Waste Ergonomics Optimization in Ilorin, Nigeria

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Abstract

In order to ease and achieve best desired results in waste management procedures and operations in Ilorin metropolis, Kwara State of Nigeria, the government, through the Kwara State Waste Management Corporation (KWMC), has provided different equipment including vehicles and containers. The distribution and utilization of these equipments are very vital. This paper attempts to examine this using TORA-Optimization model and GIS technique. Data required for this study (facilities and equipments, including container types, vehicle types and cost, maintenance cost of equipments, and manpower welfare) were sourced secondarily from the archives of KWMC, and primarily through interviews from some randomly selected street cleaners and drivers. The study observed that the optimal use of these equipments in the study area is highly decry-able. This can be attributed to non adoption of land use system for planning by KWMC. Appropriate recommendations are presented.

Introduction

Careful and beautiful design of equipments to aid waste management is an attempt to ease the procedures and operations of the managers, and to yield the best desired result. Ergonomics refers to equipment designs for an intended uses, and optimal uses of this equipment need to be appraised for posterity sake. Since wastes are materials that are of no use and has no economic values, it therefore means that appropriate equipments and optimal uses of these equipments are of great importance (Beyene, 1999).

Mathematical optimization is the branch of computational science that seeks to answer the question 'what is best?' for the problems in which the quality of any answer can be expressed as a numerical value (Beroggi, 1999). He further states that a mathematical optimization model consist of an objective function and a set of constraints in the form of a system of equations or inequalities. The general procedure that can be used in the process cycle of modeling is to (1) describe the problem, (2) prescribe a solution, and (3) control the problem by assessing/updating the optimal solution continuously, while changing the parameters and structure of the problem. It is based on these three processes that the model for this research is hinged on. However, Agunwamba (2003) noted that, while it is desirable to optimize the unit operation of the collection process, too little attention has been given to quantifying the effects of collection cost and efficiency of using different types of vehicles and containers. He further stated that substantial amount (80% of total expenditure) is spent on collection and transportation, implying that optimization of the collection system will yield significant saving in cost. In addition, random location of containers, where the waste generation is not high, results to underutilization while in some areas, there is possibility of overflowing. Hence, the utilization and distribution of the available vehicles and containers is very vital. The summation of findings of this paper will in no doubt accelerate conscious effort for optimal uses of equipments in our society and immensely contribute to the body of knowledge.

Study Area

Ilorin is located on latitude $8^0 30'$N and Longitude $4^0 35'$E with an area of about $100km^2$ (Kwara State Diary 1997). The city is situated in the transitional zone between the forest and savanna region of Nigeria (figure 1). The geology of Ilorin consists of Pre-Cambrian basement complex with an elevation that varies from 273m to 333m in the West having an isolated hill (Sobi hills) of about 394m above sea level and 200m to 364m in the East. Oyegun, 1983 further asserted that a large part of Ilorin town is laid by sedimentary rock, which contains both primary and secondary laterites and alluvial deposits. The major river in Ilorin is Asa, which flows North-South direction dividing the plain into

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two, Western and Eastern parts. The eastern part is generally steeper than the western part with height ranging from 900 – 1200 feet in some part and peaking at isolated landforms.

The climate of Ilorin is humid tropical type and it is characterised by wet and dry seasons. The wet seasons of Ilorin begins towards the end of March when tropical air mass is prevalent and ends in October. Dry season in the town begins with the onset of tropical continental air mass. This is a type of dusty wind, which carries no moisture commonly referred to as harmattan. This wind is usually predominant between the months of November and February with the mean annual total rainfall at 1,200 mm. The vegetation of Ilorin is characterized by scattered tall tress shrubs, of between the height of 10 and 12 feet. Some of the notable trees include butter trees, Acacia, Locust beans, Baobab, Akee-apple, etc.

The city is covered mainly by ferruginous soil on crystalline acidic rock. The most prevalent landuse classes are: Residential, Administrative, Institutions (Health & Educational), Commercial (Stores/Services & Markets), Transportation (Motor park), Industrial (Manufacturing/Workshop) as shown in figure 2.

