An Application Of Facility Location Models With Hotspot Analysis For Optimal Location Of Abattoir Bio-Energy Plant In Anambra State Of Nigeria

E. C. Chukwuma, G. O. Chukwuma, L. C. Orakwe

Abstract: Poor waste management strategy in abattoir in the the study area has needs a major attention considering it negative impacts on man, land and water. Sitting of centralized biogas plant in a strategic location in the state would be the major means of combating the environmental challenges of increase in abattoir waste generation as result of population explosion in the state. This study investigates optimal location for sitting central abattoir waste treatment facility in Anambra State of Nigeria using facility location models with hotspot analysis in GIS environment. The result of the study shows that Using centre of gravity model, the central location was estimated to be at X_c, Y_c = 6.900953016, 6.110157865. Based on inadequacy of the model, hotspot analysis operation was done, the hotspot analysis delineated clusters of abattoirs significantly higher in bio-wastes production than the overall study area. The hotspot analysis shows that the West regions of the study area has many abattoir that is classified as hotspot abattoirs. Using the hotspot abattoirs as proposed sites for load-distance model, three abattoirs were identified as proposed sites- Obosi slaugher house, Nkpor Private slaughter house and Oye-olise Ogbunike slaugher house. Their load distance values are 17250.40058, 16299.24005 and 18210.14631 respectively. The optimal location for construction of central abattoir bio-waste treatment facility based on the application of these location facility models and hotspot analysis is Nkpor private slaughter house or its environs.

Key Words: Load-distance model, centre of gravity model, hotspot analysis, abattoirs, bio-energy plant.

1. Introduction

The climax of methane emission from mismanagement of wastes in Anambra State is tending to a major catastrophe in the state, especially in the most populous and urbanized regions of the state [1]. From preliminary investigations on waste management in the study area, there seems to be a better system of municipal waste management while abattoir waste are heaped at closed locations around the abattoir with little or no definite waste management strategy. The impact of these wastes on land and water therefore emphasizes the need for appropriate strategies for efficient agricultural waste disposal and management in Nigeria public abattoirs. There is urgent need to adopt appropriate waste management, treatment, and recycling strategies for abattoir wastes generated in the State [2]. Sitting of centralized biogas plants in strategic locations in the state would be the major means of combating the environmental challenges of increase in abattoir waste generation as result of population explosion in the state. Centralized biogas plant represents an appropriate waste disposal and recycling possibility as this is safe, convenient and economically advantageous [3;4;5]. Although there are potential economies of scale for the centralized bio-energy plant, manure transportation and handling costs can offset the economic savings [6;7]. Decision making is an important component of investments, logistics, allocation of resources, etc. Geographers and spatial planners are interested in decision problems which are based on geographically defined alternatives.

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However location decisions on centralized location for biogas plant may be the most critical and most difficult of the decisions needed to realize an efficient waste management system. Sitting bio-energy plants in optimal locations at optimum capacities is a challenging task [8]. Facility location decisions, on the other hand, are often fixed and difficult to change even in the intermediate term. The location of a multi-million centralized biogas plant cannot be changed easily as a result of changes in urbanization, transportation costs, or component prices. Inefficient location of bio-energy plants may result in excess costs being incurred throughout the lifetime of the facilities, no matter how well the production plans, transportation options, inventory management, and information sharing decisions are optimized in response to changing conditions. Several facility location models have been used by various researchers in identification of optimal location for example, [9] considered the importance of base station placement problem for a given sensor networks such that network lifetime can be maximized. They used the gravity location model to identify the optimal location of a new base station in a wireless network. [10] researched and found an alternative factory location for Thai lime-burning company for its expanding business, the study aimed at minimizing the transportation cost. The research was conducted using facility location models, which includes the centre of gravity model, Alfred Weber's theory, and the load distance model to obtain the best alternative location. Hence, for an optimal location of bio-energy plant in any region, location analysis should be embark well ahead of time, to avoid the necessity for demolition and any resultant negative effects of poor sitting to resident, natural reserves or any sensitive area within the region. This study objective is to apply facility location model (eg centre of gravity model and load distance model) and hotspot analysis using ArcGIS in determination of optimal location for central abattoir waste treatment plant in the study area.

