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The GIS Application for Electricity Distribution Billing and Revenue Management

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Abstract: *The billing and revenue management of consumers regarding the consumption of electrical energy is critical to the profitability and expansion of the electrical network. For distribution companies to start new projects and purchase new equipment, the loss in revenue due to non-payment of electricity bills must be eliminated. In this work, a complete solution for the Ikeja Government Residential Area (GRA) under Ikeja Electric Plc. has been designed to monitor consumers and identify billed (paying) customers and unbilled (non-paying) consumers.*

This study determines three core components: mapping of electricity distribution network assets and customers, identification of billed (paying) customers, and a comparison between unbilled (consumers of electrical energy) and billed customers. The research uses Geographic Information Systems (GIS) to capture the coordinates (longitude and latitude) of network infrastructures and consumers and then compares the results with those on the existing customer database to identify billed and unbilled customers. In the past, the system was traditionally done by conventional surveying method using analog equipment; storing data in analog maps and commissioning reports found mainly in drawing offices with no integration of these activities into one system.

Electricity utilities need to keep a comprehensive and accurate inventory of their physical assets and customers. This presents a somewhat disjointed approach to the management of the electrical distribution network and revenue. GIS provides a database and a customer information system (CIS) to help utilize both spatial and customer information to manage customer billing accounts and revenue collection. Since the implementation of this system, the results obtained have revealed that GIS modeling is an effective way to tackle crucial problems of utilities with particular regard to customer energy accountability. The system has facilitated the identification of the best billing methodology that will be used to capture 1,985 consumers: 1,757 paying customers and 228 residential consumers (non-paying) that have caused the electricity distribution company ₦868,050; 198 single-phase customers = ₦632,610 and 30 customers three-phase customers = ₦235,440.

Keywords: *Geographic Information Systems (GIS), Customer Information System (CIS), water supply, billing, distribution, residential customers, revenue monitoring, and management.*

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I. INTRODUCTION

In developing countries, electricity distribution companies have been unable to effectively curb the loss of revenue caused by unbilled consumers (energy thieves or free riders). This has been problematic and has resulted in the continuous dilapidation of the network owing to the non-commencement of new projects and non-replacement of failed equipment with new infrastructures since inadequate revenue is generated to sponsor such projects. This mandates the electricity utilities to keep a comprehensive and accurate inventory of their physical assets, both as a part of typical service provision (network extensions, routine maintenance, etc.) and their obligation to the customers.

With Nigeria's fast-growing economy, changes are experienced daily through the inflow of new consumers and network connections. Conveniently, the current availability of fast computers, digital data acquisition technology, digital data processing, and information presentation technology has facilitated GIS in electricity distribution and driven a revolution in the world at large.

Several studies were reviewed in the development of this work, and their findings have been presented here to show a distinction between what exists about studies of GIS and the electricity distribution network and what this paper is looking to achieve. Utility companies are forced to make wise decisions vital to their facilities' operations, growth, and management. Consequently, information is now captured, stored, integrated, manipulated, analyzed, and displayed to allow unique identification of each asset using a hand-held global positioning system (GPS) to get the exact latitude (X) and longitude (Y) of each electrical asset [1]. In addition, the high-resolution satellite image derived from the GIS base maps can be used to capture network features and customer information over it. This approach was used in identifying high-tension (HT) and low-tension (LT) network assets and their lengths. There is a need to use this information to perform analysis to effectively determine the consumers connected to the electrical grid to ensure proper asset and customer mapping.

In agreement with [2], the standalone GIS application can be used by electrical power distribution network companies to calculate losses as well as recognize overloaded transformers. The overloaded transformers can be detected using load flow models: threshold value is defined based on transformer capacity, average load shedding time, and power factor (PF). This is used to confirm when the transformer's output power exceeds the threshold power, which stipulates that the transformer is overloaded. Overloading a transformer weakens its insulation system, which leads to overheating and, eventually, thermal degradation that may trigger an explosion. This research does not articulate the need to identify the consumers connected to transformers to ascertain the customers that are being billed and the unbilled consumers.

The study in [3] is in accordance with the one in [4] that GIS is vital in the effective management of electricity distribution by assessing the spatial relationship between the Nigerian electricity distribution company assets and their customers' connectivity within the area of study, as well as making decisions on gauging the consumption rate of customers. The studies [12] and [13] comprise mapping the existing distribution facilities and customers, categorizing the number of customers connected to the company's assets, and calculating their consumption by each customer. As good as these studies are, the parameters for identifying the customers that pay for electricity monthly as well as consumers that use electricity freely were not determined. Asides from the use of GIS and GPS, remote sensing was also included [5]. The work illustrates the use of these technologies in customer indexing, to find the exact location of the consumer feeder, transformer, and pole supplying the consumer with electricity and then estimate the customer's energy consumption. As it relates to the identification of unbilled customers, creating a more realistic environment to carry out a test as well as validation has been a challenge for researchers.

In many cases, due to cost and other factors, GIS has been used to convert data from several sources such as paper maps, AutoCAD files, Information stored in people's heads, and new data collected in the field into a common digital and map-based format to create a utility network using Geographic Information System (GIS) to enhance the quality [6]. Notwithstanding, the use of GIS begins from this approach.

In another work, GIS is employed in analyzing the effects of the proximity of the distribution transformer to the customer's premises. It identified that customers within 100 meters of the transformer would have optimal voltage levels compared to those beyond 100 meters. Furthermore, in the case of exposure to fire, customers within 20 meters of the transformer are at a higher risk than those farther away [7]. These results are satisfactory; however; the study of [7], just like [2], fails to indicate the importance of capturing all consumers connected to the grid and also the identification of the unbilled customers by comparing the billed customers with the total number of customers connected to the grid. To implement GIS for power distribution and theft control, [8] identifies priority areas for investment in power allocation. This is observed by assessing the power demand scenario, that electricity can be delivered to targeted areas willing to pay for them and thereby reduce the losses in the system. The foregoing has revealed that using patterns of distribution, demand, consumption, losses, and energy theft can be reduced. However, this work presents a rather straightforward application of GIS from readily available materials. It fails to identify the unbilled consumers and highlights revenue loss by these consumers.

The studies [14] and [16] highlighted the use of geographic information systems (GIS) in managing and improving water supply and revenue collection systems by using GIS to improve decision-making in spatial data and analysis. Additionally, [17], [18], and [19] focus on the use of geospatial technologies using GIS, to improve, and enhance the management and operations of the electricity distribution system. They suggest the implementation of GIS in the distribution system plays a vital role in planning, improvement in billing, revenue collection, and proper asset management. However, these studies do not determine three core components: mapping of electricity distribution network assets and customers, identification of billed (paying) customers, and a comparison between unbilled and billed customers which has facilitated the identification of the best billing methodology with particular regard to customer energy accountability.

With all these gaps pinpointed in these studies, this paper carefully highlights Ikeja GRA as a case study under Ikeja Electric Plc's network to expand the literature on the use of GIS to map the location of transformers, power lines, electric poles, and their attributes in the study area to identify all consumers of electricity, investigate all paying customers and compare the database to recognize the billed (paying) customers and the unbilled (non-paying) consumers connected to the grid. The modeling and simulations employing geospatial technology were carried out in ArcGIS 10.4 environment having established that in all these researches, using GIS is most suitable. The Customer Information System (CIS) was also utilized to identify billed customers and then evaluate these customers with the geographically mapped customers to establish the unbilled consumers.

II. METHODOLOGY

In [11], Tomlinson indicated that preparation is vital in the successful execution of GIS, particularly for his overlays in promoting the spatial analysis of convergent geographic data. The work was undertaken in three-branched methods; network and customer mapping coupled with system development, the identification of all billed (paying) customers, and the recognition of unbilled (non-paying) customers will have a unique code called Customer Index Number (CIN). Figure 1 explains the methods implemented in this project, it goes a long way to enumerate the field procedures involved in carrying out asset mapping and customer enumeration; identification of billed customers, and the techniques to recognize unbilled customers in the study area.

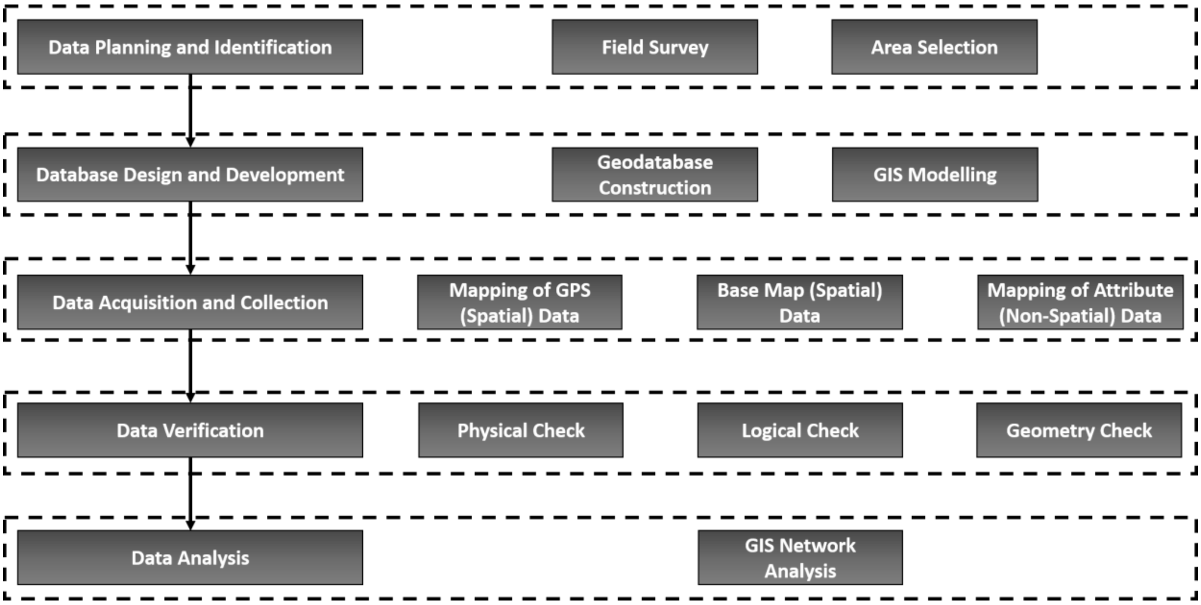

Figure 1: Methodology Flow Chart

The steps include the following:

