(RESEARCH ARTICLE)

Spatial analysis of electrical distribution system in obio-akpor local government area, rivers state, Nigeria

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Abstract

The distributions of quality electrical energy to end users and, achieving a reasonable level of customer's satisfaction from the electricity distribution companies servicing most area are faced with divers' spatial problems particularly with the use of dilapidated infrastructures and poor services. This study used spatial techniques to analyze the spatial characteristics of the electrical distribution system in Obio-Akpor Local Government Area, Rivers State. It also examined the ward pattern of Port Harcourt Electricity Distribution (PHED) customer's satisfaction and also predicted the ward level of customer's satisfaction within the study area. Primary and secondary data were used for the study. The primary data on customer's satisfaction of PHED services was obtained from questionnaire survey. Purposive sampling method was used for this study and the population for the study is the entire customers of PHED in the study area. The secondary data consist of ward boundary map of the study area, satellite image, PHED network spatial data and attribute data of all the 3200 (three thousand two hundred) transformers (11/0.415KVA and 33/0.415KVA) within the study area as at the time of this study. Geospatial analysis such as clip analysis, buffering were carried. The data attribute were analyzed using average nearest neighbor analysis, kernel density, zonal statistics, inverse distance weighting and geographical weighted regression to obtain the desired aim of the study. The result show that, the location pattern of PHED transformers are clustered. Result further reveal that the ward pattern of customer's satisfaction are geography dependent with either positive, negative or mixed relationship.

Keywords: GIS; Electrical Distribution; Transformer; Customer Satisfaction; PHED; Geographical Weighted Regression; Nearest Neighbor Analysis

1. Introduction

Electricity is one of the critical forms of energy which has been available for man's use and, has largely improved man's socio-economic and technological developments, for several years. Electricity is transmitted via the distribution system from transmission stations to meet end user's supply needs [1; 2; 3]. Distribution system is vital because it involves huge investment cost and it closes the gap between the customers and the transmission stations.

The availability of electricity supply in its right proportion is regarded as the basic needs of humans, necessary for a meaningful, productive and smooth running of all aspect of business in every nation [4]. Factors which includes but not limited to not having a precise estimate of the classes of customers/consumers that are connected to every electrical facility within the network area, and failure to ascertain these fact has led to numerous problems and faults like low voltage supply, overloading of the transformers, irregular electricity supply, less electricity supply hours per day, poor meter reading and inaccurate billing etc [5; 6]. This inability of the electricity distribution companies to correctly

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evaluate, ascertain, and estimate the right amount of power to supply, swift response to addressing faulty electrical infrastructure related issues, has over time breed dissatisfaction among customers which has further led to the degeneration of the power sector due to mistrust as to their ability to correct these errors.

The monitoring and management of data on the electricity distribution network will continue to be significantly improved by the integration of Geographic Information Systems (GIS) with the electrical distribution network. This includes the clients' spatial and non-spatial properties. GIS will increase the Disco's understanding of its customers' satisfaction and tie these findings to the infrastructures of the distribution network and the locations of these customers [7].

Applying geographic information system (GIS) in electricity distribution network is the foundation of this research. GIS is used to identify transformer types and power distribution, examine the spatial pattern of customer satisfaction with the services of Port Harcourt Electricity Distribution Company (PHED), and finally, analyze the spatial relationship between PHED's service delivery and customer satisfaction within the study area.

1.1. Study area

Obio-Akpor, a local government area in Port Harcourt, Rivers State, is situated at latitude 4°45'N, 4°60'N, and longitude 6°50'E, 8°00'E, respectively. It has a total accumulative size of 260km², as it serves as one the principal hubs for economic activity in Nigeria and a significant Niger Delta city of interest. Obio-Akpor LGA has 17 wards (Table 1), each of which elects one councilor. The Council was established on May 3rd, 1989, to manage local administration, and its own administrative and legislative bodies are responsible for carrying out the functions of governance.

