Gis hotspot application and use of set-cover problem for centralized abattoir biogas plant treatment facilities in Anambra State of Nigeria

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Abstract: Anambra state is faced with high population explosion and consequently high production of abattoir wastes in major abattoir centres in the state. There is need for strategic waste management in allocation of bio-energy plants to digest these wastes. ArGIS software was used to perform hotspot Analysis to delineate clusters of abattoir potential features with values significantly higher or lower than the overall study area mean or average value. In addition, the set covering location model was used to determine the number of bio-energy treatment plant facilities that should be constructed in the study area and where they should be located. The result of the study indicated that eight abattoirs were classified as hotspot zones/locations (L), and consequently used in the set covering location modelling. The set covering location model indicates that a minimum of two bio-energy plant should be constructed in Obosi (L1) and Umunya (L8) of the study area. The outcome of the study would be useful in harnessing abattoir wastes generated in the study area.

Keywords: set covering, biogas plant, hotspot, location modelling, abattoir waste

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1 Introduction

Dramatic increase in the production of urban solid waste, reflecting unprecedented global levels of economic activity is one of the problems of Anambra State of Nigeria. Most of the urban cities are facing problems of solid-waste collection, treatment, and disposal due to increasing population, rapid urbanization, industrialization, and commercialization (Gautam and Kumar, 2005). About 17.7×10^3 kg of animal wastes are generated in the State farms daily (Umeghalu et al., 20120), the use of these wastes and the demand for these animal wastes for agricultural purposes has being restricted to farming operations which takes place mainly during planting season (usually from April to June), accumulation of these wastes has resulted to the pollution of the environment and under-utilization of this animal waste for energy production. The impact of these wastes on land and water therefore emphasizes the need for appropriate strategies for efficient solid waste disposal and management in Nigeria public abattoirs, farms, and environs generally.

The growing concern for environmental issues and the goal of sustainable development have moved waste management to the forefront of the public agenda. Animal wastes in atmospherically unconfined locations

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emit gaseous chemical under the influence of some spontaneous reactions. These chemical substances, if allowed free escape into the atmosphere, can induce global warming scenario with the potential for greenhouse gases (GHGs) to rise into the atmosphere. However, capturing these gases, especially methane, can be useful for bio-energy production and prevention of environmental pollution (Suberu et al., 2013).

The Anaerobic Digestion (AD) of livestock waste in the State can reduce the GHG emission. Denmark is a country that has developed many centralized digesters that receive manure from many farm sources and return digestate, or slurry, back to the farm. A systematic approach of farm waste management is a desirable solution, which can be achieved only by a strategic planning approach for achieving a clean, healthy, and sustainable environment (Gautam and Kumar, 2005). Effective planning of farm waste recycling programs is a substantial challenge for the current farm waste management systems in developing countries like Nigeria.

Sitting of centralized biogas plants in strategic locations across the state would be the major means of combating the environmental challenges of increase in waste generation across the state. For abattoir wastes, centralized biogas plants represent an appropriate waste disposal and recycling possibility as this is safe, convenient and economically advantageous. 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. Siting bio-energy plants in optimal locations at optimum capacities is a challenging task. Due to high geographical dependence of biomass feedstocks, implementation of location models such as set covering location problem model in addressing this issue appears to be an appropriate methodology.

Many researchers have used facility location models in solving location/facility related problem. For instance, Ndiaye et al. (2012) used the p-median problem in solving school allocation problem for Dakar community; Baray and Cliquet (2013) used hierarchical location-allocation model that combines a maximum covering model and p-center models to optimize locations of the three levels of maternity hospitals found in France; Shariff et al. (2012) used maximal covering location problem to study the healthcare facilities of one of the districts in Malaysia. One of the most popular models among facility location models is covering problem. While covering models are not new, they have always been very attractive for research. This is due to its applicability in real-world life (Farahani et al., 2012). Schilling et al. (1993) classified models which use the concept of covering in two categories: (1) Set Covering Location Problem (SCLP) where coverage is required and (2) Maximal Covering Location Problem (MCLP) where coverage is optimized. The objective of this study is to use the SCLP to determine the number of bio-energy treatment plant facilities that should be constructed in the study area and to where they should be located in the study area.

2 Materials and methods

2.1 Area of study

Anambra State is located in the South East region of Nigeria. The boundaries are formed by Delta State to the west, Imo State and Rivers State to the south, Enugu State to the East and Kogi State to the North. The State is divided into 21 local government areas with Awka as its state capital. The study area is located between Latitudes 05°42′56″N and 06°45′34″N and Longitude 06°37′30″E and 07°25′30″E. Figure 1 below shows the map of the study area.