1. Data Planning and Identification Phase

This involved making adequate data plans, and conceptual data identification in taking decisions that facilitated the realization and attainment of the objectives set beforehand. In this study, all requirements for field-based reconnaissance of the site, electrical assets, and consumers were carried out and identified through a field survey and area selection.

a) Field Survey

This included the asset and customer's on-site investigation and inspections of the area of study to collect information for the construction and design of the GIS database. This assisted in identifying the best way to access, the best orientation for the site, and the location of any obstacles

b) Area Selection

The first step in mapping was to specify an area to work on. The objective of the selection is to choose a site that can demonstrate the full capabilities of the GIS model in a distribution network, in a bid to increase revenue and identify all existing customers (both billed and unbilled). To carry out this project, the following were considered in the selection of the study area;

- The economic feasibility of the project
- The economic impact assessment
- The availability of secondary data for load profile and customers information
- The location of transmission stations and injection stations
- Environmental Considerations for Field Mapping
- Network Structure

Ikeja Government Residential Area (GRA) was selected for this purpose not only to demonstrate the full capabilities of the GIS model in a distribution network but also due to the relative ease of access, location of the area, and recent technical improvements in the region which has resulted in the ability to direct more power towards this vicinity.

Ikeja GRA, shown in Figure 2, comes under the Ikeja Local Government Area (LGA). Ikeja is the capital city located in the North West of Lagos State and a local government in the Lagos Mainland part of Nigeria. On its grounds lay the Murtala Muhammed Airport one (1) and two (2) (both domestic and international airports). Over time, Ikeja has morphed into a prime commercial and industrial city like other Local Governments in Lagos state. Several manufacturing companies have their factories/head offices in Ikeja. Ikeja Districts include Agidingbi, Alausa, Magodo, Maryland, Ogba, Ojodu, Opebi, Oregun, and the Government Reserved Area of Ikeja (Ikeja GRA). Given this review, we will focus on Ikeja GRA.

Ikeja GRA shares the state's general climate and weather conditions of Lagos, which has a tropical wet and dry climate with two distinct rainy seasons. The more intense season occurs between April and July, with a milder one from October to November. At the peak of the rainy seasons, the weather in Lagos is wet about half the time while the dry season which is between December to March is accompanied by harmattan winds from the Sahara Desert, which is at its strongest from December to early February. The temperature range is small, generally staying between a high of 33°C and a low of 21°C. The hottest month is March, when the average daytime temperature reaches 29°C, while July is the coldest month with an average temperature of 25°C.

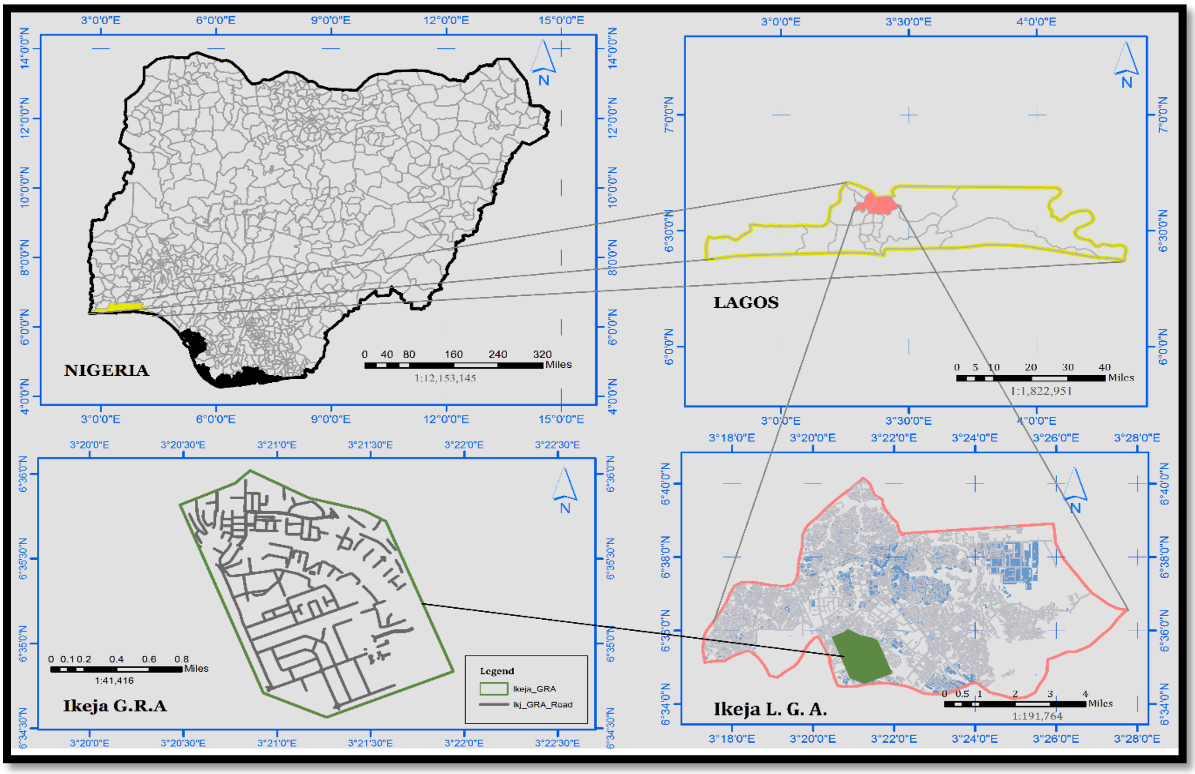

Figure 2: Study Area (Ikeja Government Residential Area (GRA))

Ikeja GRA, a posh residential locale, is situated between latitude 6.566511 to 6.593802 and longitude 3.337838 to 3.362835. Ikeja GRA is 4.85 sq km, and it is fully electrified by Ikeja Electric Plc (IE). Ikeja Electricity Distribution Company (IKEDC) Plc was officially handed over to New Electricity Distribution Company (NEDC), the preferred bidders, on November 1, 2013, by the Bureau of Public Enterprises (BPE) as part of the Federal Government's power sector privatization program. In 2015, the company changed its name from Ikeja Electricity Distribution Company (IKEDC) to Ikeja Electric PLC (IE) in line with the organization's commitment to creating a more dynamic brand focused on quality service delivery [9].

Ikeja Electric Plc is Nigeria's largest power distribution network; and serves over 700,000 registered customers predominantly within the mainland areas of Lagos State and some parts of Ogun State recorded to have consumed over 3,000 Gigawatt hours (GWh) of electricity in 2018. The network spans over 16,000sq. kilometers (km) route length of overhead and underground lines, over 14,000 distribution Transformers (of over 3500 MVA capacity), and 65 Injection Substations (of over 2000 MVA capacity) [10]. The network profile is explained below:

Table 1: Ikeja Electric's Network Profile

S/N	Description	Unit	Value
1	Projected Avg. Net Generation	MW	4,256
2	Actual Avg. Net Generation	MW	3,478
3	Maximum demand	MW	1,330
4	Load Based on Projected Generation	MW	687
5	15% Based on Actual Net Generation	MW	522
6	Avg. Actual Load Received	MW	464
7	TCN Capacity in IE	MVA	2,375
8	Injection S/S Capacity	MVA	2,115
9	Distribution S/S Capacity	MVA	3,953
10	Overloaded Feeders	#	110
11	Overloaded Distribution Transformers	#	599

IE powers five (5) feeders in the Ikeja GRA locality comprising 352 DTs (254 private DTs and 98 public DTs), and 1985 unique customers which were considered in this study.

The next step was to identify the assets as well as customers that will be mapped in the area of study. Figure 3 displays the surveyed assets that evacuated the power supply to Ikeja GRA and the customers within these areas that were visited. These include Transmission Substations (132kV/33kV), High Tension Poles and Lines (HTP/L) 33kV, Distribution Substation (DSS) 33kV, Injection Substations (ISS), High Tension Poles and Lines (HTP/L) 11kV, Distribution Substation (DSS) 11kV, Low Tension Pole and Lines (LTP) 11kV/ 33kV, Building (BLDG) 11kV/ 33kV and Customers (CUSTOMER) 11kV/ 33kV.