As Ilorin city grew over time, particularly after it gained the status of a state, social-economic activities and physical development doubled, and thus affected inflow of people. This population and social-economic activities increase resulted into daily increase in waste generated by the dwellers. Hence, of the intervention strategy of the state government was the establishment of government agencies backed by legislation to take up the challenges of waste management in the state. Amongst the numerous agencies set up by the government to tackle waste management problems is Kwara Waste and Environment Protection Agency (KWEPA) under the Ministry of Environment and Tourism. KWEPA met an untimely death due to fund restriction, government policies continuity, and un-professionalism in her operations. Despite all these, the site of heaps of waste in the city became unbearable especially in the neighborhood of commercial areas such as open markets, and motor garages. In a bit to maintain the scenic view, and sanitation of the environment, another agency was established by the present democratic government named Kwara Waste Management Company (KWMC) still under the Ministry of Environment and Tourism. KWMC was established in August 18^{th} 2003, given legal backing and empowered with the Environmental Sanitation Law and Offences, No 5.

The company is saddled with the following responsibilities:

1. The cleaning and maintenance of the streets.
2. The collection and disposal of Waste.
3. Maintenance of all Waste dump sites.
4. Planting and maintenance of flowers in the state (Gardening).

Some of the equipments used by KWMC are Trailer trucks 10 (Plate 2), 6 Dyno trucks (Plate 1), 108 Ro-Ro bins (waste containers as shown in Plate 1), shovels, brooms, among others. A total of 28 routes were designed by KWMC for the purpose of efficient waste management in the city.

Methodology

The data required for this research are facilities and equipments, including container types, vehicle types and cost, maintenance cost of equipments, and manpower welfare. These data were sourced secondarily from the archives of Kwara Waste Management Company (KWMC), and primarily through interviews from some randomly selected street cleaners and drivers. In addition, landuse system as evidently seen was also adopted. This surely afforded the opportunity of a better analysis of waste generation in the city since quantity, type, rate, and pattern of waste generation differ from one land use to another (Table 1).

For further purpose of capturing, querying, and presentation of findings in this research, a GIS method of analysis was employed. Here, spatial positioning of Ro-Ro bins (waste containers) were collected through the use of a hand held Global Positioning System (GPS, etrex, 12 Channel GPS). The GPS was helpful in obtaining their coordinates and was later transferred into a digital map through the Arc view software. The map of the selected containers is presented in figure 3.

The quantity of waste generated per land use/capita/day as presented in Table 1 was obtained using the tonnage capacity of the waste collection vehicles. In addition, the capacity of the waste containers and frequency of waste disposed were all calculated.

Two cleaners from each of the 28 routes were randomly selected making 56 cleaners, while 3 dyno truck drivers and 5 trailer truck drivers covering the 28 routes were also randomly selected for interview. The cost obtained were on actual salary, fuel and maintenance cost in Ilorin, time and motion studies on loading and travel times and one 10 hours operating shifts daily for 6 days per week. Average direct haul of 10km one way from the refuse collection service route to the ultimate disposal were used. A traveling speed of 30km/hr was assumed based on the stipulated speed for vehicles of this kind. The cost of refuse collection system consist of the cost of purchase of vehicles and maintenance of containers, personnel, power and fuel, spare parts and replacement costs. The service life period of tractors and trailers, refuse collection vehicles and tippers is 7 years each (UNDP, 1978). Information on daily turnover, unit collection cost of each vehicle as well as the budgetary constraints based on the past fund allocation and estimates are presented in Tables 2 and 3. Six zones were used based on the number of Dyno trucks and proximity of KWMC 28 routes to one another.

The solution of the optimization problem expressed by equations (1) to (4) was obtained using TORA Optimization system (Taha, 1992). This software is for solving both ordinary linear and integer programming problems.

Interest rate 5%; Vehicle life 7yrs. Budgetary constraints: Capital (fixed assets) N942, 000.00 per annum. Working capital = N11, 850,000.00 per annum.