2.2 Data collection and analysis

Data used for the study were collected from field survey through visit to about 43 slaughter houses in the study area, to determine the biomass potentials of the various abattoirs. The name of the abattoirs and the waste generation capacity is shown in the appendix. In addition, a Global Positioning System (GPS) receiver (Handheld GARMIN 76S) was used in the field survey to determine the geographical co-ordinate of the abattoir houses for GIS data analysis. ArcGIS version 10 software was used for all GIS operations and in hotspot GIS map production. Tora software version 2.00 (Computer algorithms for H. Taha, Operations Research: An introduction, 8^{th} ed. 2007) was used for integer programming solution of the set cover problem. Lat Long converter software was used for conversion of the geographical co-ordinate points from

Decimal Minutes Seconds obtained from the GPS device to Decimal Degrees to aid further calculations, the software was also used in distance computation between the hotspot cities using Euclidean distance.

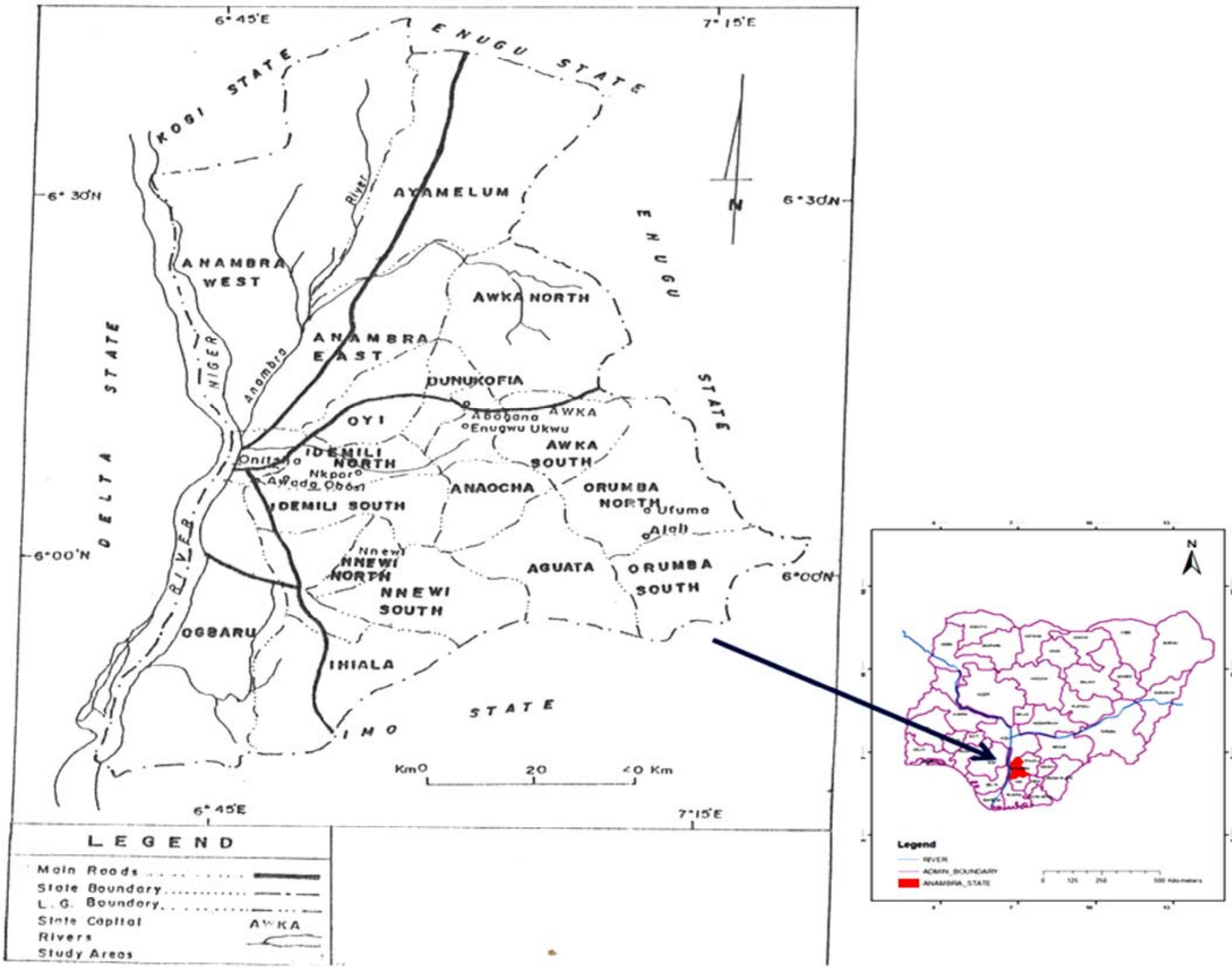

Figure 1 Map of Anambra State of Nigeria

2.3 Hot spot spatial statistic analysis

One of the tools in the Mapping Clusters toolset in ArcGIS 10 is the Hot Spot Analysis Getis Ord Gi* statistic, it 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. The result of the hotspot and cold spot analysis is shown in Figure 3.

2.3 The set covering location problem

The objective of the SCLP is to find the minimum-cost (or minimum-cardinality) set of locations such that every node in V is covered by some node in the set.

Problem Definition

Then the set covering model is given as:

$$SCP = \min \sum_{1=1}^{p} X_i \qquad (1)$$

$$\text{s.t} \sum_{j}^{p} X_i \geq 1 \quad \forall i \qquad (2)$$

$$xi\varepsilon B, \quad \forall i \qquad (3)$$

The Equation (1) minimizes minimizing the number of facilities that are to be located. Constraint (2) stipulates that each demand node must be covered by at least one of the selected facilities. The left-hand side of (2) represents the total number of selected facilities that can cover demand node i. Finally, constraints (3) are standard integrality conditions