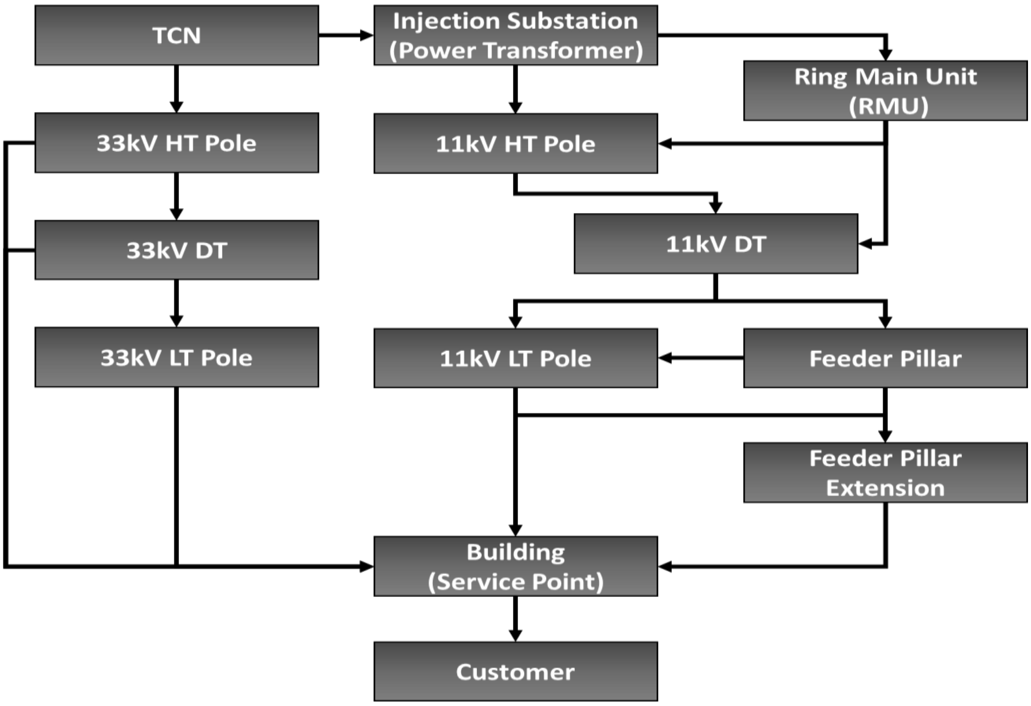

Figure 3: Asset and Customer Study

2. Database Design and Development Phase

During the database design and development phase, the database was designed and developed for the research. Firstly, a standards-compliant data and metadata definition on ArcGIS using the geodatabase and features class with the WGS_1984_UTM_Zone_31N coordinate system was built. Figure 4 shows the GIS database constructed for this research while Table 2 shows these coordinates as compiled into the GIS database using the WGS_1984_UTM_Zone_31N coordinate system.

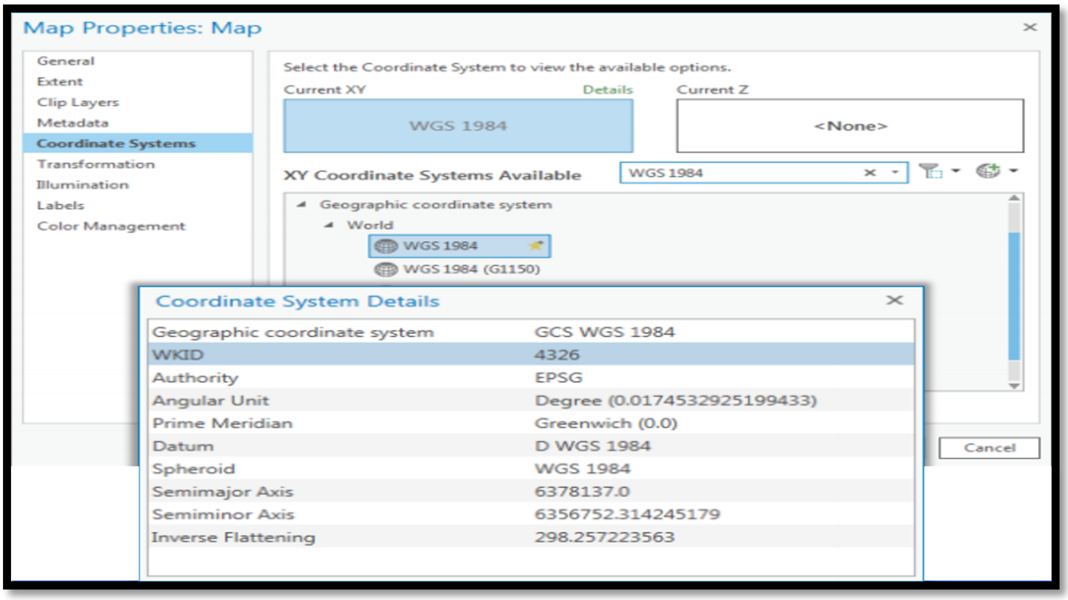

Figure 4: Projected Coordinate System

Table 2: Ikeja Electric's Network Profile

S/N	Description	Input
1	**Projected Coordinate System**	WGS_1984_UTM_Zone_31N
2	**Projection**	Transverse_Mercator
3	**Linear Unit**	Meter
4	**Geographic Coordinate System**	GCS_WGS_1984
5	**Datum**	Oblate spheroid (D_WGS_1984)
6	**Angular Unit**	Degree WGS 1984 UTM zone 31N.

Figure 5 exemplifies the template used for the asset and customer data uploaded into the GIS database to capture all the base map attributes. The relationship between these assets and customers will provide the geographic Information for Ikeja GRA.

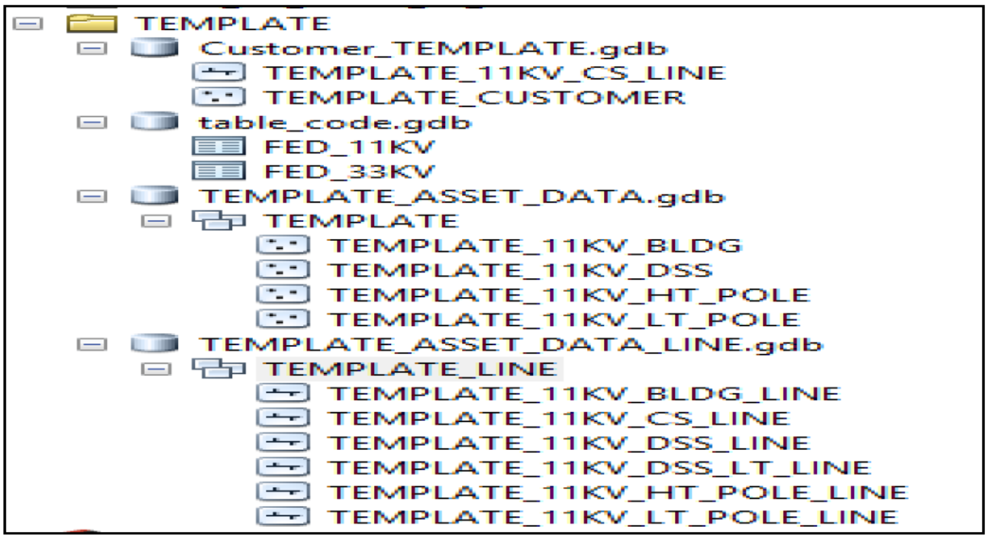

Figure 5: Template for all Assets and Customer Data

3. Data Acquisition & Collection Phase

The data acquisition began with the physical phenomenon to be measured. The first step in the methodology of this work was the collection of the required data from the study area. In this case, there were two types of GIS data involved which included: spatial and non-spatial data.

GIS Datasets

a. **Spatial data:** This explains all data that describes the location, that is geographic data that possesses coordinates. The spatial data used for the research study includes;

i. **Base Map:** The digitized building footprint, and base maps derived from satellite or aerial imagery (raster data) are acquired. Figure 6 shows the base map which consists of roads, buildings, facilities, and other points of interest digitized from High-Resolution Image data, this was gotten from the open-source street map on ArcGIS using Google Maps. The base map consists of roads, buildings, facilities, and other points of interest digitized from a High-Resolution Image data

ii.

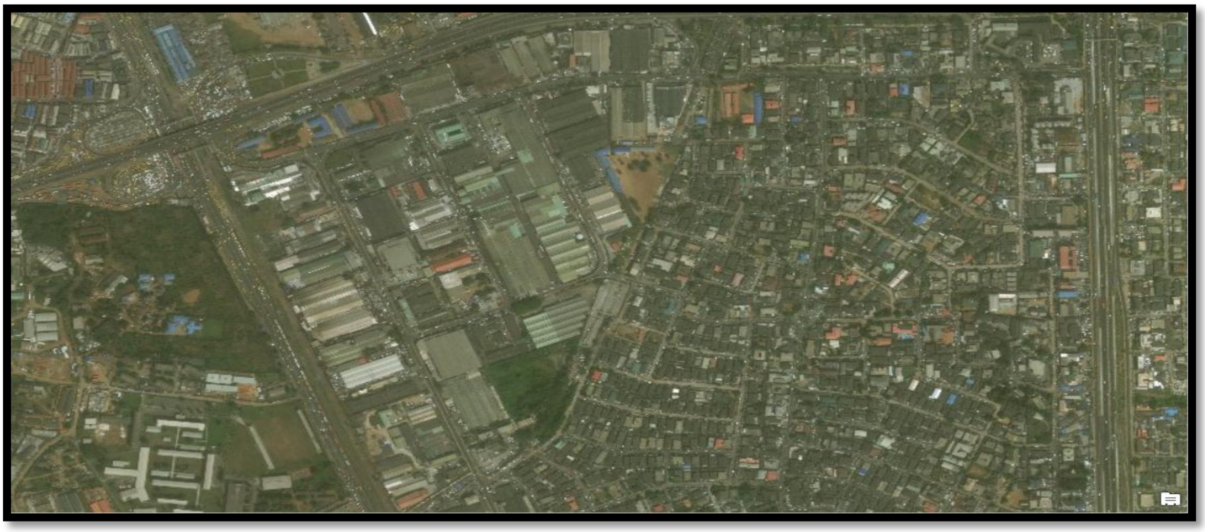

Figure 6: Base Map of Area

iii. **GPS Data:** GPS coordinates of Ikeja Electric's facilities (Poles, Transformers) for the area of study were acquired using a Handheld GPS device (Trimble ArcPad Juno 3D). Figure 7 demonstrates the survey of electrical assets done by Trimble ArcPad Juno 3D to allow unique ID and get the exact latitude (X) and longitude (Y) of each electrical asset.