2. Materials and Methods

2.1 Study Area

Anambra State is one of the 36 states of Nigeria, and is located in the South East geopolitical zone of the country. The national population census of 2006 gave the population of Anambra State as 4.06 million with a population density of 1,500 to 2,000 persons living within every square kilometer. Anambra State occupies a land area of about 4,844 square kilometre and is bounded in the east by Enugu State, in the north by Kogi State, in the south by Rivers and Imo States, and in the west by Delta State. The State is divided into 21 local government areas with Awka as its state capital. It has equatorial type of climate with two main seasons viz. the rainy season which is often characterized by heavy thunderstorm and lasts from April to October. Figure 1 below shows map of Nigeria, the various political zones and the study area highlighted.

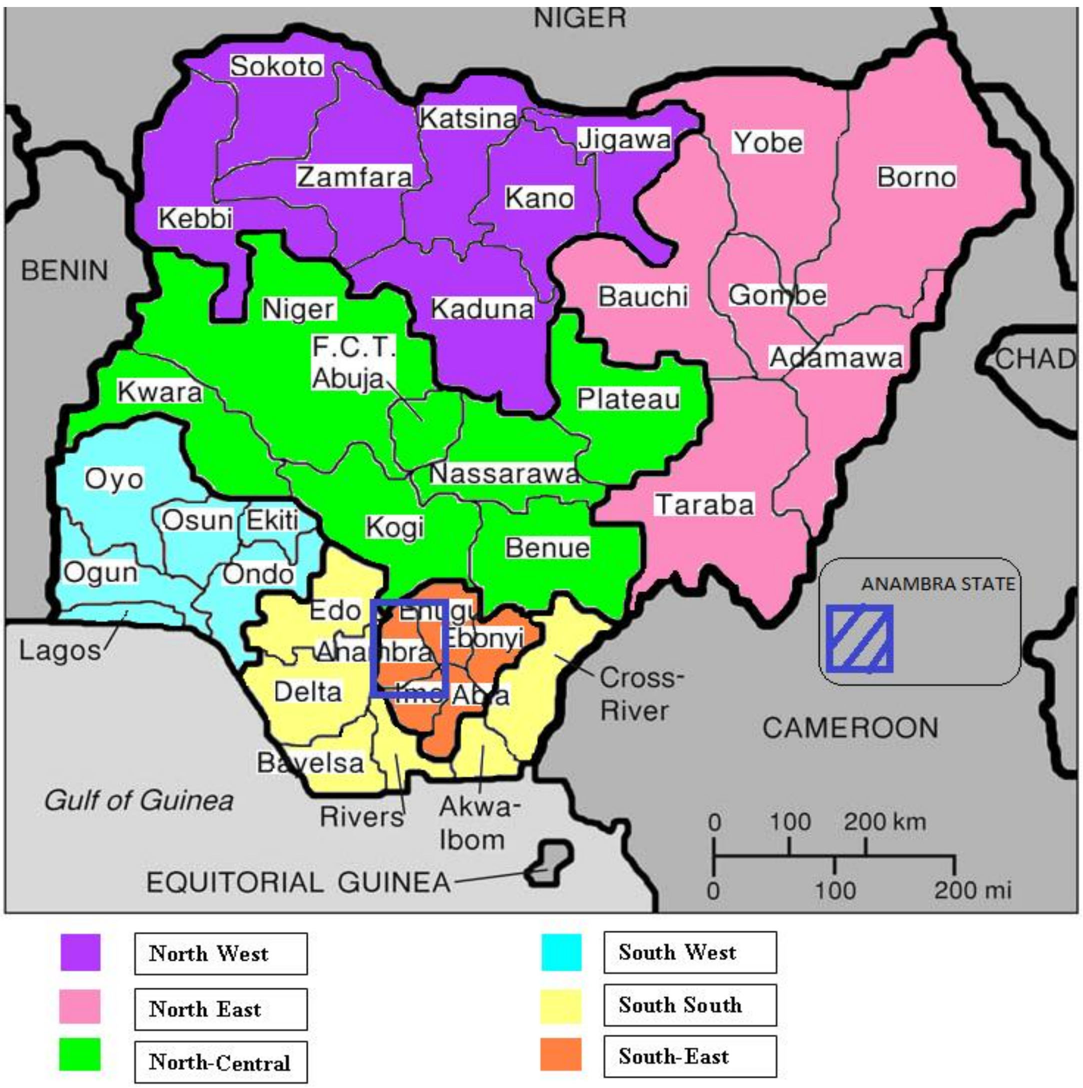

Figure 1: *Map of Nigeria showing the study area*

2.2 Data Collection and Sources

Data used for this study include primary and secondary data collected from various organizations, abattoirs, literatures and individuals. The primary data obtained from field survey was collected through visit to abattoirs in the study area. About 43 abattoirs located in the state were all visited. Interviews, onsite observations and use of questionnaires were also used in data collection process, to determine the biomass potentials of the various the abattoirs. It was observed from preliminary studies that most of the abattoirs rarely process pig, goat and sheep meat. Since cow meat is the major processed meat, intestinal content of a typical cow was therefore used in the estimation of volume of waste generated in each abattoir. In addition, a Global Positioning System (GPS) receiver was used in the field survey to determine the geographical co-ordinate of the abattoir facility for data analysis in the study.