There are eight hotspot cities from the GIS operations, these hotspot zones were used for the set cover location problem. A transportation distance of 10 km from farms waste source to optimal potential sites for treatment was used as recommended by several researchers (Thompson et al., 2013; Delzeit, 2008). A minimum distance for bio-energy plants within 10 km distance to each hotspot town was assumed for the model. Distance required to move from one town to the other is shown in Table 1. To formulate the integer program, each town is considered whether to build the bio-energy plant there. A 0-1 variable x_1, x_2, x_3, x_4, x_5, x_6, x_7 and x_8 is defined by

$$x_j = \begin{cases} 1 & \text{if a bioenergy plant is built in city } i \\ 0 & \text{Otherwise} \end{cases} \quad (4)$$

Then the total number of bio-energy plants that is to be built is given by $x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8$. The constraint is to ensure that bio-energy plant is built within 10 km distance. Table 2 indicates which locations are within the 10 km distance specified. The objective function and the constraint are given below:

$$\text{Min. } Z = x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8 \quad (5)$$

Subject to:

$x_1+x_2+x_3+x_4+x_5+x_6+x_7 \geq 1$ (L1 constraint)

$x_1+x_2+x_3+x_4+x_5+x_6+x_7 \geq 1$ (L2 constraint)

$x_1+x_2+x_3+x_4+x_5+x_6+x_7 \geq 1$ (L3 constraint)

$x_1+x_2+x_3+x_4+x_5+x_6 \geq 1$ (L4 constraint)

$x_1+x_2+x_3+x_4+x_5+x_6 \geq 1$ (L5 constraint)

$x_1+x_2+x_3+x_4+x_5+x_6 \geq 1$ (L6 constraint)

$x_2+x_3+x_6+x_7+x_8 \geq 1$ (L7 constraint)

$x_7+x_8 \geq 1$ (L8 constraint)

$$x_j = (0,1),\ j = 1, 2, 3...,8 \quad (6)$$

3 Result and discussion

Hot spot analysis uses vectors to identify the locations of statistically significant hot spot and cold spot of data. The analysis is focused on determining if high or low biomass resource centre are clustered. The result of the hotspot analysis is shown in Figure 2, the result shows that among forty-three abattoir centre in the study area,

Figure 2 Hotspot analysis of Abattoirs in the study area

about eight abattoirs were classified as hotspot zones, an indication of high biomass availability in the area. The west region of the study area where Onitsha is located (known as town with highest population density) has about three of the hotspot abattoirs, with hotspot value greater than 2.58 of standard deviation. This suggests that there is correlation between population density and abattoir waste biomass generation. Other hotspot zones with hotspot value that ranges from 1.96 to 2.58 standard deviation were also located in proximity to Onitsha town.