Figure 7: Trimble ArcPad Juno 3D

b. **Non-spatial data:** The non-spatial data includes information acquired from Ikeja Electric's facilities, infrastructure, and customer information. This is also known as attributes. Figure 8 shows an example of a field mapping mobile (Android) application called Collector for ArcGIS used to capture customers. The different attributes comprise the following;

i. **Consumer Attributes:** Meter number, account number, address of the consumer, building, the line transmission pole/pillar to which a consumer is connected.

ii. **Network Asset Attributes:** 33/11/0.415kV poles, conductor type, route length, conductor sizes, distribution substation (DSS) transformers, parameters of the equipment, feeder pillars, poles, pole supports, and low voltage distribution systems.

iii. **Transformer Attributes:** The details about transformers and other related facilities as indicated on the transformer nameplate.

The captured information will allow for the auto-generation of index numbers and the construction of tables, figures, and maps. This will facilitate all analysis and visualization of patterns and relationships in the study area.

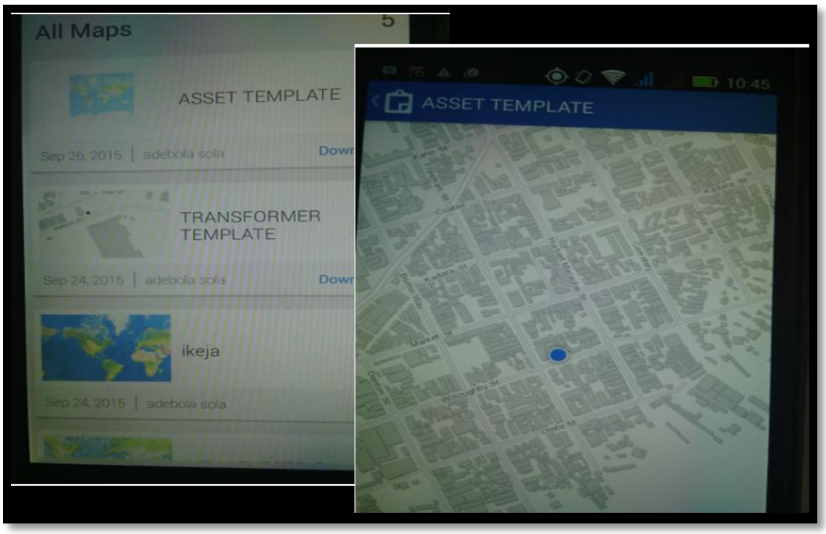

Figure 8: Collector for ArcGIS on Android Phone

The combination of the base maps, GPS data (coordinates), and attributes provide the representation of the Ikeja GRA infrastructures, assets, and customers, which would be displayed on the ArcGIS software and used for further data analysis.

1. Mapping of Electricity Distribution Network Assets and Customers

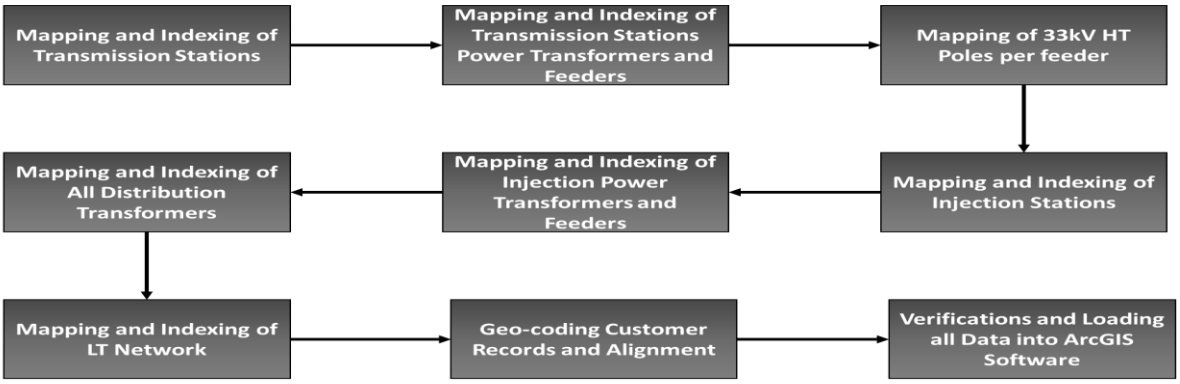

Figure 9: Collector for ArcGIS on Android Phone

Figure 9 above shows the mapping of assets and customer workflow for this research after the GPS data, base maps, and attributes have been identified and captured.

Mapping Work Process

- Mapping of Transmission Stations
- Mapping of radiating 33kV feeder poles
- Mapping of injection Stations on 33kV feeder lines
- Mapping and 11kV feeder poles
- Mapping of Distribution Transformers on 33kV and 11kV feeder lines
- Mapping of LT network.
- Indexing for the electrical sub-transmission and distribution network was developed.
- Each of the elements like 33kV and 11kV feeders, feeder branches, and transformers were uniquely indexed with defined relationships based on the normal mode of feeding envisaged
- Network documentation is required to have the Electrical address and feeding arrangement of localities and consumers for carrying out Energy Accounting and maintenance of supply.
- Coded asset data if sub-transmission and distribution networks of the circle were to be delivered sub-division-wise. The coding shall be such that any addition/modifications to the network can be assigned codification without any difficulty
- Based on the details of the network available, with the circles, divisions, and sub-divisions, pole-to-pole surveys of 33kV, 11kV, and LT Lines existing in the study area, and distribution network from 11kV and 33kV to LT systems were developed
- The sub-transmission and distribution network indicating details of feeders and stations were developed and superimposed on a geographical map using ArcGIS such that the physical position of the lines, and substations is known on the Map.
- During the survey of lines, the line parameters and conductor sizes were documented and the interconnections between sections were also compiled and marked.
- The documentation, indexing, and coding for the various elements of the network such as 33kV feeders, 33/11kV substations, 33/11kV Transformer,11kV feeders, and Distribution Transformers were to be carried out in such a way that it would be possible to relate the locate:
- The location of the network concerning the geographical area of the division and subdivision
- The location of 33/11kV substation and related feeders
- The main road, branch roads, and the lanes through which the feeder lines pass.
- If data is null, a snapshot photo must be attached to prove that the data is null.
- The Customer Enumeration and mapping of all customers on the 33/11kV to 11/0.415kV voltage level, this involves the identification of both legal and illegal customers within the Network. A customer index number is generated to identify clusters of customers feeding from a particular power distribution asset. The main objective of CIN is to enhance the efficiency of distribution in terms of increased power allocation, reduced outages as well as technical and commercial losses.

All these coordinates (infrastructures and customers were demonstrated in Figure 12 below.

Table 3a: Customer and Asset Index Number

D No	SUB D No	SUP TYPE	ISS	PT	FDR	HT PID	DT ID	UP ID	LT PID	SW ID	C ID
06	03	1	032	1	02	0189	01	1	005	01	001

Table 3b: Index Number Description

Abbreviation	Meaning
Disco No	Distribution Company Number
Sub D No	Sub Distribution Company Number (Undertaking)
Sup type	Supply Type
ISS	Injection Substation
PT	Power Transformer
FDR	Feeder
HT PID	High Tension Pole Identification
DT ID	Distribution Transformer Identification

Abbreviation	Meaning
UP ID	Upriser Identification
LT P ID	Low Tension Pole Identification
SW ID	Service Wire Identification
C ID	Customer Identification

Source: (Researcher, 2018)

The CIN, therefore, references each customer by the assets responsible for the customer's power supply. The Network documentation on ArcGIS was developed to have the facility for tracing the electrical connectivity for any part of the network. That is, it is possible to find out all the elements electrically connected to any particular line or transformer with distinguishing points marked. This is what was used to verify together with the billing information gotten from the Customer Information System (CIS) the customers that are billed and those unbilled.

2. Identification of Billed Consumers

GIS was used in combination with the CIS, to solve the problem of unbilled customers – consumers connected to the Ikeja GRA network but still do not pay for their energy consumed. The billing data was queried using the CIS to retrieve the billing information of all customers within the study area. The CIS customer query functionality supports quick inquiry of customer information, including account number, customer name, tariff class, tariff, amount of energy consumed, the last date of payment, customer category, contact phone, creation time, power utilization, payment type, etc. By logging in to the CIS, it is possible to generate a customer query from the customer relationship management menu. The export button allows you to export customer information in an Excel format according to the query to be able to see all paying customers in Ikeja Electric. After the billing data has been downloaded, it is then imported to ArcGIS and converted to a table, that can be analyzed in ArcGIS. Following that the CIN is used to visualize all billed customers in the ArcGIS software. Figure 13 displays the process after downloading the table from CIS and opening it in the ArcGIS software, to convert it to a data table readable in ArcGIS.