Table 1 Names and Codes of Wards in Obio-Akpor Local Government Area

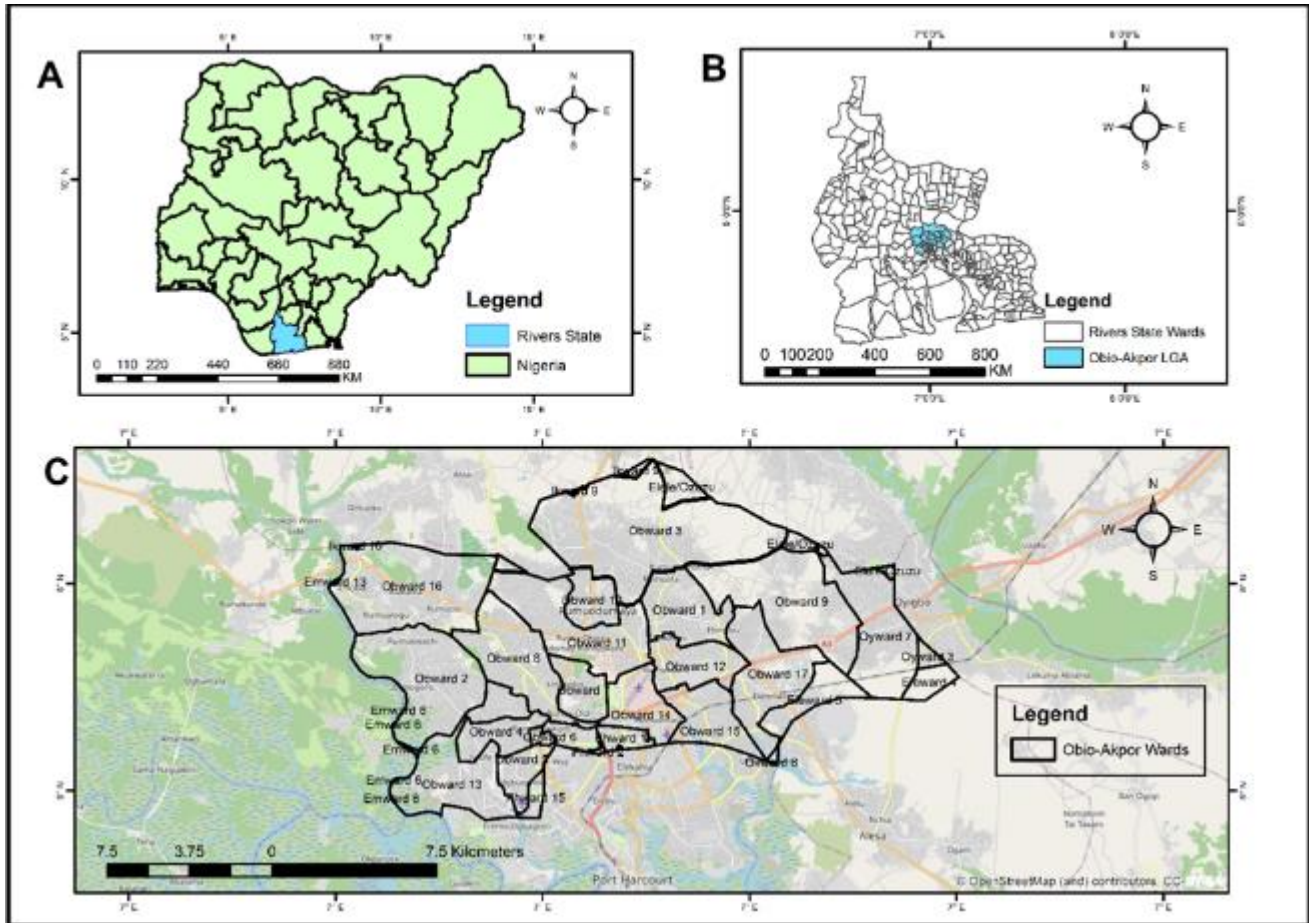| S/N	Name Of Registration Area (RA)	Ward Code
1	ORO-IGWE	01
2	RUMUODARA	02
3	RUMUOKWU(2B)	03
4	RUMUODUMAYA	04
5	ELELENWO	05
6	WOJI	06
7	RUMUOKORO	07
8	RUMUOMASI	08
9	RUMUEME(7A)	09
10	RUMUEME(7B)	10
11	RUMUEME(7C)	11
12	RUMUIGBO	12
13	RUMUOKWUTA	13
14	RUDOKWU	14
15	CHOBA	15
16	OZUOBA/OGBOGORO	16
17	RUMUOLUMENI	17

Figure 1 Study area maps

2. Material and methods

Enumerated data containing spatial attributes of 3200 (three thousand two hundred) transformers (11/0.415KVA and 33/0.415KVA) from Port Harcourt Electricity Distribution (PHED) network for Obio-Akpor LGA and its environs will be analyzed using Geographic Information System (GIS) techniques to effectively identify the spatial characteristics and distribution of transformers by transformer types, examine spatial pattern of customer's satisfaction with PHED services, and analyze the spatial relationship between service delivery of PHED and customer satisfaction in the study area.

Geographically Weighted Regression (GWR) will also be used to analyze and ascertain the level of consumer satisfaction with respect to PHED services. The data set for this objective are obtained from questionnaire survey. Weights are apportioned to the questions in the questionnaire which will be used to ascertain the level of customers' satisfaction. The respondents will be asked both open ended and scaled questions. They will be required to rate the importance of each of their choice of answer following the principle of the Likert Scale (Likert, 1961)

Furthermore, Purposive sampling method was used as the study area was divided into 17 wards base on National Electoral Commission (2017). Approximately 6 customers were selected for the administration of questionnaire. In all a total of 104 customers were interviewed for the study area. This method sampling was used because it gives customers freedom of participating in the survey.