2.3 Data Processing and Analysis

The centre of gravity model was used to compute the mean centre of the various abattoirs. To identify proposed sites in the load distance modelling, the hotspot analysis operation was carried out first using ArcGIS software, the proposed sites identified for load distance modelling were the abattoirs classified as hotspot sites in the hotspot analysis.

The criteria for selection of proposed sites in load distance modelling are:

(1) It should be in proximity to the central location spot
(2) It must be ranked as hotspot site
(3) It must be suitable site considering appropriate distance away from residential area, adequate space for construction of bio-energy plant and accessible with minimal road traffic.

Criteria (1) and (2) were easily identified from the GIS operation, while criterion (3) was based on onsite visitation and the researcher's experience of the study area. Using the above criteria, and it was feasible to identify proposed sites for load distance modelling.

2.4 Load-Distance Model

Load-Distance Model is used to evaluate and compare different possible locations. It is a mathematical model that focuses on distance and load between facilities. Distance can be actual mileage, or a straight line based on X, Y coordinates. In this method, various proposed locations are evaluated using a load-distance value that is a measure of weight and distance. For a single potential location, a load-distance value is computed as follows:

$$LD = \sum_{i=1}^{n} l_i d_i \qquad 1$$

Where

LD = the load-distance value
l_i = the load expressed as a volume of abattoir waste generated, number of trips, or units being shipped to the proposed site from abattoir location *i*
d_i = the distance between the proposed site and abattoir location *i*

The distance d_i in this formula is the Euclidean distance. It is computed using the following formula:

$$d_i = \sqrt{(x_i - x)^2} + (y_i - y)^2 \qquad 2$$

Where

(x, y) = coordinates of proposed site
(x_i, y_i) = coordinates of abattoir facility

The load-distance technique is applied by computing a load-distance value for each potential facility location. The implication is that the location with the lowest value would result in the minimum transportation cost and thus would be preferable.

2.5 Center-of-Gravity Model

In general, transportation costs are a function of distance, weight, and time. The center-of-gravity**,** or *weight center* technique is a quantitative method for locating a facility at the center of movement in a geographic area based on weight and distance. This method identifies a set of coordinates designating a central location on a map relative to all other locations. The coordinates for the location of the new facility are computed using the following formulas:

$$X = \frac{\sum_{i=1}^{n} x_i V_i}{\sum_{i=1}^{n} V_i} \text{ and } Y = \frac{\sum_{i=1}^{n} y_i V_i}{\sum_{i=1}^{n} V_i} \qquad 3$$

Where, X and Y = coordinates of the new facility at centre of gravity

x_i, y_i= coordinates of existing abattoir facility *i*, V_i = annual Volume of abattoirs wastes transported from facility *i*
The steps used for determination of optimal location using the centre of gravity model are:

1. Obtain a grid map of the area.
2. Identify the coordinates of the demand and supply points.
3. Assign the volume to both demand and supply points.
4. Calculate the center of gravity.

2.6 Hot Spot Spatial Statistic Analysis

Hot Spot Analysis is used to delineate clusters of features with values significantly higher or lower than the overall study areas mean or average value. This tool identifies clustering in both the high and the low attribute values. A standardized Z score is calculated for each feature. A high Z score results when a feature has a high value and it is surrounded by other features with high values. This is a hot spot. Similarly, a low Z score results when we have features with low values surrounded by other features with low values. This is a cold spot. Getis-ord local statistic is given as:

$$G = \frac{\sum_{j=1}^{n} w_{ij} x_j - \dot{X} \sum_{j=1}^{n} w_{ij}}{s\sqrt{\frac{\left[n \sum_{j=1}^{n} w^2{}_{ij} - (\sum_{j=1}^{n} w_{ij})^2\right]}{n-1}}} \qquad 4$$

$$\dot{X} = \frac{\sum_{j=1}^{n} x_j}{n} \qquad 5$$

$$s = \sqrt{\frac{\sum_{j=1}^{n} x^2{}_j}{n}} - (\dot{X})^2 \qquad 6$$

Where x_j is the attribute value for the feature j, w_{ij} is the spatial weight between feature i and j, n is equal to the total number of features. The hotspot analysis was performed and used to select the hotspots closed to the centre of gravity point.