Preliminary Assignment of Vehicles by Type:

Preliminary assignment of vehicles to zones is necessary for realistic optimum solution. The collection system chosen depends on the rate of some identified factors which also influences the choice of vehicle assignment (Agunwamba, 2003). The factors identified for this research, which are also referred to as the constraints are summarized as follows (Table 3 also shows the distributive pattern and waste generation).

- Type of Residential area: In the low-rise detached places of Government Residential Area and Housing estates, manually loaded vehicles can compete favorably with mechanically loaded ones. In medium high rise buildings, higher waste generation rates may imply the use of bigger size waste containers, which must be loaded mechanically into the collection vehicle.
- Accessibility and Proximity of Routes: Certain vehicles cannot easily operate on difficult terrain. For such areas, the Trailer truck vehicle type may be used. Also, the proximity of the 28 routes designed by the KWMC for street cleaning and waste collection determines the vehicle assigned to each area.
- Rate of Waste generation and number of Ro-Ro bins: Quite an appreciable number of Ro-Ro bins are needful in areas of high generation rate such as Residential and Commercial centers. Hence, the associated roll-on container and lift able container trucks may be used. However, the residents must be willing to carry their wastes to the containers.
- Efficiency and Economy of vehicles: The Trailer truck system is easy to maintain. However, their slow speed renders them uneconomical when the ultimate disposal site is greater than 6 km away. Rear-loading compaction trucks are easiest to load. The compaction device facilitates the filling of a large capacity body and thus, making fewer trips than the side-loading non-connection truck for tonnage collected. Although, it conserves fuel, its hydraulic system requires maintenance, repair costs and longer downtime. Table 4 shows the waste generation quantity by zones and number of Ro-Ro bins attached to each of them.

Problem Description and Formulation

The problem is formulated as an integer programming problem (Lowler and Wood, 1966; Mitten, 1970; William, 1985 and Taylor, 1986). Only one programme is considered. The programme is based on Solid waste collection minimization subject to 4 constraints with the number, type and distribution of vehicles in the zones as the state variables.

Programme

Objective Function: The objective function is the total daily collection cost (including capital, maintenance, labor, oil and fuel) of daily operation of all the collection vehicles. This is formulated as

$$C = \sum_{J=1}^{n1} \sum_{I=1}^{n2} N_{ij} C_i \text{ ……………(1)}$$

N_{ij} is the number of vehicle of type i assigned to zone j; n1 & n2 is the number of identified constraints, and C_i is the annual collection costs of a vehicle type i which is obtained from Table 1.

Constraints

The constraints due to rate of solid waste generation and number of Ro-Ro bins is formulated from special consideration of the efficiency of the economy, types of dwellings, and accessibility of the area.

$$\sum_{t=1}^{n1} N_{ij}\ t_i > T_j, \text{ J = No of constraints ……………(2)}$$

Where t_i is the daily turnover of vehicle I and T_j is the minimum total amount of waste generated in zone j daily. The constraints specify that the capacities of all the vehicles in each of the zones must exceed rate of waste generated in that zone. The values of t_i are given in Table 2.

Budgetary constraints

The budgetary constraints are considered under the capital funds (fixed assets and working capital). The total costs of all the vehicles should be less than or equal to the budgetary provision of capital for vehicle (P_o = N 8,650,000). Similarly, the budgetary provision for working capital (maintenance, labor and fuel/oil) should be less than or equal to the budgetary provision of working capital (W_o = N 11,850,000.00). That is

$$\sum_{j=1}^{N2} \sum_{i=1}^{n1} N_{ij}\ P_i \leq P_o \text{ …………(3)}$$

And

$$\sum_{j=1}^{N2} \sum_{i=1}^{n1} N_{ij}\ W_i \leq W_o \text{ ……… (4)}$$

Results and Discussions

The solution of the optimization problem expressed by equations (1) to (4) was obtained using TORA Optimization system (Taha, 1992). This software is for solving both ordinary linear and integer programming problems. An infeasible solution was obtained during the first attempt to solve the above problem. It was suspected that the less than (<) were too restrictive. The problem of infeasible solution was resolved by rewriting each of the constraints such that it is violated at a certain high cost (Williams, 1985). For instance, equation (3) was rewritten as