Table 2 Secondary data sources

| S/N	Data	Data type	Year	Source	Usage
1	Internet	Secondary	2021	ArcGIS	Study area map, road network and land use
2	Electrical network data	Secondary	2021	Port Harcourt Electricity Distribution Plc	Electric network distribution information
3	GPS location electric infrastructures	Secondary	2021	Port Harcourt Electricity Distribution Plc	Electric infrastructure network map
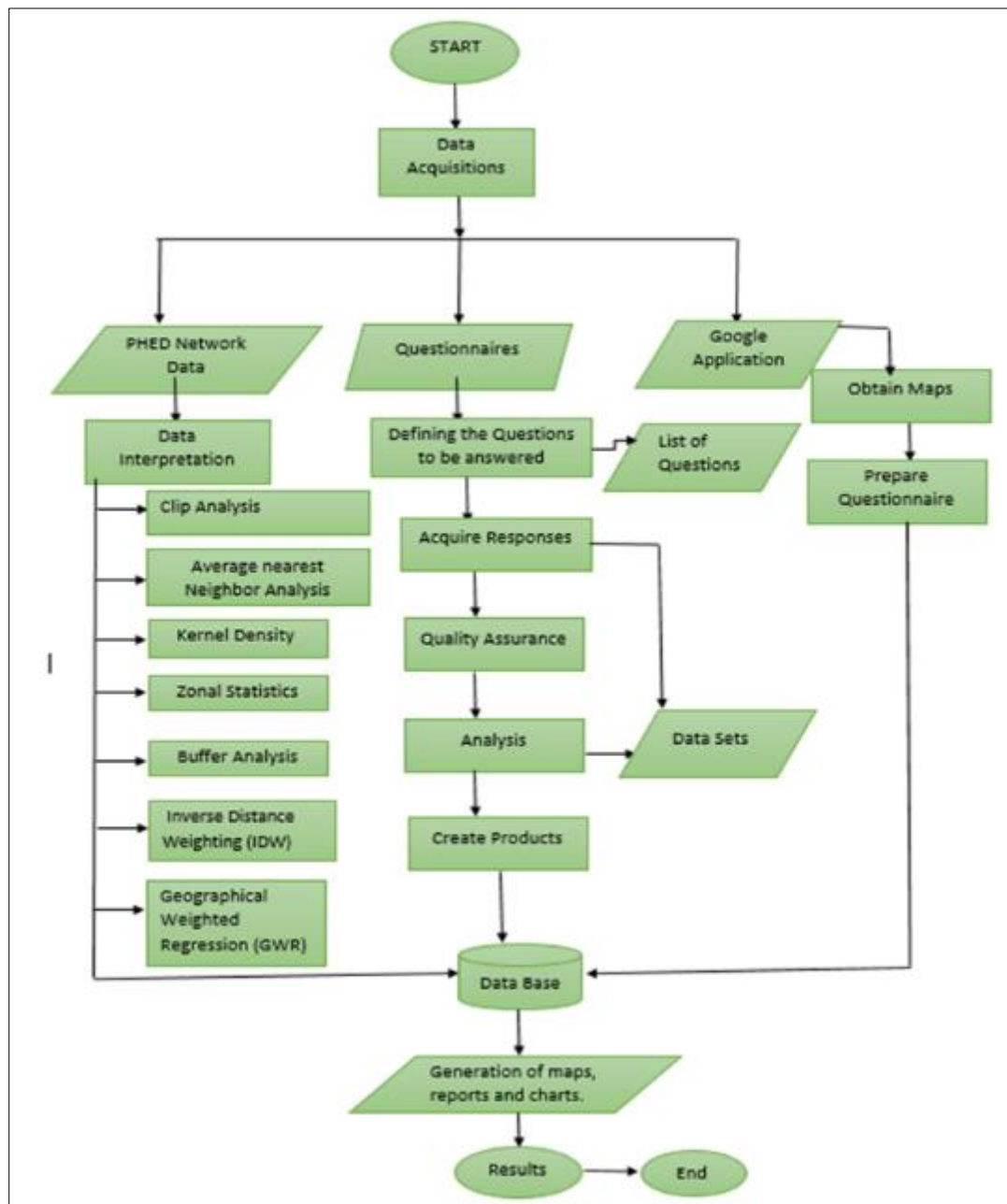
Figure 2 Methodology flowchart

3. Results and discussion

Analysis were conducted using Port Harcourt Electricity Distribution (PHED) network data and questionnaires which are both suitable for GIS analysis. The findings are divided into sections based on the objectives of the study which are; (1) Characteristics of the transformers: This talks about transformer types and power distribution, (2) Examining the spatial pattern of customer satisfaction with the services of Port Harcourt Electricity Distribution Company (PHED) in the study and finally, (3) Analyzing the spatial relationship between service delivery of PHED and customer satisfaction in the study area.

3.1. Characteristics of the Transformers

For this research, two types of distribution transformers were examined: 11/0.415KVA and 33/0.415KVA.

A total of 3200 (three thousand two hundred) transformers; 11/0.415KVA (2,504) and 33/0.415KVA (696) were identified within the study area. Two Thousand One Hundred and Forty Three (2143) transformers (approximately 67%) of the total transformers within the study area are plinth mounted while the remaining One Thousand Fifty Seven (1057) transformers (approximately 33%) are pole mounted.

Furthermore, these transformers are either owned by private bodies, Port Harcourt Electricity Distribution Company (PHED) or the Federal Government through the National Integrated Power Project (NIPP).

A summary of the status of the transformers as at the time this data was obtained (Table 2)

Table 3 Status of transformers

S/n	Transformers status	Number of transformers
1	Abandoned	1
2	Active	12
3	Capacity Inter-Winding	8
4	Direct Current	75
5	Earth Fault Indicator	1
6	Faulty	17
7	Fault Passage Indicator	5
8	Injection Sub-Station Auxiliary	2
9	Not Available	18
10	Not Connected	62
11	NFP	2
12	Not In Use	93
13	Not Yet Connected	9
14	Not Yet Installed	1
15	OK	2861
16	Over grown Vegetation	1
17	Removed	24
18	Vandalized	1
19	No Status	7
	Total	3,200

3.1.1. Private Transformers

A total of 864 (Eight Hundred and Sixty Four) transformers are privately owned. These transformers consist of 602 (Six Hundred and Two) 11/0.415KVA and 262 (Two Hundred and Sixty Two) 33/0.415KVA transformers are within the area.