Figure 12: Customer Information System (CIS) Platform

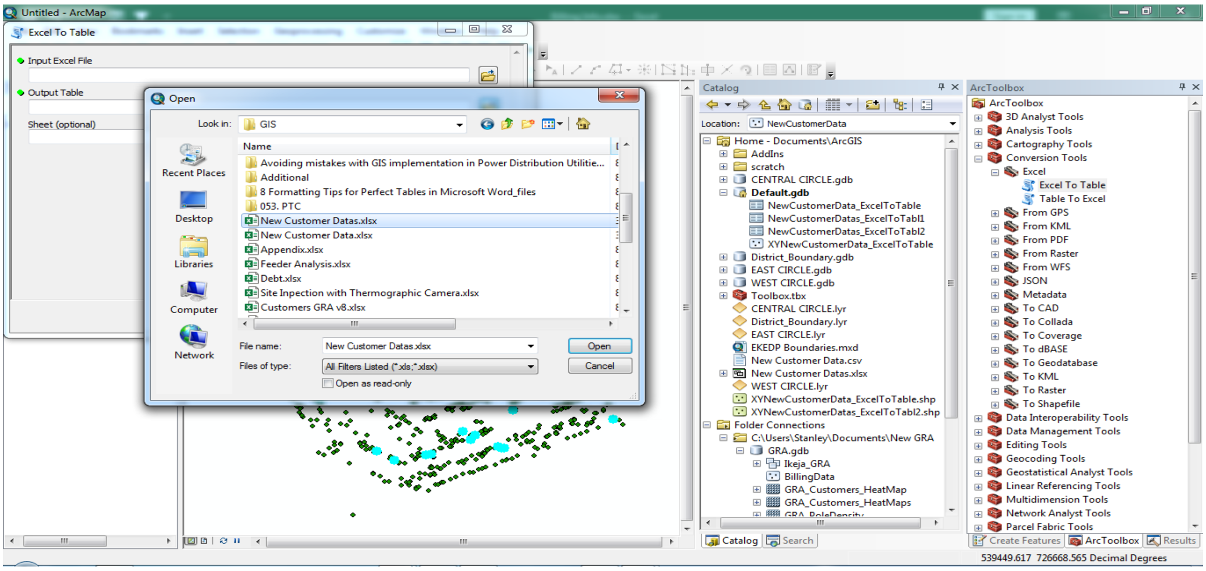

Figure 13: Conversion of Excel to ArcGIS Table

3. Comparison of Billed Customers and GIS-captured Consumers

This comparative analysis identified the geo-coded consumer connection points without any billing data attached to them, that is the customers captured or mapped on-site versus the customers found in the billing data. The implication of this is that the identified customers without any billing information are a potential consumption point with is not accounted for in the utility company's energy accounting and billing records. By cross-checking these customers and building points from the GIS with the billing information from the CIS we can identify all unbilled consumers at that service connection point. The Excel exported file for both reports is then analyzed and imported to the GIS software to ascertain the exact location of the customers that are not captured in the billing data and consequently not making payments for electricity. The Join and Relate feature combines the two datasets to find out the matching records. Consequently, the records that match identify the customers that are billed and captured by GIS while the unmatched records show the customers that are unbilled and are captured by the GIS system. Figure 14 illustrates the creation of a join between these two datasets, i.e., if a record in the GIS data doesn't have a match in the billing data after performing the join, that record is given null values which indicate those customers that are currently unbilled.

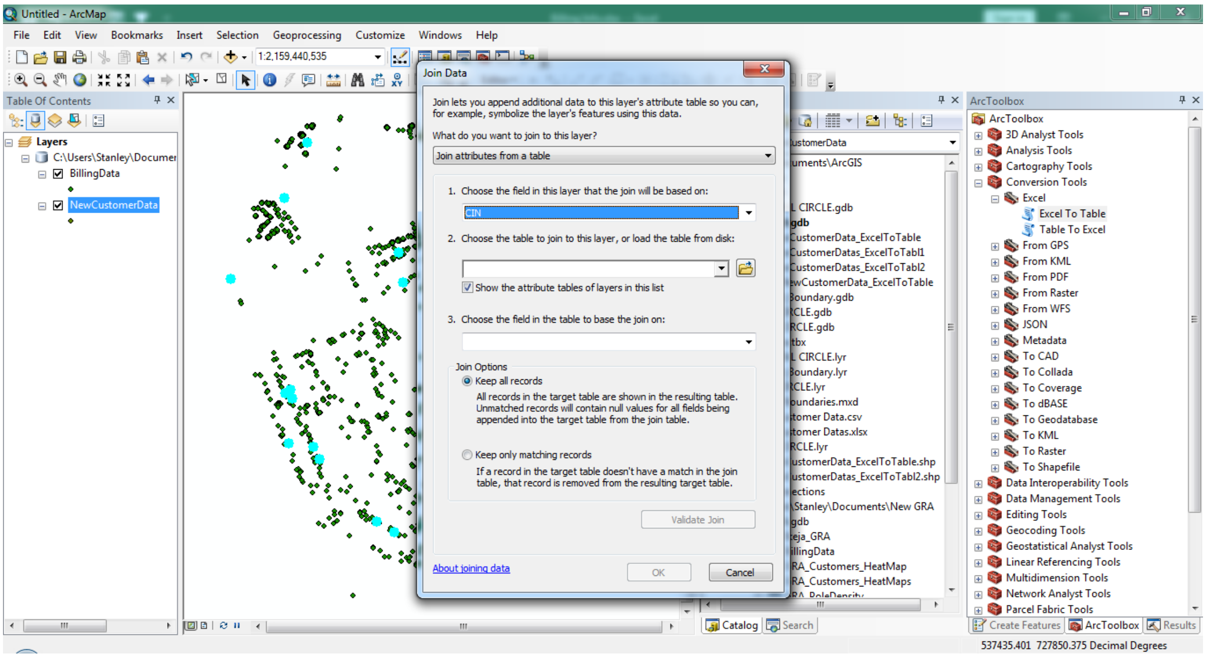

Figure 14: Join and Relations to compare Billing and GIS Data

4. Data Verification

The data is verified firstly through a site visit and then by conducting a Quality Assurance/Quality Control (QA/QC) check. Figure 10 illustrates the entire Quality Assurance/Quality Control (QA/QC) check and analysis performed for this project.

- **Verification through site inspection:** Revisit the site to check if there are any inconsistencies between collected data and field status (Random Check). Unless passed, a revisit is executed to get the correct data.
- **All captured data are downloaded for Quality Assurance/Quality Control (QA/QC) checks and analysis** i.e., the asset information from the Trimble Juno 3D and the customer data from the Android phone. After which the data is published in ArcGIS online. This RAW DATA (*.gdb) will be forwarded for QA/QC Data Verification highlighted in yellow below.

The QA/QC subjects the data captured into 5 stages of verification before acceptance. Stages include:

- **Physical Check** – Check on Null Values, Unnecessary Spaces between Data, Improper Information inputted, etc.
- **Logical Check** – Check on Logical Values and Corresponding Values.
- **Geometry Check** – Check on Geometry Attributes (Duplicate Object, Long / Wrong Connection between Objects, Geometry Location).
- **System Check** – After clearing the Physical and Geometry Check it will be forwarded to Converting Field Names (Blue). From RAW format Field Names, it will be converted to Field Name format that will be Submitted as FINAL VERIFIED DATA.
- **End User's Check** – Generating CIN Number is done after the Field Names and Data are converted (Blue).

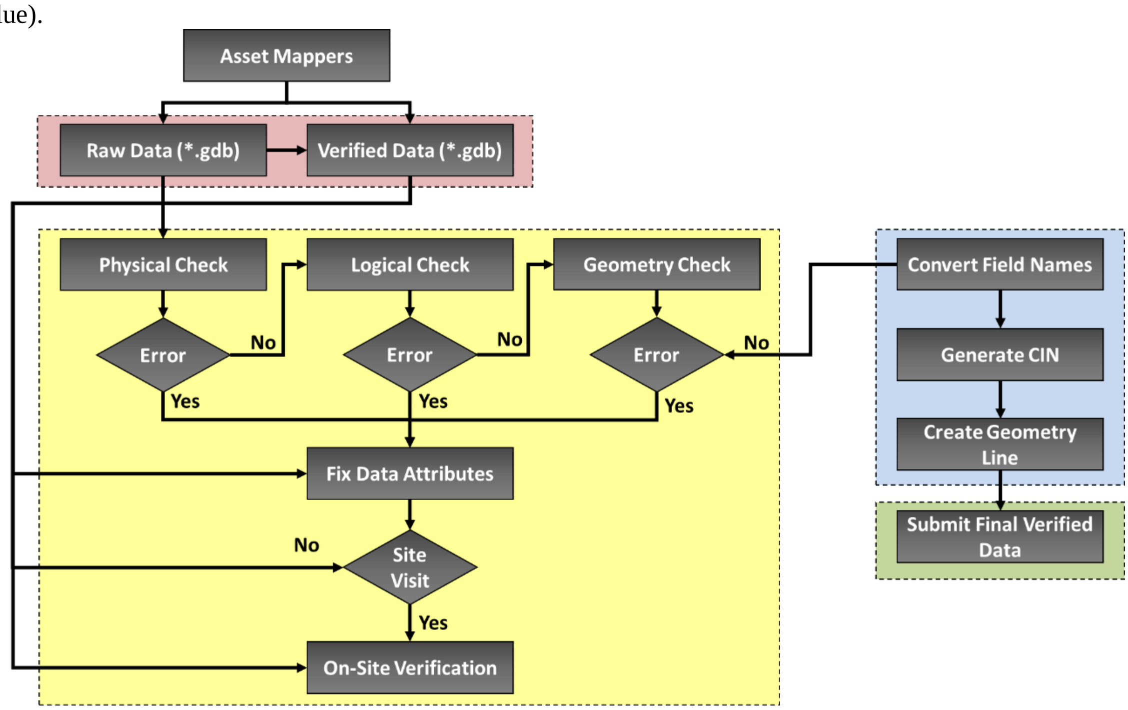

Figure 10: Data Processing and Verification

Data Processing and Verification help data to be;

- Correct information for physical and logical data for mapped assets.
- Accurate Data Connection between objects through Geometry Checking.