$$\sum_{j=1} N_{ij}\ P_i - U_i \leq P_o \text{ ………………(5)}$$

The other three equations were similarly modified. In the objective function, U1 is given any positive coefficients (for minimization) say ai. Hence, with the 2 constraints, the objective function becomes

$$C1 = \sum_{J=1}^{n1} \sum_{i=1}^{n2} N_{ij}\ C_i + \sum_{K=1}^{2} a_k\ u_k \text{……..…(6)}$$

The minimum value of the objective function in the programme obtained was N18, 256,521.5 at the summation of 6 zones computation, giving an excess of N1, 688,696 over a supposed amount of N16, 567,825.5. Apart from ensuring that the solution is feasible, this modification reduced the number of nodes examined by 5, thereby reducing the computer time. The results support the use of different collection vehicles. Collection service to be most cost-effective would not rely on one method or type of equipment. Ilorin like most cities, made up of diverse types of neighborhood conditions, require diverse types of technical responses. Agunwamba (2003), obtained similarly in Onithsha the minimum value of the objective function in programme 1 as N21, 039,512.5 at 52 over an initial cost of N18, 731,033.5.

The inadequacy of the refuse collection system is evident in table 4. The number of Trailer trucks is presented to be enough, provided additional new types of containers are introduced to justify their uses. These containers are more cost effective compared to having the Ro-Ro bins, since the content will be manually loaded. Therefore, maintenance cost will be reduced and employment will be created with more people employed to cater for them. Consequent upon this, a tabular presentation of the optimization model formulated is presented in Table 5. Table 4, which depicts the present distribution or Ro-Ro bins, and vehicles in Ilorin city, obviously undermined the task involved in them. Therefore, Table 5 an aftermath of the optimization model presents a redistribution of the containers and the vehicles for optimal uses.

Table 5, deduced from the model formulated, propose 54 and 8 Ro-Ro bins respectively to Residential and Administrative areas, making a total of 62, with waste generation rate put at 0.19kg; and 3 Dyno trucks for the lifting of the containers. This is in contrast with what presently obtains in the distribution pattern because, zones 1&3 have 58 containers with 2 vehicles, while they are both generating 0.12kg waste per capita per day, lower than what is generated in zones 2 and 4, which have just 29 containers with waste generation as 0.24kg. Agunwamba (2003) also noted after the use of Optimizataion system for waste collection in Onithsha that there is evidence of inadequacy of refuse collection system. He supported this by saying that "the total capacity of vehicles assigned to zone 5 in the existing scheme in Onithsha exceeds the amount of wastes collected. That is, less than half of the capacities of the collection vehicles are utilized". Furthermore, Commercial areas in Ilorin have 36 containers with 2 vehicles to take care of 0.18kg waste/capita/day being generated. Likewise, Industrial land use areas has 4 containers, followed by Education land use 3, Transportation land use 2, and lastly, Health land use 1, all having waste generation put at 0.11kg waste/capita/day. Also, in order to still achieve better waste collection, the optimization programme suggests the use of extra smaller containers to be distributed as follows; Residential areas 4, Market areas 8, and educational 2.

In this model formulated with the aid of TORA Optimization system, priority is given to Residential and Commercial land use areas in both distribution of waste containers and collection vehicles. Also, the suggested smaller containers are also largely in favour of these areas. This can be justified by the quantity of waste generated by these land use areas, where 0.13 & 0.1kg per capita per day is being generated. With this, it is believed that waste collection equipment will be optimally utilized in Ilorin city.