The density maps, illustrating the distribution of privately owned 11/0.415KVA and 33/0.415KVA transformers are shown (Figures 3 and 4). From the maps, it is observed that the color changes from dark green which represent area with little or no installed transformers, to deep orange which shows dense transformer distribution in some locations. These dense areas are identified as Obward 1, 3, 10, 15 and less dense areas as Eleward 4, Kward 9 and Obward 2 for 11KVA transformers. Also, the dense areas for 33KVA transformers are identified as within Obward 1,3,5,6,10,12,15 and less dense areas are within Eleward 4, Kward 9 and Obward 2. These dense transformers distribution areas could be attributed to high urbanization activities and early settlement in these parts of the study area.

Also, there are few scattered installed transformers around the eastern and western parts of the study area particularly in Ob 2, 4. Clusters are identified within Obward 15, 12, 17, 9 and Oyward 7. Furthermore, other clusters are identified within Phward 11, Obward 7, 8 and 11. And lastly, Obward 15, 12, 11, 8 and 16. These clusters are transformers located in a linear form. The arrangement of these transformers followed a road direction (Figures 3 and 4).

3.1.2. Public Transformers

Also, total of 2,336 (Two Thousand Three Hundred and Thirty six) public transformers which consist of 1,902 (One Thousand Nine Hundred and Two) 11/0.415KVA and 434 (Four Hundred and Thirty Four) 33/0.415KVA transformers are within the area.

The density maps, illustrate the distribution of publicly owned 11/0.415KVA and 33/0.415KVA transformers as shown (figure 5 and 6). From the maps, it is also observed that the color changes from dark yellow which represent area with little or no installed transformer, to blue which shows dense transformer areas.

Both 11/0.415KVA and 33/0.415KVA transformer maps are denser around Obward 1 and 16 and least dense around Eleward 4 and Kward 9 part of the area. These dense areas could still be liken to high urbanization activities and early settlement within these areas.

Also, transformers installed along a straight line which could be liken to roads coming in and out of the area as seen when analyzing private transformers distribution are noticed within the same wards earlier mentioned.
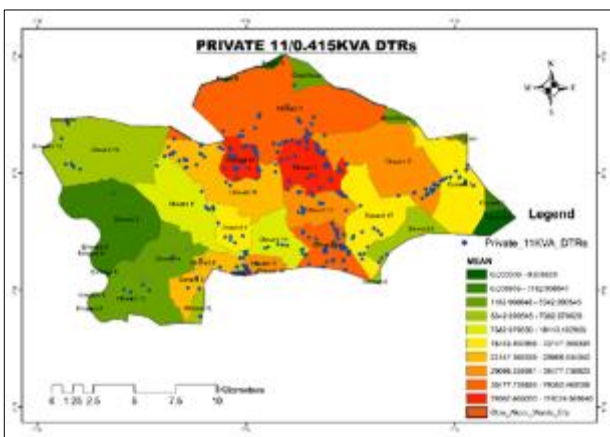

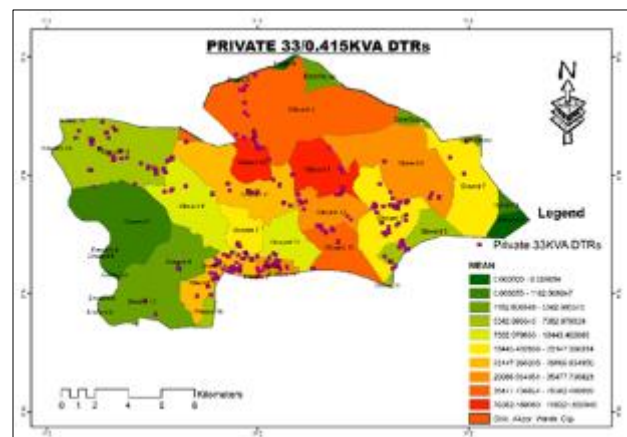**Figure 3** 11/0.415KVA Private Transformers Distribution

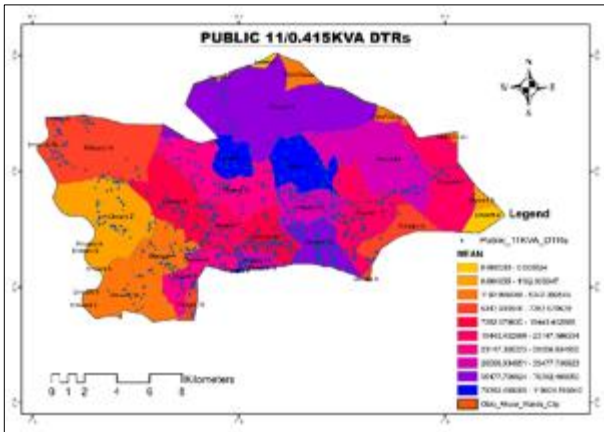**Figure 4** 33/0.415KVA Private Transformers Distribution