3. Result and Discussion

The co-ordinate points of the various abattoirs obtained using GPS is as shown in Figure 2 below: The figure shows clustering of the abattoirs at west of the plot with few abattoirs located some extreme. A good example is abattoir located at Umunze labelled 39, it seems to be farther away from other abattoirs and could incur may transportation cost.

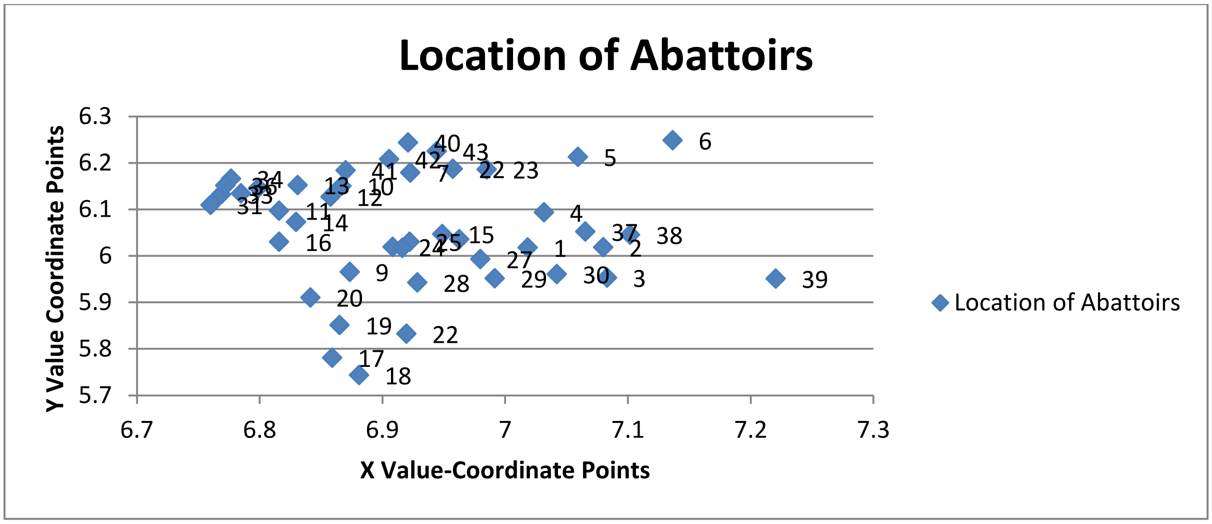

Figure 2: *Location of the abattoirs in the coordinate*

From Figure 3 below, the abattoirs seems to cluster at the central regions of the study area. There are no abattoir facilities in the Northern regions, while the East has dispersed abattoirs. The West region of the study area has the highest human population density, it follows that majority of abattoirs were located in this region. Using centre of gravity model above, the central location is estimated to be at X_c, Y_c = 6.900953016, 6.110157865. The central location obtained is also shown as a red spot on the map of the study area in Figure 3 below. Appendix 1 shows the data used for the estimation of the central location.