These should be observed in the generation of CIN in which the line geometry will be created after the CIN Number is generated. The final verified data is ready for submission and implementation.

The Network documentation on ArcGIS was developed to have the facility for tracing the electrical connectivity for any part of the network. That is, it is possible to find out all the elements electrically connected to any particular line or transformer with distinguishing points marked. These data are then uploaded to the ArcGIS Desktop software for spatial data storing, manipulating, analysis, displaying, and querying.

5. **Data Analysis Phase**

Geospatial analysis was carried out by the use of both hardware and software to perform various spatial data processes during the project execution such as; data acquisition, management, analysis, and presentation of information. The instruments used in the actualization of the research objectives can be classified into three (3);

A. Hardware
B. Software
C. Human ware

a) **Hardware:** there are several hardware that was utilized in this research, this includes;

- HP Intel Pentium Laptop with 2.5GHZ processor with 350GB hard drive and 8GB RAM.
- External or transferable device such as USB Flash Drive, CD/DVD Reader, or writer.
- HP DesignJet T7200 42 Production Printer (A0 Paper Size)
- Kyocera TASKalfa 3051ci KK A3/A4 Color Printer/Scanner/Copier/Fax Machine.
- Handheld GPS device (Juno Trimble 3D)
- Android Collector tab and phone
- Hard drive
- Mouse

b) **Software:** the software used includes;

- Microsoft Office packages such as Microsoft Word, Microsoft Excel, and note pad.
- Window 7 Professional Operating System.
- ArcGIS/ArcMap 10.4 by ESRI
- GPS Pathfinder office software

c) **Human ware**: this is the researcher involved in this study

- **Importing all data points and creating a Feature Class**

Spatial and attribute data were imported into the ArcGIS environment. Figure 11 explains how the GIS data captured in the field were imported to the ArcGIS environment using the Arc Toolbox. The projection was set to "WGS 1984" for each of the feature classes defined following a "Batch projection" of all feature classes projected to "WGS_1984_UTM_Zone_31N" to more accurately represent locations of the assets on the earth's surface. A satellite image of the study area was overlaid alongside the feature classes collected during the field survey and vectorized to obtain a base map, highlighting geographical features such as; (LG Boundary, Roads & Buildings) to best describe the area. Further alignment on the asset captured was done using Google Maps.

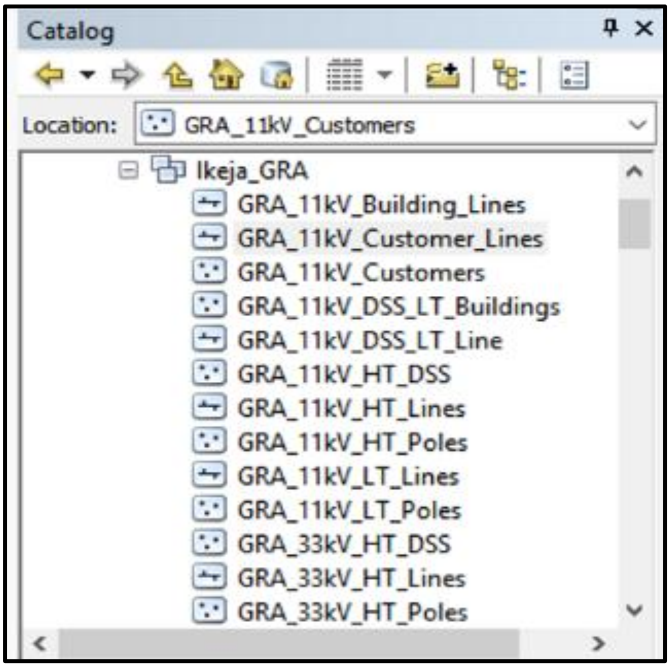

Figure 11: Importing data into ArcGIS

III. RESULTS

a. NETWORK ASSET AND CUSTOMER MAPPING OF STUDY AREA

In a general view of Ikeja GRA asset and customer mapping, different categories of network infrastructures were evaluated and captured to ascertain the whole geographic area of the locations. It is also important to have a holistic view of the entire network you need to see it on GIS. These are represented below in Figure 12a which shows ArcGIS assets that supply to customers within Ikeja GRA by Ikeja Electric while Figure 12b shows the legends for electrical asset map interpretation.

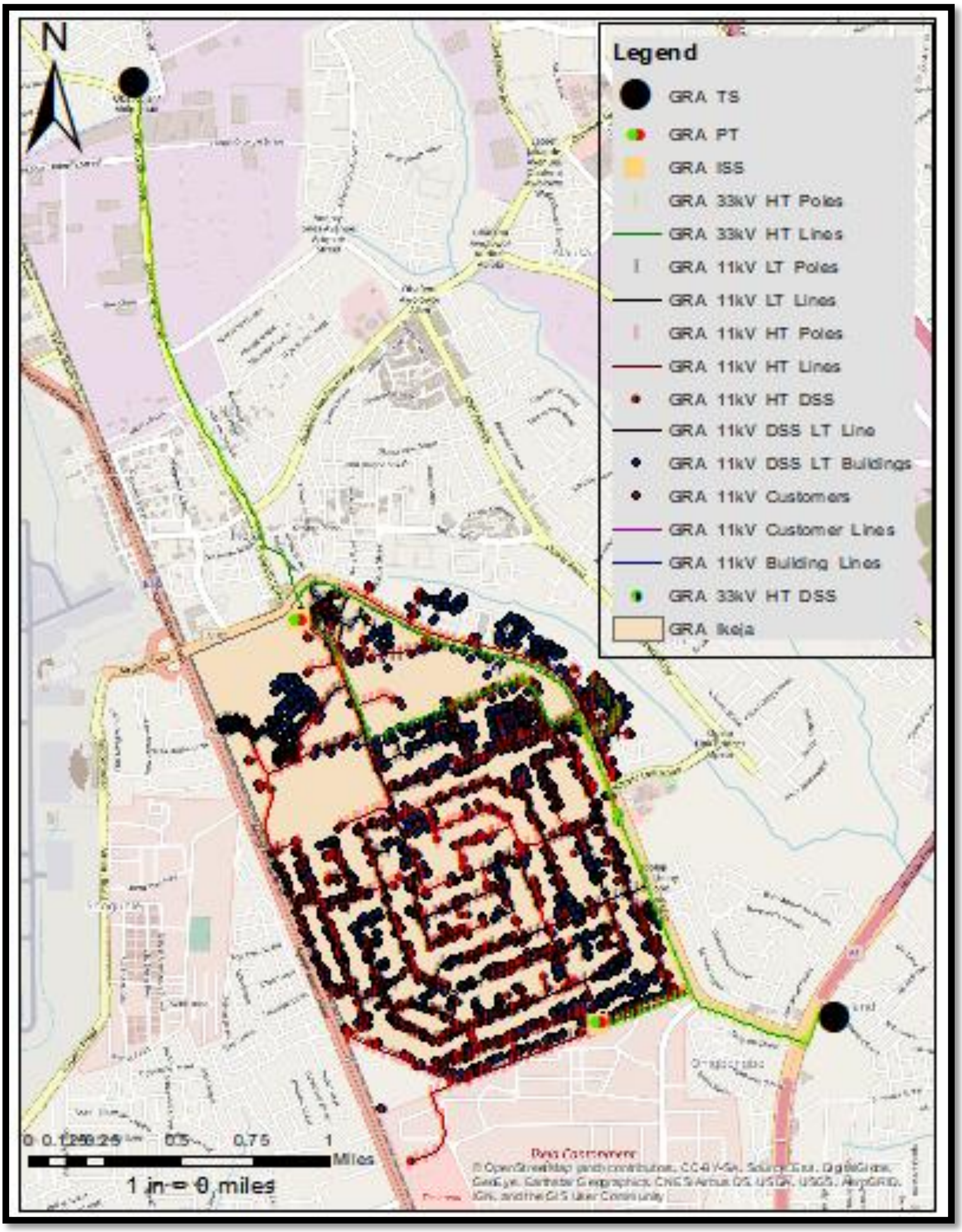

Figure 12(a): Ikeja GRA assets and customers in ArcGIS Software

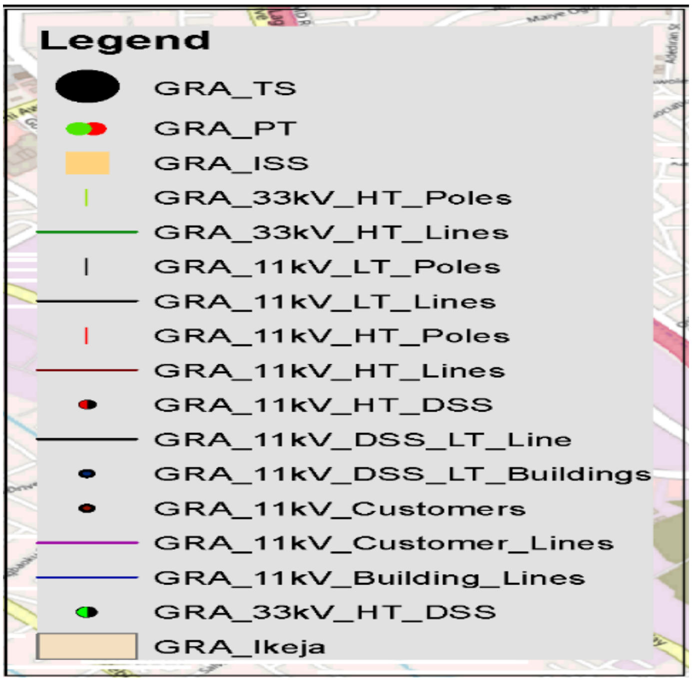

Figure 12(b): Ikeja GRA assets and customers in ArcGIS Software Legend

Tables 4 – 9 were derived from the GIS geodatabase information as seen in Figure 12. After the coordinates were captured the breakdown of the different asset levels can be seen in the table. This makes it possible to compare what is currently on the ground (in reality) with the information in the GIS system as well as for easy updates.