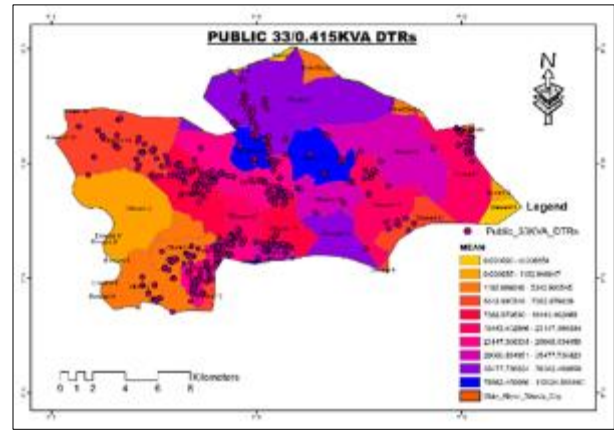**Figure 5** 11/0.415KVA Public Transformers Distribution

Figure 6 33/0.415KVA Public Transformers Distribution

3.1.3. Average Nearest Neighbor Analysis

The Average Nearest Neighbor Analysis (ANNA) for both the 11/0.415KVA and 33/0.415KVA transformers show that the physical location of these transformers are significantly clustered (ANNI = 0.286339) and (ANNI = 0.349127) respectively. This could be attributed to high urbanization and other factors which have over time encourage both private and public ownership of transformers in the area.

In addition, more of 11/0.415KVA and less 330.415KVA transformers are installed within the area. The results of the average nearest neighbor analysis is shown (Table 4).

Table 4 Average Nearest Neighbor Analysis Result

	11KVA Transformer	**33KVA Transformer**
Nearest neighbor ratio	0.286339	0.349127
P-Value	0.000000	0.000000
Z-Score	-68.3187269245	-32.8497397669
Observed distance	52.8018 meters	116.9993 meters
Expected distance	184,4029 meters	335.1198 meters

3.2. Spatial Pattern of Customer Satisfaction with the Services of Port Harcourt Electricity Distribution Company (PHED) within the Study Area

The location satisfaction pattern of 104 customers within the study is shown (Figure 9). These are the customers that were able to completely fill the administered survey forms. Based on the principle of the Likert Scale (Likert, 1961), the overall customers satisfaction was weighted from 1 being the least (color green on the map) to 7 being the highest (color blue on the map) and an Inverse Distance Weighting (IDW) interpolation tool clearly show the geospatial pattern of these customers satisfaction across the wards.

Obward 9 has the highest records of least satisfied customers within its LGA. This could be attributed to several factors but not limited to the installation of little/no transformers within larger area of the LGA. Transformers are very important in electricity distribution as they are used to raise and droop the voltage so the electricity power could be transmitted over a long distance thereby, improving the quality of energy distributed to end-user. When the distance between two transformers is greater than necessary, the customers within these areas experiences low voltage, irregular power supply, and customer's loads outweighing the size of the transformer, faulty and damaged utility infrastructure etc, all of which will eventually result to customers dissatisfaction with the quality of service received from PHED. The distribution of all other levels of satisfaction could be observed within the wards in the LGA (figure 9).
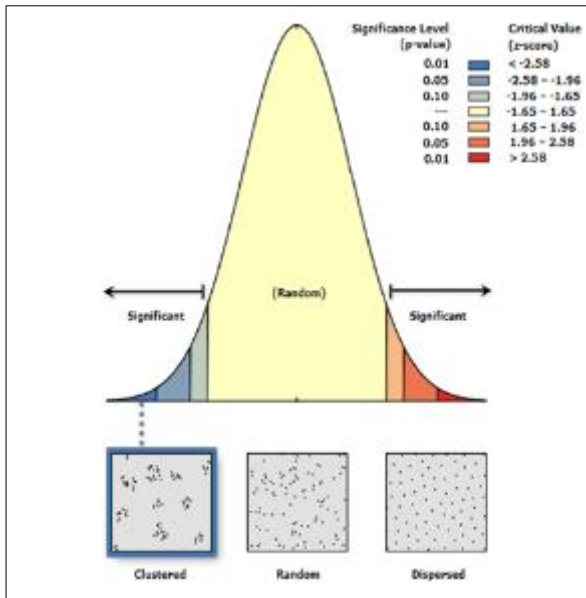
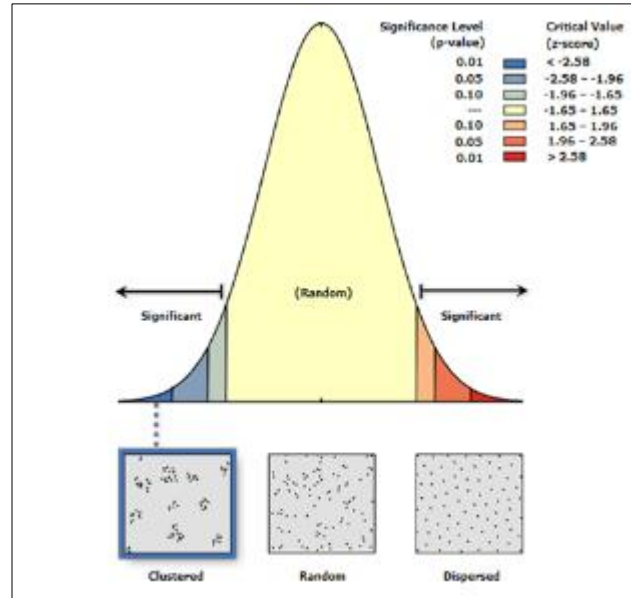**Figure 7** Average Nearest Neighbor Analysis Result for 11KVA Transformer