Comparison of the Existing Programme with the Optimal Solution Obtained

Just as it is evidently observed in Table 4, the locations of the collection containers, and the distribution of vehicles are not well planned. Apart from the need for provision of additional containers, their optimum distribution and utilization in the various zones is important. More often they are clustered around zones 1 & 3, with stores & services, industrial, and educational areas, instead of serving the residential and commercial areas that produce most quantity of wastes. Hence the containers are not optimally utilized and sometimes have to stay longer for it to be filled, thereby constituting nuisance to the environment or are disposed off when half full.

In Japan and China, Takeshi (2006), argued for the improvement in waste management in developing countries through the estimation of waste emission. This was hinged on the fact that people desire sanitary life and clean city which has resulted in frequent waste collection and longer transportation; advocating for larger number of waste collection vehicles and more fuel. In addition, Mala et al, also observed in their study in Canada that in Optimizing for waste projects in construction projects, there has been serious over utilization and underutilization of waste collection equipments.

The results of the optimization problem solved vividly frowns at the underutilization of the Trailer trucks and inability to service the interiors of the residential areas, thereby suggesting the introduction of smaller containers to be well strategically and spatially positioned for onward manual loading. Also, it suggests the relocation of some of the presently used Ro-Ro to areas where they are to be optimally utilized. By so doing, maintenance cost of vehicles will be reduced, employment will be created, and optimal utilization of equipment will be achieved. In essence, the vehicle assignment and container distribution of Ro-Ro and routes done by KWMC appears to be inappropriate. Consequent upon this, a tabular presentation of the optimization model formulated is presented in Table 5 and a proposed map presented in figure 4.

Conclusions and Recommendations

Waste ergonomics has been of tremendous help in Ilorin with great land mark achievements in attempting to make the streets clean and free of refuse. Notwithstanding, the optimal uses of these equipment is highly decry-able. Pockets of refuse in some places, with the waste containers overflowing indicate an over utilization of these containers while places where they are always half full and left for long till they are filled up indicates underutilization thereby emitting fowl odor (Plate 3). This can be attributed to non adoption of land use system for planning by KWMC. Also, it is noted that huge amount of money can be saved from cutting down the expenses of KWMC management through proper & optimal uses of equipments. In addition to this, excessive spending on servicing some of the expensive equipment will be diverted to paying the employees replacing the high technical equipment.

It is therefore highly recommended that small containers should be provided for the interior areas where the service vehicles cannot reach. Also, instead of attempting to obtain more high technical vehicles, they should be replaced with trailer trucks that will serve the new small containers. Places where the containers are left for long before being filed, should receive urgent restructuring and reduction of containers to be transferred to places where the existing ones are overflowing. Finally, immediate maintenance of vehicles and containers should be encouraged to avoid accumulated expenses which results in higher expenses.

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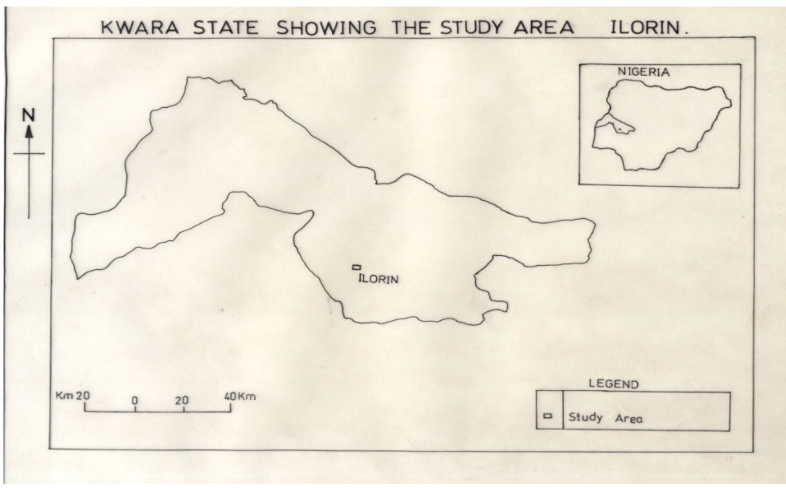

Fig. 1: Map of Kwara State, showing Ilorin, the study area.