The origin cost destination matrix of the abattoir hotspots determined with the Lat Long Software is shown in Table 1. The table shows clustering of these towns, however Umunya abattoir seems to be farther apart from all the other abattoirs with a distance of about 10 to 15 km to the rest of the abattoirs. Table 1 indicates that bio-energy plant can be optimally located with optimum capacities in all the towns identified as hotspot zones in this study except Umunya.

Table 1 Origin cost destination matrix of abattoir hotspots (distance in km)

		Obosi (L1)	Nkpor Private (L2)	Nkpor (L3)	Ochanja (L4)	Marine (L5)	Ugwunabamkpa (L6)	Oye-olisa Ogbunike (L7)	Umunya (L8)
1	Obosi (L1)	0	5.701	6.310	5.3209	8.7283	5.6999	11.2658	15.7317
2	Nkpor Private (L2)	5.701	0	4.0954	8.1489	9.9844	6.8835	6.386	10.3535
3	Nkpor (L3)	6.310	4.0954	0	5.5139	6.2117	3.6399	5.5409	10.2834
4	Ochanja (L4)	5.3209	8.1489	5.5139	0	3.6273	2.043	10.9374	15.6792
5	Marine (L5)	8.728	9.9844	6.2117	3.6273	0	3.2937	10.5615	15.0414
6	Ugwunabamkpa (L6)	5.699	6.8835	3.6399	2.043	3.2937	0	8.9357	13.6665
7	Oye-olisa Ogbunike (L7)	11.2658	6.386	5.5409	10.9374	10.5615	8.9357	0	4.7499
8	Umunya (L8)	15.73	10.3535	10.283	15.6792	15.0414	13.6665	4.7499	0

Table 2 shows the towns and the cities covered within the recommended 10 km distance from abattoir waste generation site to each town. For example, Obosi town has all the towns within 10 km distance with the exception of Oye-olisa Ogbunike (L7) and Umunya (L8). The screen shot of the solution of the problem using Tora operation research software is shown in Figure 3. The objective value of two was obtained from the problem, which means that a minimum of two bio-energy treatment plant should be built in the study area.

Table 2 Distance within 10 km

	Within 10 km Distance
Obosi (L1)	1, 2, 3, 4, 5, 6
Nkpor Private (L2)	1, 2, 3, 4, 5, 6, 7
Nkpor (L3)	1, 2, 3, 4, 5, 6, 7
Ochanja (L4)	1, 2, 3, 4, 5, 6
Marine (L5)	1, 2, 3, 4, 5, 6
Ugwunabamkpa (L6)	1, 2, 3, 4, 5, 6
Oye-olisa Ogbunike (L7)	2, 3, 6, 7, 8
Umunya (L8)	7, 8