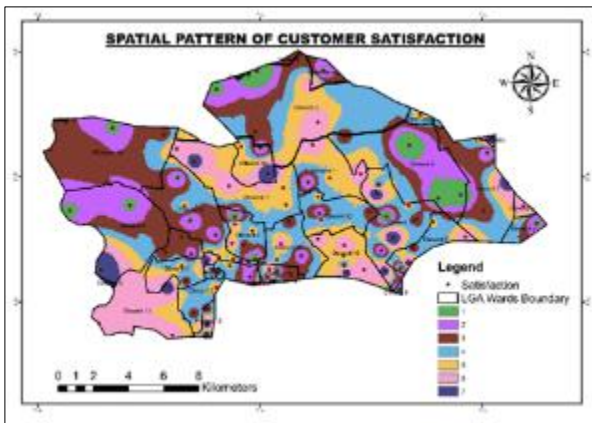**Figure 8** Average Nearest Neighbor Analysis Result for 33KVA Transformer

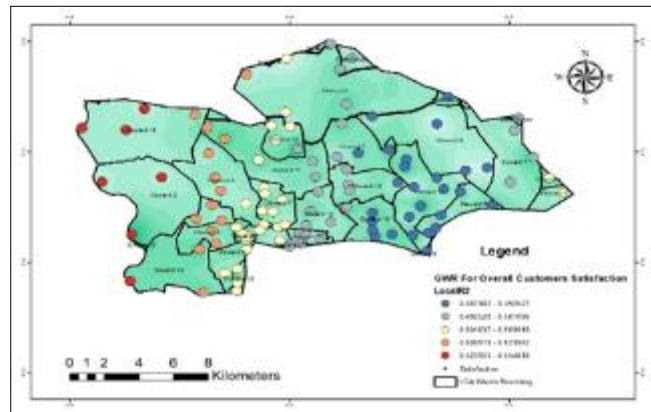**Figure 9** Overall customers' satisfaction with PHED services

Figure 10 Overall Customers Satisfaction Local R2 Values

3.3. Analyzing the Spatial Relationship between Service Delivery of PHED and Customer Satisfaction in the Study Area

The spatial relationship between PHED service delivery and overall customer's satisfaction were analyzed using geographically weighted regression (GWR). The GWR values for the dependent and, all the explanatory variables and their level of significance is clearly shown (Figure 10 to figure 17). GWR provided a better interpretation for the data because it allows increase in the number of variance by 7, resulting to 55% variance explained.

The (GWR) model result for overall customers satisfaction with its R Square values ranging from 49% to 55% which is great because it shows how well the model fits the data in each area and, how the explanatory variables are affected by geography (Figure 10). Obwards 2, 13 and 16 are the most satisfied and this could be attributed to many factors and not limited to the explanatory variables used for this analysis.

3.3.1. Variations in local Estimate.

The local coefficients of the relationship between the customer(s) satisfaction and the seven explanatory variables that have significantly spatially varying effects is shown (figures 11 – 17). In the maps, the points indicates the local coefficients for that location. Here are how the seven variables are associated with customers satisfaction across the study area.

Excess Transformer Load

This displays the spatial distribution of the model coefficient for excess load. The GWR model coefficient for excess transformers' load ranges from -0.16 to -0.45 which suggest a negative relationship between customer's satisfaction and excess load within the study area (Figure 11).

Billing Accuracy

The spatial association between customer's satisfaction and accurate billing within LGA is (Figure 12). The effect of the determinant, customer's satisfaction in explaining the variance of accurate billing is strong ranging from 12% to 15% within the southern and eastern part of the LGA which consist of Obwards 8, 9 11, 12, 14, 15 and 17, and extending into Elewards 4 and 5, Oywards 7and 8 and lastly Elele/Ozuzu.

Irregular Power Supply

The GWR coefficient as shown (figure 13) shows a negative relationship between customer satisfaction and irregular power supply with a maximum satisfaction level of -0.13%. The coefficients of the negative relationship ranges from -0.13 (which consist of only Obward 16) to -0.24 which makes up the remaining parts of the study area.

Low Voltage

Also, the GWR estimate as shown (0.10 to -0.21) for low voltage display a mixed relationship within the study area with majority of the local government area within the negative margin (figure 14).
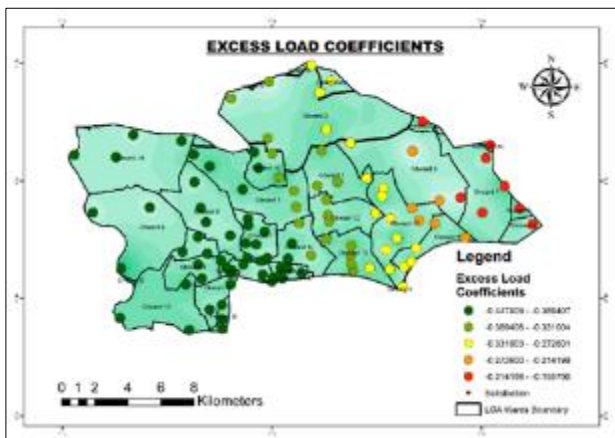
Meter Reading