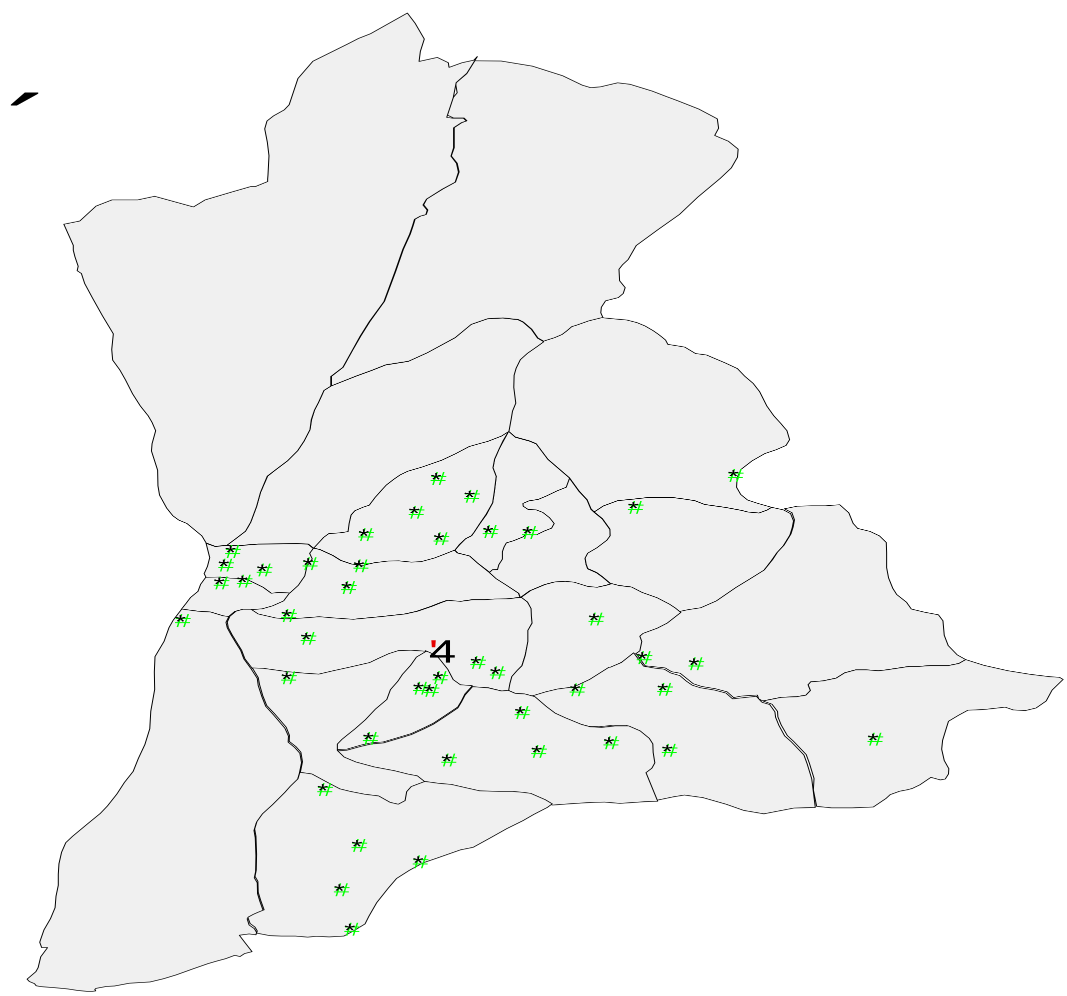

Figure 3: *Location of bio-energy plant using centre of gravity Model*

The central location obtained using the centre of gravity model is critcised as not being an optimal solution for location of facilities because the demand for each location i is not constant and equal to all other locations. Thus in this study, the central location could serve as optimal point if the volume of wastes generated in the various abattoirs are equal. This however, is far from reality. The higher the volume of wastes generated at abattoir location i, the higher the cost of shippment to the treatment facility say j. Thus to reduce transportation cost, the centralized bio-energy plant would best be located in proximty to high volume waste generating abattoirs. To determine abattoirs with high volume wastes generating capacity, the hotspot analysis operation was carried out in ArcGIS and is as shown in Figure 4 below:

