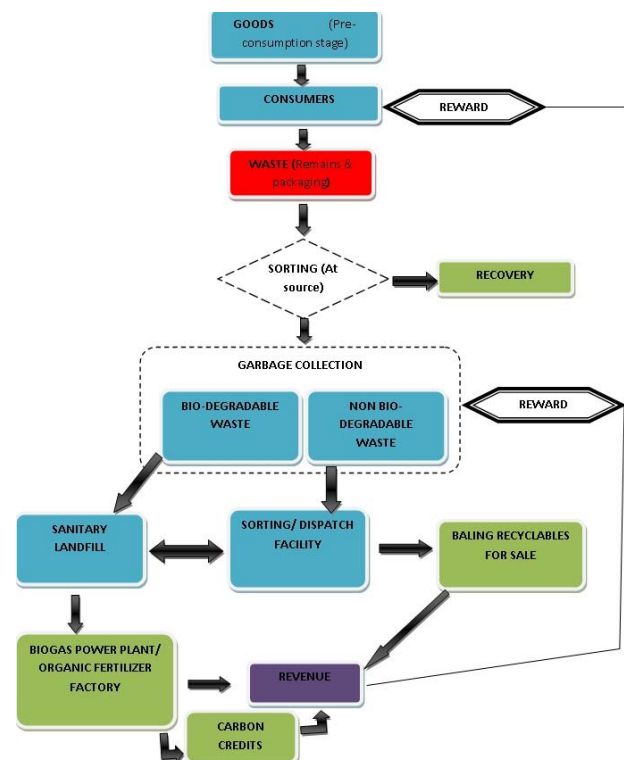


Figure 7: The Eco-taka S.W.M model workflow diagram

Once the goods have been consumed, the remains and packaging constitute the waste. The Eco-taka S.W.M model heavily banks on consumer participation. First, the waste generated is sorted at the source by the consumer/ waste producer. First of all, some of the waste e.g. glass bottles, plastic bottles, newspapers or E-waste is not introduced into the waste stream but instead is recovered from the consumer. This helps in maintaining the re-usability of the items as well as reducing the sorting costs.

The waste going into the waste stream is sorted into two main groups i.e. the bio-degradable waste and the non bio-degradable waste. The two are collected separately with the bio-degradable waste hauled to the sanitary landfill while the non bio-degradable waste is transferred to the sorting sites.

At the sorting sites, an automated sorting process is undertaken to clean the waste, separate the waste into desired components e.g. different grades of plastics, polythene bags, glass, cans etc. and shredding/ crashing them to requisite sizes before they are baled for sale. Any bio-degradable waste at the sorting site transferred to the sanitary landfill while any non bio-degradable items at the landfill are transferred to the sorting site.

To motivate the various S.W.M players to play their roles, various rewards may be used. These may range from monetary rewards and tax waivers for the garbage collectors. As for the waste producers/ goods consumers, the rewards may range from shopping vouchers to monetary rewards in addition to the free garbage collection.

6.4 S.W.M Zoning Model

The Zoning was done in a bid to divide the County into ideal management zones whereby the zones' unique waste generation characteristics would be taken into account when defining the waste management operating procedures. The use of G.I.S for the zoning exercise enabled the consideration of a number of spatial and non-spatial factors while at the same time maintaining objectivity and ensuring complete coverage of the entire county.

Various factors were considered in the zoning exercise. First, there was the need to have accessibility to the various zones. The accessibility via tarmac roads, murram roads and tracks was spatially analyzed. The second factor considered was the population at the sub-location level as per the 2009 national census. The population size is a good indicator of the quantity of waste generated. The optimal zones ought to be balanced in terms of population such that overloading and under-loading of zones is avoided.

The third factor, which is still related to the population, was the number of households at the sub-location level. This was considered since it gave an indicator of the volume of waste expected as well as the number of collection points that may be necessary such that ideally many households would yield smaller zone while fewer households would mean larger zones. Finally, the Income Level Class of the areas was also considered. This was keeping in line with the study findings where the Income Level was found to have an impact on the

waste generation. ESRI ArcGIS's Model Builder was used to design the Zoning Model as shown below.

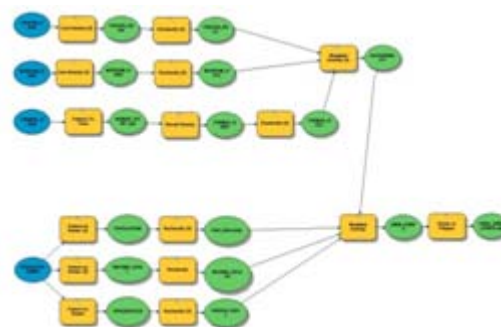


Figure 8: The S.W.M zoning model flow diagram.

The various datasets were rasterized and reclassified before a weighted overlay was performed to generate the optimal zones. The results yielded 165 zones divided across five classes. However most of the Raw Zones were outliers. The Raw S.W.M Zones were refined by dissolving the tiny polygons resulting into 24 Proposed S.W.M Zones.