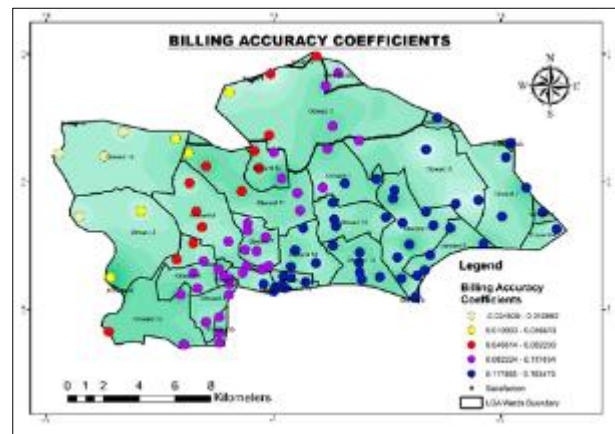**Figure 11** GWR parameters between customer's satisfaction and excess transformer load

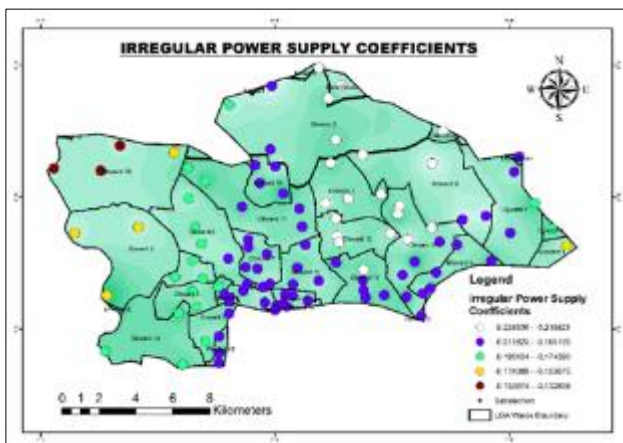**Figure 12** GWR parameters between customer's satisfaction and accurate billing

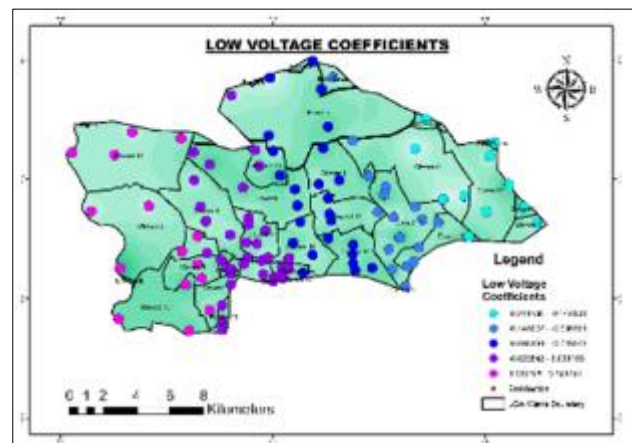**Figure 13** GWR parameters between customer's satisfaction and irregular power supply

Figure 14 GWR parameters between customer's satisfaction and low voltage

The GWR estimate for customers meter reading which also has a mixed relationship with most of the wards trending in the negative direction (0.02 to -0.07). Obward 16 had the most satisfied customers for this particular run as shown (figure 15).

Repair of Damaged Infrastructures.

The GWR model result for this run has revels that the repair of damaged infrastructures has a positive relationship. This is attributed to the 64% coefficient value for customer's satisfaction with damaged infrastructures repair. The overall relationship all within the positive direction (0.64 to 0.27) is shown (Figure 16).

Transformer Repair.

The spatial distribution of the GWR estimate is graphically represented (figure 17).

The values of the ranges from 0.085 to -0.20 which demonstrate a mixed relationship. It shows that the explanatory strength of the model varies by wards. Also, there is a clear regional pattern in the graphical presentation of the estimated values, which also means the data is geography dependent. Although, customers in Obwards 1,9,11,12,14,15, 17 and others within the south-east and north-eastern part of the local government area are very satisfied with transformer repairs.
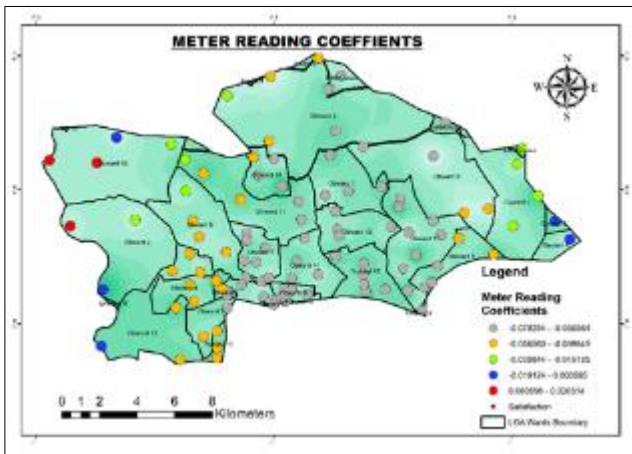