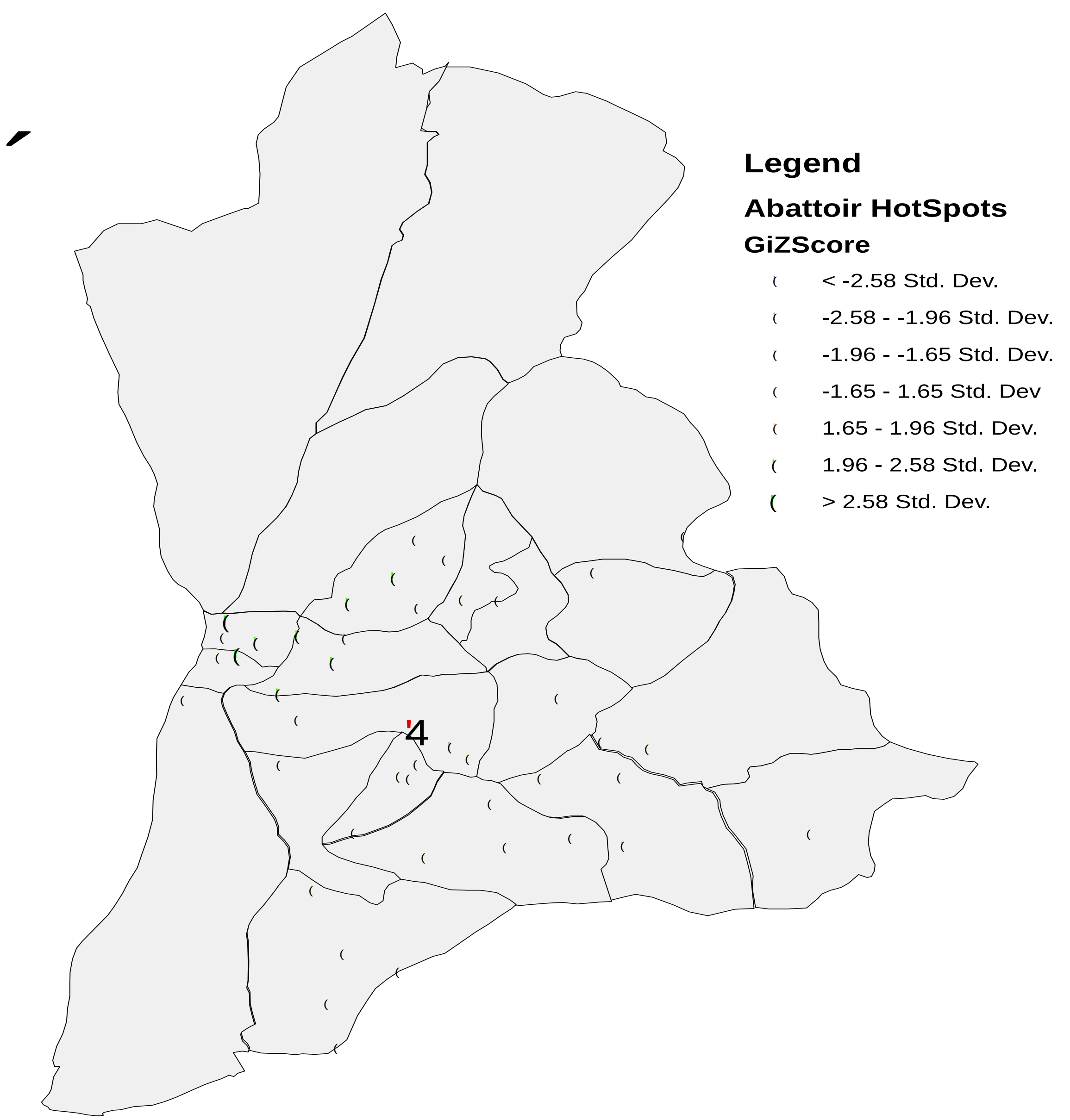

Figure 4: *Hotspot analysis for identification of hotspot abattoir sites*

The hotspot analysis delineated clusters of abattoirs significantly higher in bio-wastes production than the overall study area. The hotspot analysis shows that the West regions of the study area has many abattoir that is classified as hotspot abattoirs. About eight abattoirs were classified statistically as hotspots. Their z score ranges from 1.96 to above 2.58 standard deviation as shown in Figure 4 above. Sitting of abattoir waste treatment facility on hotspots abattoirs in proximty to the central location obtained using the central of gravity model will eventually reduce transportation cost. The proposed sites for load-distance was obtained as a way of seeking compromise between the central location (inadequate as a result of varying waste generating capacity of the abattoirs) and hotspot sites. Using the criteria already stipulated in section 2.3 above and the researchers experience, three of the hotspot sites were identified as proposed sites for load-distance modelling. The sites selected are Obosi slaughter house (11), Nkpor private slaughter house (12) and Oye-olise Ogbunike slaugher house (41). These slaugher houses are number 11, 12 and 41 respectively in Appendix 1. From the load-distance modelling and Appendix 2, the load distance value of Obosi slaugher house is 17250.40058, while the load-distance value of Nkpor Private slaughter house is 16299.24005 and Oye-olise Ogbunike slaugher house is 18210.14631. From the application of the facility location model and hotspot analysis in the study area, it follows that the optimal site for bio-energy plant installation in the study area is in Nkpor Private slaughter house or it environs.

CONCLUSION

This study investigated optimal location for bio-energy treatment plant by apply facility location model (eg centre of gravity model and load distance model) and hotspot analysis in ArcGIS for Anambra State of Nigeria. The centre of gravity model was used to compute the mean centre of the various abattoirs. To identify proposed sites in the load distance modelling, the hotspot analysis operation was carried out first using ArcGIS software. Three of the hotspot sites were identified as proposed sites for load-distance modelling. The sites selected are Obosi slaughter house, Nkpor private slaughter house and Oye-olise Ogbunike slaugher house (41). These slaugher houses are number 11, 12 and 41 respectively in Appendix 1. From the load-distance modelling, the load distance value of Obosi slaugher house is 17250.40058, while the load-distance value of Nkpor Private slaughter house is 16299.24005 and Oye-olise Ogbunike slaugher house is 18210.14631. The lowest value of the load distance is the preferene location, it follows that the optimal site for bio-energy plant installation in the study area is in Nkpor Private slaughter house or it environs.