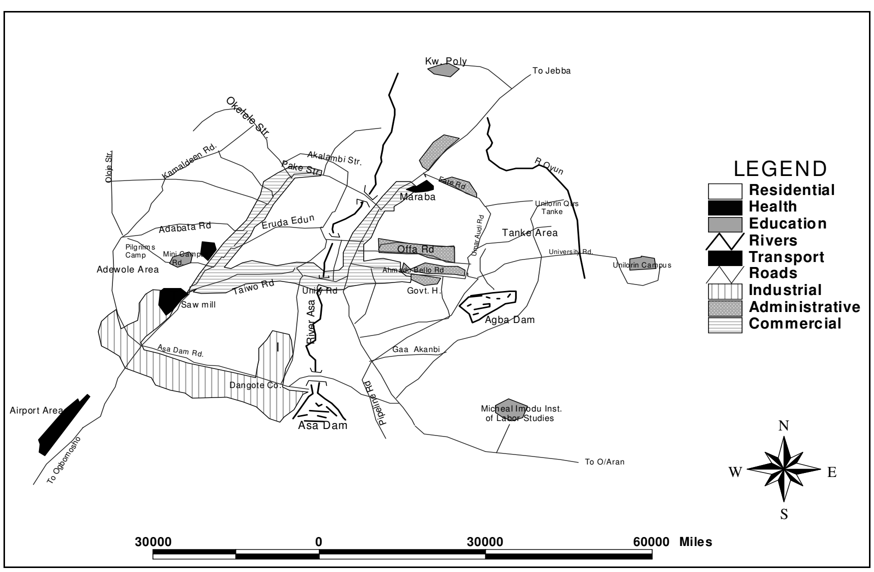

Fig. 2: Most Prevalent Land Uses in Ilorin
Author's fieldwork, 2006

Plate 1: Dyno Truck lifting a Ro-Ro bin.

Plate 2: Trailer Truck loading waste around the commercial center
Source: Authors' fieldwork.

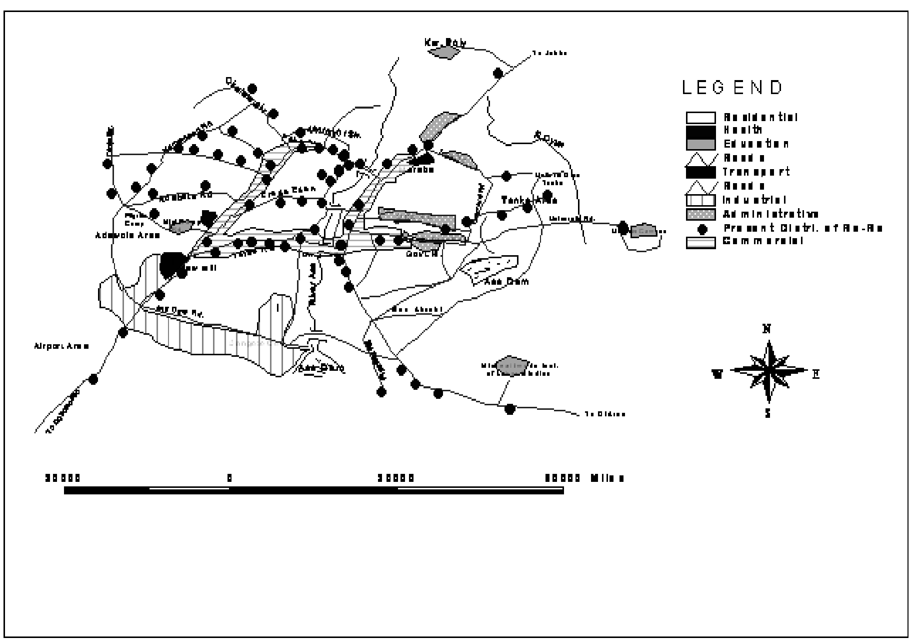

Fig. 3: Present distribution of RO-RO bins in Ilorin.
Source: Author's fieldwork (2006).