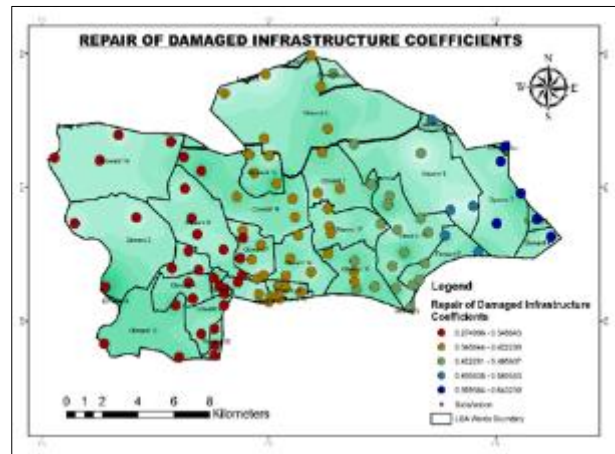**Figure 15** GWR parameters between customer's satisfaction and meter reading

Figure 16 GWR parameters between customer's satisfaction and damaged infrastructure repairs
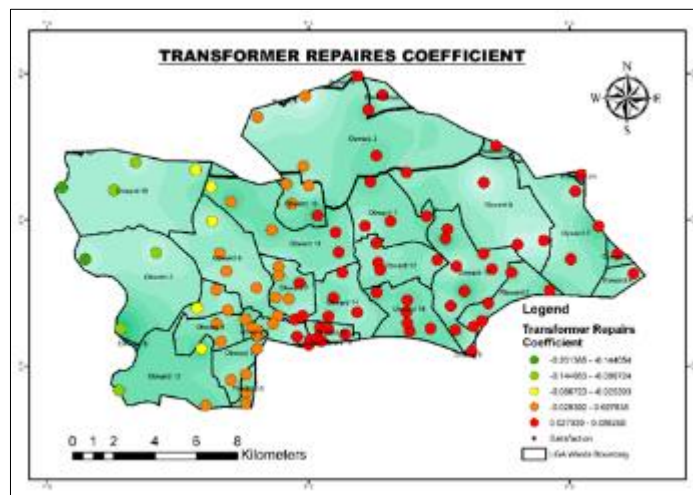

Figure 17 GWR parameters between customer's satisfaction and transformer repairs

4. Conclusions

This research has shown the effectiveness of using GIS in analyzing PHED facilities and services with regards to PHED customer's satisfaction in Obio-Akpor local government area. This was important in bridging the gap between quality service delivery and the overall customer's satisfaction. Using GIS to show the spatial distribution of transformers, their status, and their embedded attributes in all of Obio-Akpor was imperative as it broadened our understanding of the quality of electricity supply within the study area.

The Characteristics of transformers in Obio-Akpor local government area was examined through systematic assessment of the spatial distribution of PHED transformers and it's embed attributes. The study also examine the spatial pattern of customer satisfaction with the services of Port Harcourt Electricity Distribution Company (PHED) in the study area. It furthermore analyze the spatial relationship between service delivery of PHED and customer satisfaction in the study area.

Findings on the spatial Pattern of Customer Satisfaction with the Services of Port Harcourt Electricity Distribution Company (PHED) within the Study area shows variation in the pattern of satisfaction with Obward 9 having the highest records of least satisfied customers within its LGA.

In terms of the spatial Relationship between Service Delivery of PHED and Customer Satisfaction in the study area, the geographical weighted regression (GWR) predicts between 49% and 55% of the variance in overall customers satisfaction.

Findings also showed that the relationship between excess loads and irregular power supply is negative within the wards in the local government. It also shows that there is a mixed relationship between billing accuracy, low voltage, meter reading and transformer repairs. Also, repairs of damaged infrastructure showed a positive relationship across all wards which indicates overall customer satisfaction is positively influenced by repairs of damaged infrastructure.

Furthermore, the values for overall customer satisfaction (dependent) and, all the explanatory variables and their level of significance are affected by geography.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Adejoh, IY., Ajileye, OO., Alaga, AT., Samson, AS. and Onuh, SO. 2015. Application of GIS in Electrical Distribution. European International Journal of Science and Technology, 4(8): 81–95.

[2] Avila, N., Carvallo, JP., Shaw, B. and Kammen, DM. 2017. The energy challenge in sub- Saharan Africa: A guide for advocates and policy makers. Generating Energy for Sustainable and Equitable Development, Part 1: 1–7

[3] Kaseke, N., and Hosking, S. 2013. Sub-Saharan Africa Electricity Supply Inadequacy: Implications. Eastern Africa Social Science Research. Organization for Social Science Research in Eastern and Southern Africa, pp. 113–1

[4] Sekhar, A. N., Rajan, K. S., & Jain, A. (2008, December). Application of geographical information system and spatial informatics to electric power systems. In Proceeding of Fifteenth National Power Systems Conference (NPSC), IIT Bombay.

[5] Ogunbiyi, O., Olayinka, A. A., & Ahmed, M. O. (2019). Spatial Modelling and Analysis Of An Electrical Distribution System.

[6] Santos, A.D., Faria, L.T., Lopes, M.L., & Minussi, C.R. (2023). Power Distribution Systems' Vulnerability by Regions Caused by Electrical Discharges. Energies.

[7] Khaire, S. A., Khan, K. J., Gawade, A. B., & Charde, D. S. (2019). GIS IN ELECTRICAL DISTRIBUTION NETWORK SYSTEM. IJRAR-International Journal of Research and Analytical Reviews (IJRAR), 6(1), 412-418.