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Appendix 1: Abattoir coodinate points, waste production capcity and central location calculation.

	X	Y	Location	No. Slaughter Cow	Amount Paunch Kg/yr	X*V	Y*V
1	7.018555	6.017395	Nkwo Igboukwu	5	61137.5	429096.9233	367888.4868
2	7.080091	6.018026944	Eke Ekwulobia	8.5	103933.75	735860.4484	625476.1079
3	7.08316	5.952746944	Oye Uga	10	122275	866093.389	727872.1326
4	7.031785	6.093185	Nwagu-Agulu	8	97820	687849.2087	596035.3567
5	7.059412	6.212848056	Amikwo, Awka	18	220095	1553741.272	1367416.793
6	7.136735	6.248326667	Amansea	23	281232.5	2007081.826	1757232.529
7	6.922932	6.1790836	Afor-Igwe Umudioka	6.5	79478.75	550225.9555	491105.8407
8	6.873527	5.965326667	Ugwu-oye Ozubulu	8	97820	672368.3785	583528.2545
9	6.816021	6.030126667	Oraifite	3	36682.5	250028.7046	221200.1215
10	6.8667	6.15	Nkwo-Ogidi	14.5	177298.75	1217457.327	1090387.313
11	6.816085	6.097141667	Obosi	16	195640	1333498.869	1192844.796
12	6.858018	6.126923611	Nkpor Private	5	61137.5	419282.0959	374584.7923
13	6.831115	6.152293056	Nkpor	15	183412.5	1252911.829	1128407.45
14	6.82974	6.0725219	Afor-Oba	7	85592.5	584574.5466	519762.3307
15	6.948936	6.046831667	Afor-Nnobi	17	207867.5	1444458.035	1256939.781
16	6.962635	6.03555	Eke-Awka Etiti	35	427962.5	2979746.681	2582989.067
17	6.859224	5.7808097	Eke-Agba, Uli	5	61137.5	419355.7828	353424.253
18	6.881035	5.743306667	Amorka	6	73365	504827.1124	421357.6936
19	6.865356	5.850741944	Nkwo Ogbe	10	122275	839461.4525	715399.4713
20	6.841392	5.910508056	Nkwo Okija	5	61137.5	418265.583	361353.6862
21	6.919651	5.832136667	Isseke	4	48910	338440.1494	285249.8044
22	6.957437	6.186866667	Oye-Agu Abagana	6	73365	510432.3411	453899.473
23	6.985188	6.186026667	Eke-Agu	4	48910	341645.5206	302558.5643
24	6.90853	6.019105	Nkwo-Nnewi	10.5	128388.75	886977.5667	772785.3671
25	6.922315	6.030278333	Orie-Agbo	3	36682.5	253927.82	221205.685
26	6.91624	6.016755	Oba-Isi Edo	14.5	177298.75	1226240.742	1066763.141
27	6.979822	5.993021389	Amichi	4.5	55023.75	384055.9624	329758.5106
28	6.92856	5.942223611	Afor-Ukpor	2	24455	169437.928	145317.0784
29	6.991637	5.951456667	Osumenyi	3	36682.5	256470.712	218314.3092
30	7.04232	5.960568333	Unubi	0.5	6113.75	43054.9822	36441.42465
31	6.760187	6.109338333	Iyi-owa Odekpe	2	24455	165320.3649	149403.8689
32	6.785008	6.133826667	Ochanja	70	855925	5807458.258	5250095.59
33	6.768772	6.131866389	Bridge-Head	11.5	140616.25	951799.2889	862240.0571
34	6.776812	6.165645	Marine	26	317915	2154450.081	1960151.03
35	6.798992	6.14584573	Ugwunabamkpa	1.5	18341.25	124702.015	112722.493
36	6.772032	6.151048056	Main Mkt	20	244550	1656100.344	1504238.802
37	7.065565	6.051811944	Afor Nanka	2	24455	172788.3921	147997.0611
38	7.102022	6.045285278	Eke Oko	8	97820	694719.7594	591349.8059
39	7.220546	5.250685278	Nkwo Umunze	4	48910	353156.9239	256811.0169
40	6.921057	6.243793611	Nteje	13	158957.5	1100153.865	992497.8229
41	6.870187	6.183493056	Oye-olisa Ogbunike	52.5	641943.75	4410273.57	3969454.72
42	6.905594	6.207611667	Umunya	65	794787.5	5488479.688	4933732.158
43	6.944423	6.224766667	Orie Awkuzu	12.5	152843.75	1061411.704	951416.6802
				Total	6914651.25	47717683.4	42249610.72
					X_c, Y_c	6.900953016	6.110157865