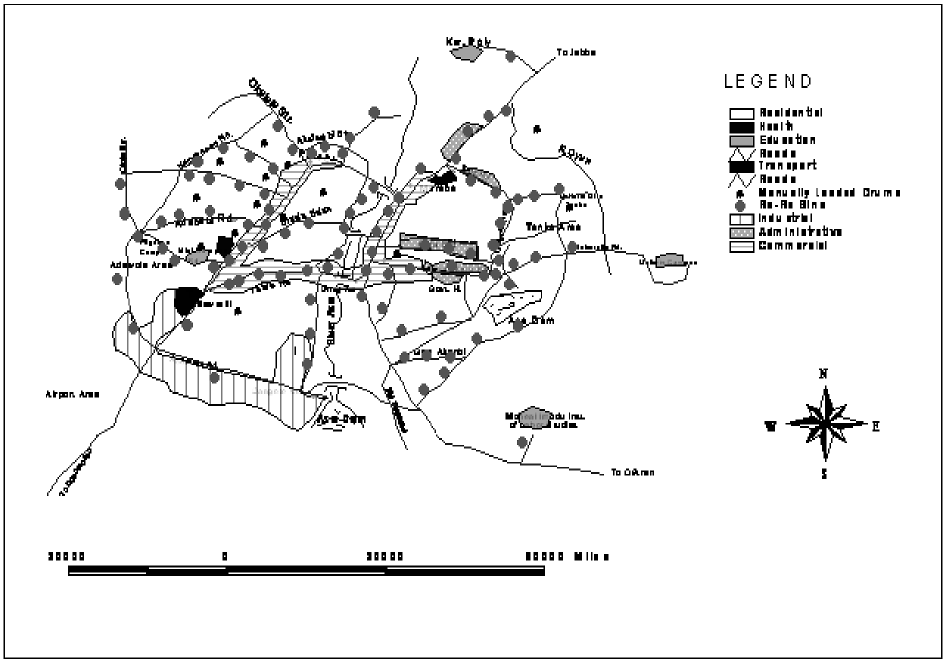

Fig. 4: Proposed distribution of RO-RO bins and Drums
Source: Authors' fieldwork

Plate 3: Waste container filled and overflowing with waste.
Source: Author's fieldwork (2006).

Table 1: Waste generation per land use area in Ilorin

Residential		0.13 kg/capita/day
Administrative		0.06 kg/capita/day
Institution	Health	0.01 kg/capita/day
	Education	0.03 kg/capita/day
Commercial	Stores /Services	0.08 kg/capita/day
	Markets	0.1 kg/capita/day
Transportation		0.02 kg/capita/day
Industrial (Manufacturing/Workshop)		0.05 kg/capita/day
	Total	**0.48** kg/capita/day

Source: Authors' fieldwork.

Table 2: Daily Turnover and Unit collection costs for each vehicle type

Type of vehicle / method of loading (i)	Daily Turnover (tons day - 1) (ti)	Unit collection =N=/day
Dyono truck (Anchor lifter)	8.4	1,325.2
Trailer truck (Rear loader)	12.1	1,852.4

Source: Authors' fieldwork.

Table 3: Unit Component costs for all the collection vehicles & the Budgetary constraints based on 2003 prices (US $1.00=N130.00).

Type of vehicle / Method of collection	Unit costs N/day			
	Capital Fuel/oil (Pi)	Maintenance (Mi)	Labour (Li)	Fuel/oil (Fi)
Dyno truck (Rear-loading compact truck)	7,255.60	2,500	33.33	6,900.23
Trailer truck	8,120.22	2000	208.33	7,750.20

Source: Authors' fieldwork.

Table 4: Zoning and preliminary distribution of Ro-Ro bins & vehicles based on KWMC routes proximity.

Zones (j)	Quantity of Waste / capita / day	No of Vehicles		No of Ro-Ro	No of Routes
		Dyno	Trailer		
1	0.05	1	2	27	5
2	0.1	1	2	13	5
3	0.07	1	2	31	4
4	0.14	1	2	16	7
5	0.08	1	1	14	4
6	0.06	1	1	7	3

Source: KWMC