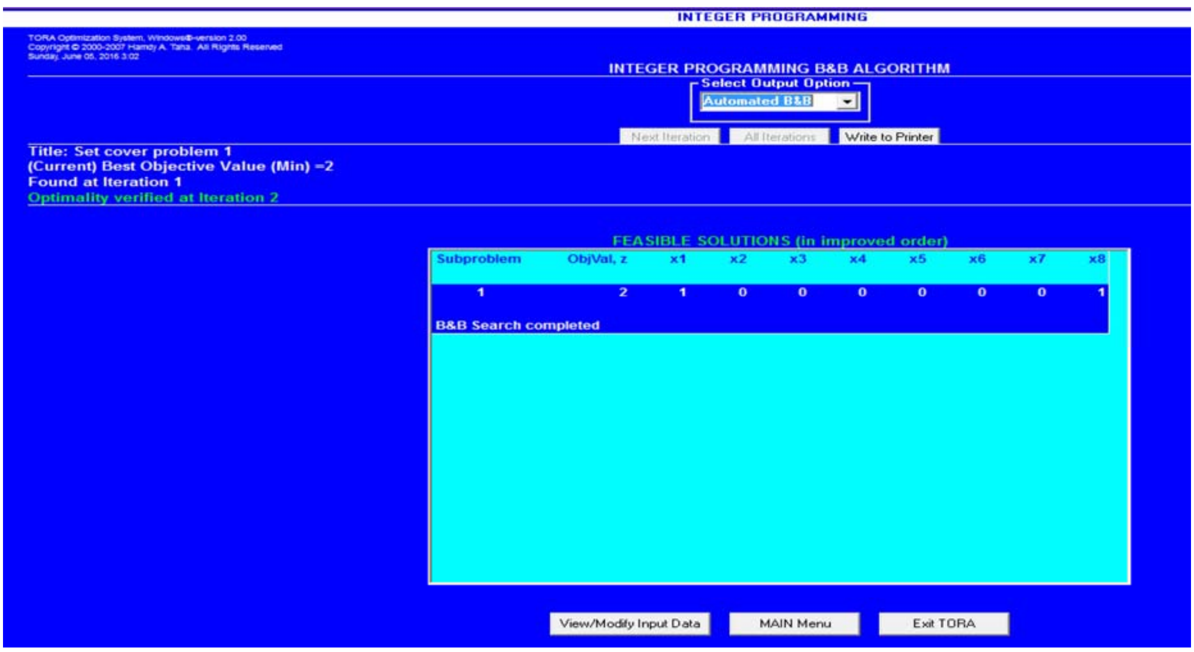

Figure 3 Tora solution of the set cover location model of bio-energy plant for the study area

The solution of the problem is $x_1=x_8=1$ and $x_2=x_3=x_4=x_5=x_6=x_7=0$. This entails that two bioenergy plant should be constructed in the study area in Obosi and Umunya. Facility constructed in L1 (Obosi) should manage self-generated wastes and wastes generated in Nkpor private, Nkpor, Ochanja, Marine and Ugwunabamkpa abattoirs, while abattoir treatment facility in Umunya should manage self-generated wastes and wastes generated in Oye-olisa Ogbunike.

4 Conclusion

Sitting of centralized biogas plants in strategic locations across the state would be a major means of combating the environmental challenges of increasing abattoir waste generation across the state. This study used the GIS hotspot analysis and set-covering location problem to determine the number of bio-energy treatment plant facilities that should be constructed in the study area, and to determine where they should be located. The result of the study shows that among forty-three abattoir centres in the study area, about eight abattoirs were classified as hotspot zones. Further analysis using the set covering location model shows that a minimum of two bio-energy plants should be constructed in Obosi and Umunya town. This study therefore will enhance strategic waste management and planning in the study area.

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

	X	Y	Location		X	Y	Location		X	Y	Location
1	7.018555	6.017395	Nkwo Igboukwu	16	6.962635	6.03555	Eke-Awka Etiti	31	6.760187	6.109338333	Iyi-owa Odekpe
2	7.080091	6.018026944	Eke Ekwulobia	17	6.859224	5.7808097	Eke-Agba, Uli	**32**	**6.785008**	**6.133826667**	**Ochanja**
3	7.08316	5.952746944	Oye Uga	18	6.881035	5.743306667	Amorka	33	6.768772	6.131866389	Bridge-Head
4	7.031785	6.093185	Nwagu-Agulu	19	6.865356	5.850741944	Nkwo Ogbe	34	**6.776812**	**6.165645**	**Marine**
5	7.059412	6.212848056	Amikwo, Awka	20	6.841392	5.910508056	Nkwo Okija	**35**	**6.798992**	**6.14584573**	**Ugwunabamkpa**
6	7.136735	6.248326667	Amansea	21	6.919651	5.832136667	Isseke	36	6.772032	6.151048056	Main Mkt
7	6.922932	6.1790836	Afor-Igwe Umudioka	22	6.957437	6.186866667	Oye-Agu Abagana	37	7.065565	6.051811944	Afor Nanka
8	6.873527	5.965326667	Ugwu-oye Ozubulu	23	6.985188	6.186026667	Eke-Agu	38	7.102022	6.045285278	Eke Oko
9	6.816021	6.030126667	Oraifite	24	6.90853	6.019105	Nkwo-Nnewi	39	7.220546	5.250685278	Nkwo Umunze
10	6.8667	6.15	Nkwo-Ogidi	25	6.922315	6.030278333	Orie-Agbo	40	6.921057	6.243793611	Nteje
11	**6.816085**	**6.097141667**	**Obosi**	26	6.91624	6.016755	Oba-Isi Edo	**41**	**6.870187**	**6.183493056**	**Oye-olisa Ogbunike**
12	**6.858018**	**6.126923611**	**Nkpor Private**	27	6.979822	5.993021389	Amichi	**42**	**6.905594**	**6.207611667**	**Umunya**
13	**6.831115**	**6.152293056**	**Nkpor**	28	6.92856	5.942223611	Afor-Ukpor	43	6.944423	6.224766667	Orie Awkuzu
14	6.82974	6.0725219	Afor-Oba	29	6.991637	5.951456667	Osumenyi				
15	6.948936	6.046831667	Afor-Nnobi	30	7.04232	5.960568333	Unubi				

Note: Hotspot zone abattoir are presented in red.