***Appendix 2**: Load distance calculation table*

S/N	**Distance** Obosi	L*D	**Distance** Nkpor Priv.	L*D	**Distance** Ogbunike	L*D
1	0.217609155	477.9456878	0.194341522	426.8418421	0.222714451	489.1587007
2	0.27560572	605.3899661	0.247335655	543.2925118	0.267280583	587.1031389
3	0.303609769	659.6689245	0.284651157	618.4765522	0.314008424	682.2626315
4	0.215736286	479.8002028	0.177011718	393.6762787	0.185120168	411.7095727
5	0.269436394	610.9980917	0.218957523	496.5276847	0.191488425	434.2362977
6	0.354504339	808.4965048	0.304009346	693.3356416	0.274319637	625.6241266
7	0.134650255	303.6855424	0.08327308	187.8112318	0.05292872	119.3736103
8	0.143787132	313.0740831	0.1623394	353.4687566	0.21819195	475.0789847
9	0.06701503	147.4998297	0.105514889	232.2378726	0.162650413	357.9929455
10	0.073183889	164.2795346	0.024655447	55.34531485	0.033674079	75.58988824
11	3E-10	6.67637E-07	0.051433147	114.4622423	0.101899866	226.7737413
12	0.051433147	115.021342	3.16228E-10	7.07189E-07	0.057863436	129.4015702
13	0.057162647	128.363695	0.036978548	83.03854481	0.050000785	112.281112
14	0.028153155	62.4006377	0.061312261	135.8968167	0.118112355	261.7925504
15	0.142058395	313.5361691	0.121164402	267.4211722	0.157727012	348.1182727
16	0.158966776	350.1999531	0.138902066	305.9978819	0.174452833	384.3153602
17	0.319259851	673.6368609	0.34611601	730.3032366	0.402832571	849.974928
18	0.35974668	754.1394598	0.384306797	805.6250028	0.440320033	923.0459384
19	0.251277721	536.6088022	0.276279134	589.9998405	0.332786172	710.6717963
20	0.188341531	406.3158596	0.217053308	468.2567945	0.274499505	592.1875112
21	0.284523544	605.6737706	0.301161047	641.09052	0.354821143	755.3183706
22	0.167424219	378.0784327	0.116091236	262.1579637	0.087314921	197.1751067
23	0.191039783	431.348675	0.140232551	316.6310385	0.115028462	259.7227336
24	0.12097872	265.7870216	0.119064308	261.5811087	0.168800605	370.8504261
25	0.125520987	276.2781692	0.116079159	255.4962171	0.161839691	356.2175087
26	0.128425388	282.0369951	0.124607017	273.6514104	0.17298116	379.8866196
27	0.194037955	424.44887	0.181013417	395.9583064	0.219770854	480.7383713
28	0.191442334	415.221502	0.197712361	428.820636	0.24823039	538.3897758
29	0.228128269	495.5588596	0.220550465	479.0977355	0.261898685	568.9177159
30	0.264262039	574.9304576	0.248276218	540.1515877	0.281647165	612.7536672
31	0.05721348	127.5808257	0.099399582	221.6519722	0.132661162	295.8222517
32	0.048078565	107.6405383	0.073335614	164.1871991	0.098600943	220.752399
33	0.058688652	131.352904	0.089383435	200.0518581	0.113799698	254.6986579
34	0.078962658	177.7023366	0.08996593	202.4647658	0.095065743	213.9416927
35	0.051616382	115.787608	0.061984963	139.0467582	0.080535821	180.6606665
36	0.06961749	156.3004921	0.08930675	200.5054907	0.103378608	232.0986759
37	0.253564694	560.1019335	0.220720143	487.5512308	0.235610908	520.4436109
38	0.290600865	641.2192717	0.257298357	567.736318	0.269905036	595.5533239
39	0.938124423	1797.915576	0.948272222	1817.363834	0.99643469	1909.66721
40	0.180349227	411.0131222	0.132787155	302.6198896	0.078891607	179.7927625
41	0.101899866	229.9854466	0.057863435	130.5963253	5.65685E-10	1.27674E-06
42	0.142181077	322.1507929	0.0936696	212.2345442	0.042841076	97.06837851
43	0.180994111	411.2258306	0.130533856	296.578121	0.084938522	192.9837043
		17250.40058		**16299.24005**		**18210.14631**