- Table 4: Elaborates all captured coordinates (assets and customers)
- Table 5: Explains the Transmission Stations and the feeders emanating from them
- Table 6: Describes the 33kV feeders providing power injection Substations within Ikeja GRA
- Table 7: Highlights the Injection Substations and the feeders emanating from them.
- Table 8: Underlines the 11kV feeders supplying power to the customer's distribution transformers.
- Table 9: Emphasizes the customers that are supplied electricity and are connected to all assets

Table 4: Breakdown of Electrical Assets in Study Area

S/N	Description	Comments
1	Transmission Substations (132kV/33kV)	Maryland Transmission Station Ogba Transmission Station
2	High Tension Poles and Feeders (HTP/L) 33kV	PTC Express Maryland PTC Maryland Ajegunle
3	Distribution Substation (DSS) 33/11kV (Private and Public)	33kV Feeders Distribution Substation
4	Injection Substations (ISS)	PTC Injection Substation Adekunle Fajuyi Injection Substation
5	High Tension Poles and Lines (HTP/L) 11kV	Opebi Awuse/Mafoluku General Hospital Isaac John Oba Akinjobi
6	Low Tension Pole and Lines (LTP) 11kV/ 33kV	33/11kV Feeders Low Tension Poles and Distribution Lines
7	Building (BLDG) 11kV/ 33kV	Customer's Buildings
8	Customers (CUSTOMER) 11kV/ 33kV	Customer's Service Point

1. Transmission Station

Table 5: Transmission Stations

S/N	NAMES	PT*	FEEDERS	FEEDER NAMES (33kV)	VOLTAGE RATIO	LATITUDE	LONGITUDE
1	Maryland TS	2X30MVA 1X60MVA	2	T1 (Ajegunle, PTC)	132/33kV	3.335615	6.618082
2	Ogba TS	3X60MVA 1X45MVA	1	T2 (PTC Express)	132/33kV 132/33/11kV	3.369378	6.572815

***PT = Power Transformer**

2. 33kV High Tension Poles and Feeders

Table 6: 33kV Poles and Feeders

Transmission Stations	Maryland		Ogba
Feeders	**Maryland Ajegunle**	**Maryland PTC**	**PTC Express**
33kV Feeders/Lines (#)	1	1	1
33kV Poles (#)	58	116	134
Distribution Substations (#)	0	3	0
33kV Feeder Route Length (km)	2.5412	5.0636	5.2675

Figure 13a indicates the GIS coordinates for the transmission stations, power transformers, and 33kV lines and poles. Figure 13b shows the legends for electrical asset map interpretation.

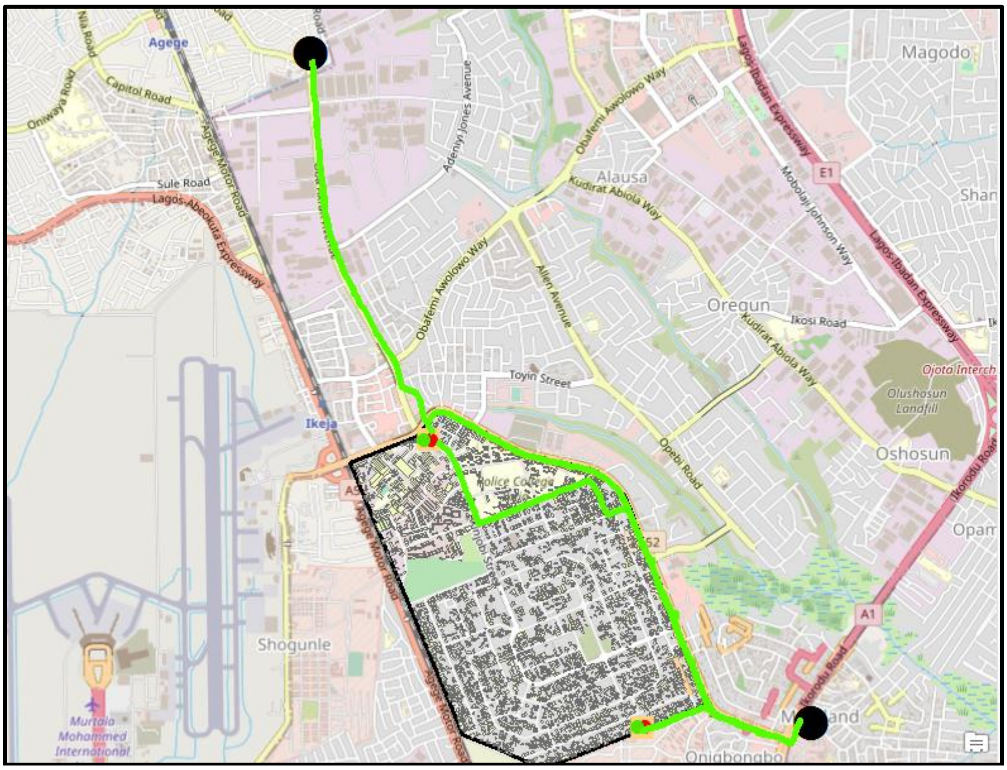

Figure 13(a): Transmission Stations, Injection Substations and 33kV Poles and Lines

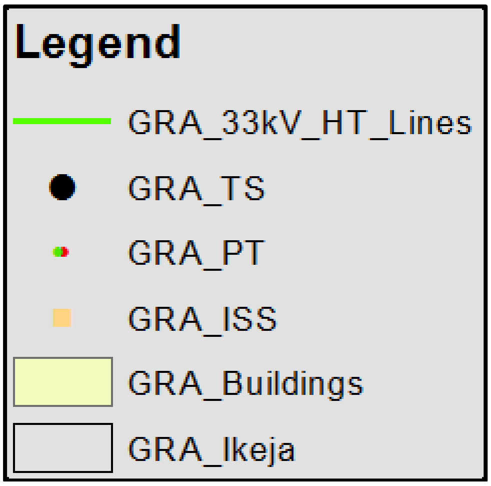

Figure 13(b): Transmission Stations, Injection Substations and 33kV Poles and Lines Legend

3. Injection Substation

Table 7: Injection Substations

S/N	NAMES	PT	FEEDERS	FEEDER NAMES (11kV)	VOLTAGE RATIO	LAT	LONG
1	Adekunle Fajuyi Inj.SS	1X15MVA	1	T1 (Isaac John)	33/11kV	3.357835	6.572437
2	PTC Inj.SS	2X15MVA, 1X7.5MVA	4	T1 (Opebi), T2 (Awuse), T3 (Oba Akinjobi, General Hospital)	33/11kV	3.343493	6.591891

4. 11kV Poles and Feeders (HT and LT)

Table 8: 11kV Poles and Feeders (HT and LT)

Injection Stations	Adekunle Fajuyi	PTC			
Feeders	**Isaac John**	**Awuse**	**Gen. Hosp.**	**Oba Akinjobi**	**Opebi**
11kV Feeders/Lines (#)	1	1	1	1	1
11kV Poles (#)	206	170	344	291	73
11kV Feeder Route Length (km)	6.4662	10.5821	10.7298	8.7055	2.7557
Distribution Substations (#)	69	54	105	115	13
LT Poles (#)	113	209	440	194	131
LT Lines Route Length (km)	0	6.1119	10.0360	9.5378	1.4688

Figure 14a indicates the GIS coordinates for the Injection substations, power transformers, and 11kV lines, poles, and distribution transformers. Figure 14b shows the legends for electrical asset map interpretation.