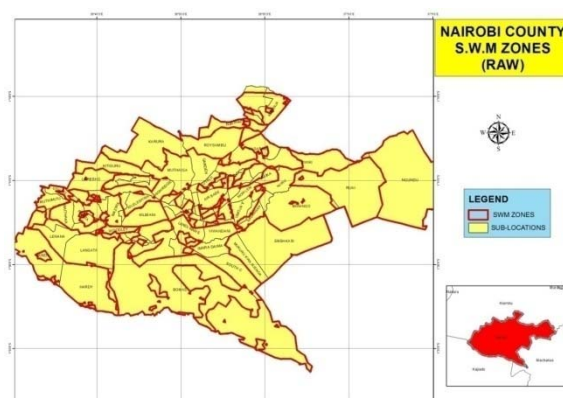


Figure 9: The Raw S.W.M Zones

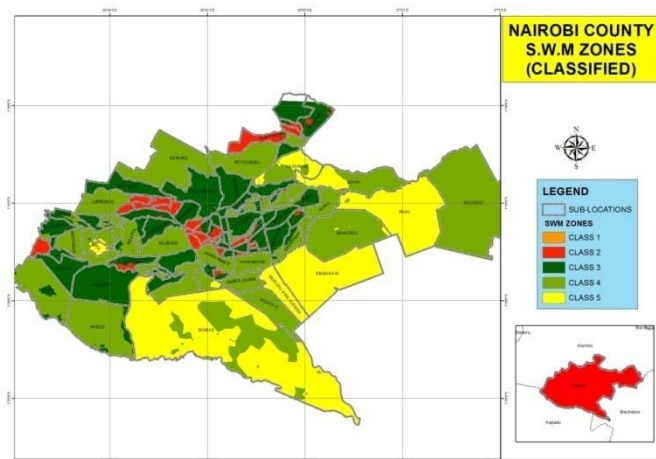


Figure 10: The RAW S.W.M Zones classified into 5 data classes.

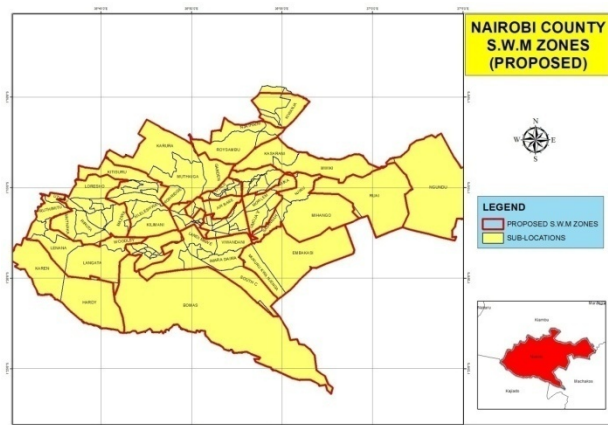


Figure 11: The Proposed S.W.M Zones.

7. Conclusions

The design of a S.W.M Plan is an expensive and complex undertaking especially due to the tangled web of interested parties. However the use of G.I.S technology could lessen the burden by providing scientific objectivity and accurate projections for planning and decision making.

It was also clear that the human population is constantly evolving in terms of growth, settlement patterns, land uses and subsequently their waste generation characteristics. It is thus important for the S.W.M Zones to evolve also with the trends so as to constantly stay in control of waste stream flows.

Despite the advanced scientific and technological inputs incorporated into S.W.M planning, the human factor remains the weakest link. For instance in Nairobi, it would need a system that motivates the masses to ditch their environmentally carefree mindsets that result in illegal dumping. This is where the Eco-taka S.W.M Model comes in. With the self sustaining reward system it is possible to achieve the Vision 2030 target of 100% waste collection.

8. Recommendations

This study relied heavily on sampled data and secondary datasets. It is therefore important to carry out a detailed study for the entire Nairobi County for better results. The study also presented a need to carry out suitability studies for various reward schemes used in S.W.M with the aim of coming up with an approach that is locally feasible.

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Author Profile



David Muriithi received his BSc in Geomatic Engineering and Geospatial Information Systems from Jomo Kenyatta University of Agriculture and Technology in 2013 and is currently pursuing his MSc degree at the same institution. He has been working as a G.I.S Analyst especially in the Survey and Urban Planning sector since 2013.

Felix Mutua received his BSc. in Geomatic Engineering from Jomo Kenyatta University of Agriculture and Technology, Kenya with honors in 2006. He continued his studies at the same university where he obtained his MSc. in Environmental Information Systems in 2009. He acquired a Ph.D. in Civil Engineering from The University of Tokyo, Japan in 2013. Felix Mutua's current interests involve GIS and applications of satellite products in monitoring water resources, land use and land cover as well as applications of microwave remote sensing for extreme weather and climate change impact assessment.