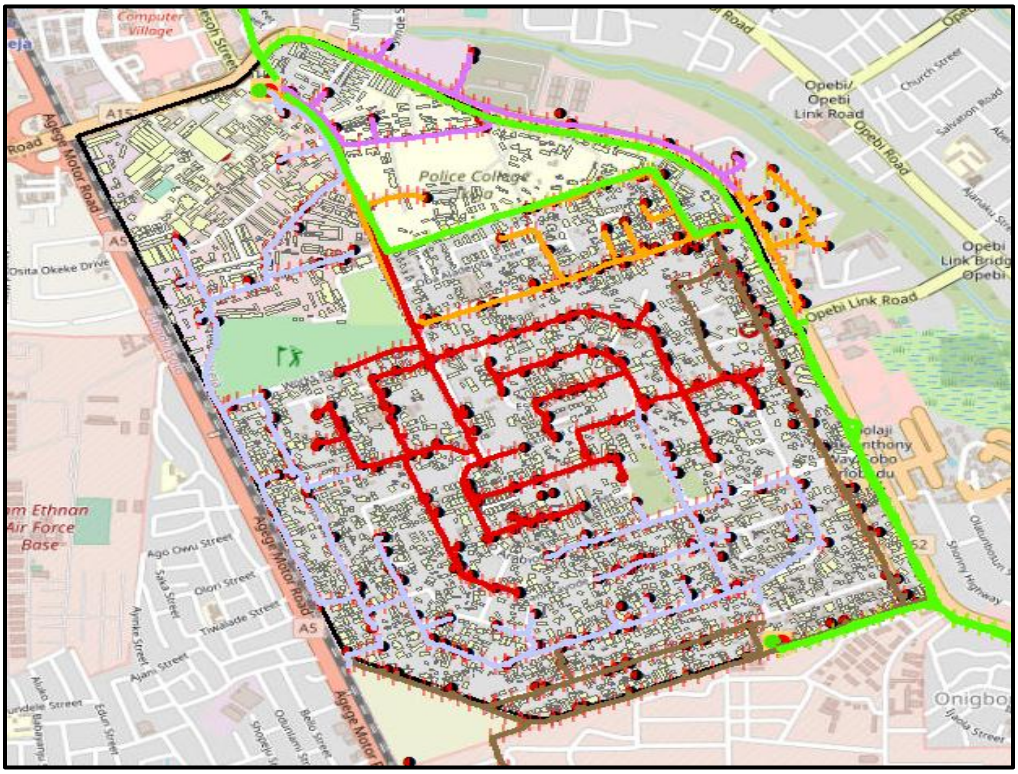

Figure 14(a): 11kV Poles and Lines and 33/11kV Distribution Transformers

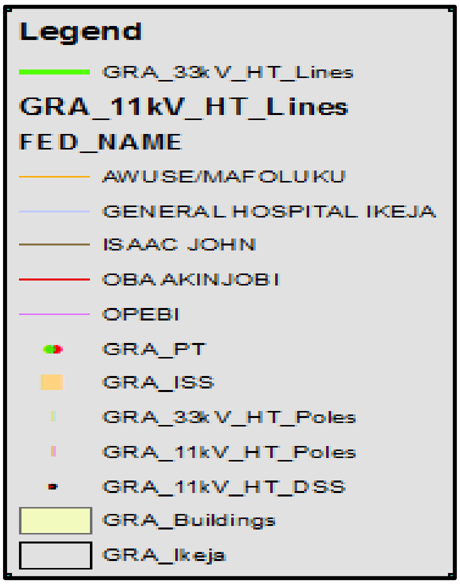

Figure 14(b): 11kV Poles and Lines and 33/11kV Distribution Transformers Legend

5. Customer Mapping and Enumeration

Table 9: Customer Mapping and Enumeration

Injection Stations	Adekunle Fajuyi	PTC			
Feeders	**Isaac John**	**Awuse**	**Gen. Hosp.**	**Oba Akinjobi**	**Opebi**
11kV Feeders/Lines (#)	1	1	1	1	1
11kV Poles (#)	206	170	344	291	73
11kV Feeder Route Length (km)	6.4662	10.5821	10.7298	8.7055	2.7557
Distribution Substations (#)	69	54	105	115	13

Injection Stations	Adekunle Fajuyi	PTC			
Feeders	**Isaac John**	**Awuse**	**Gen. Hosp.**	**Oba Akinjobi**	**Opebi**
LT Poles (#)	113	209	440	194	131
LT Lines Route Length (km)	0	6.1119	10.0360	9.5378	1.4688
Buildings (#)	150	281	568	216	140
Customers (#)	152	507	667	286	373

Figure 15a indicates the GIS coordinates for the customer locations and buildings. Figure 15b shows the legends for electrical asset map interpretation.

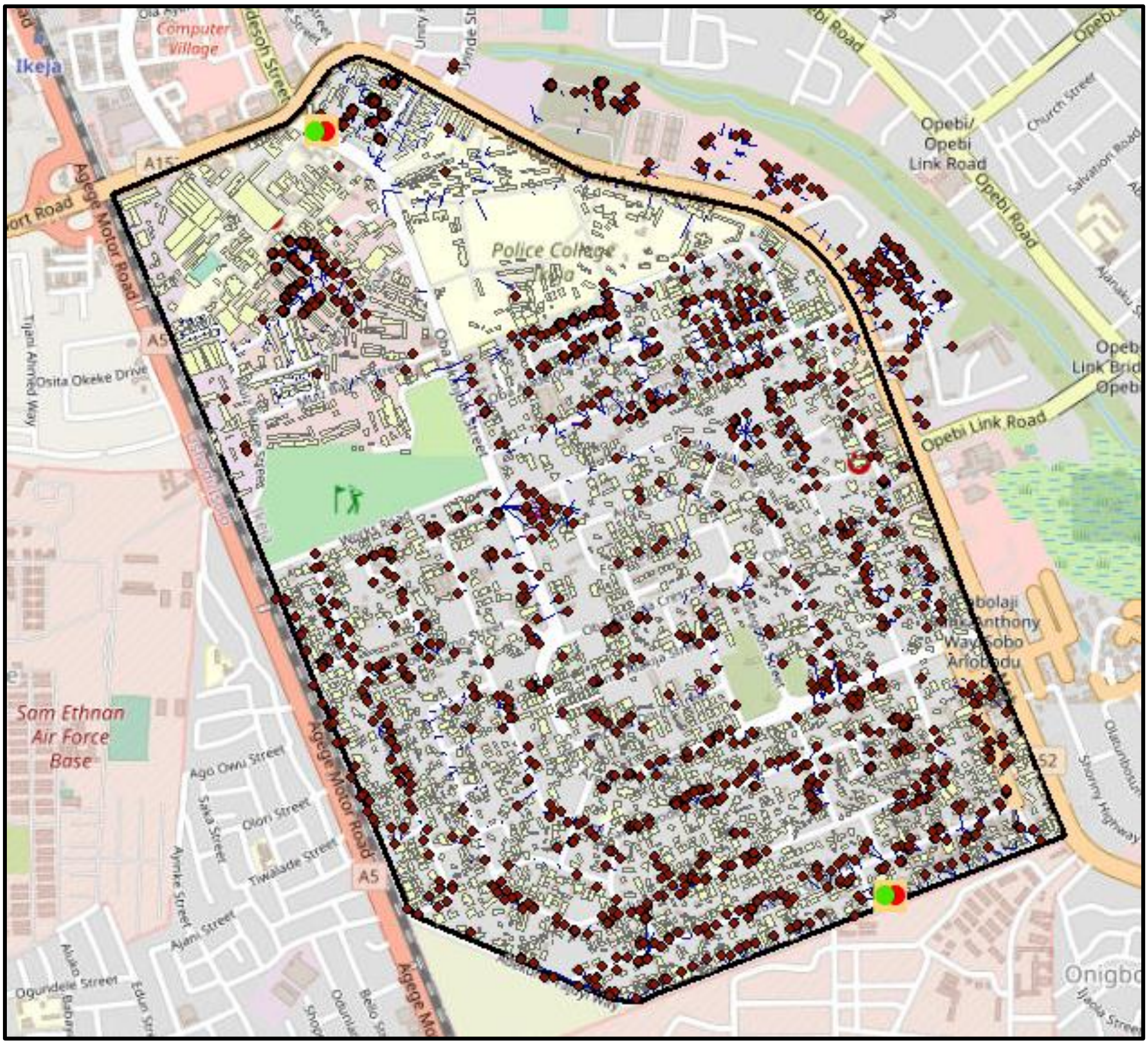

Figure 15(a): Ikeja GRA Buildings and Customers

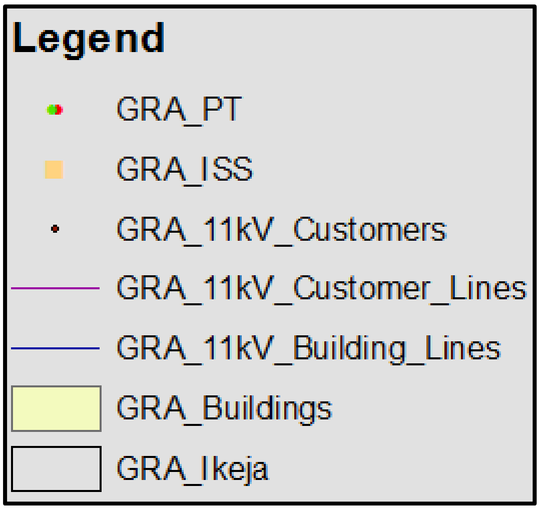

Figure 15(b): Ikeja GRA Buildings and Customers Legend (Electrical Asset Map Interpretation)

b. IDENTIFICATION OF BILLED CUSTOMERS

The customers billed were exported from the CIS database and can be seen that not all the customers in the study area have been captured for billing. It was observed from the qualitative data that 1757 customers are currently been billed in the system by IE. The identified customers without matching records were highlighted after using the CIN number as a common unique identifier between the two datasets. When subjected to further investigations the difference between the 1985 consumers connected to the grid and the 1757 customers that pay monthly for power supply, equates to a total of 228 customers discovered to be unbilled customers (free riders and/or energy thieves). Figure 16 exemplifies the CRM login page for spooling the monthly billing data on the CIS platform.

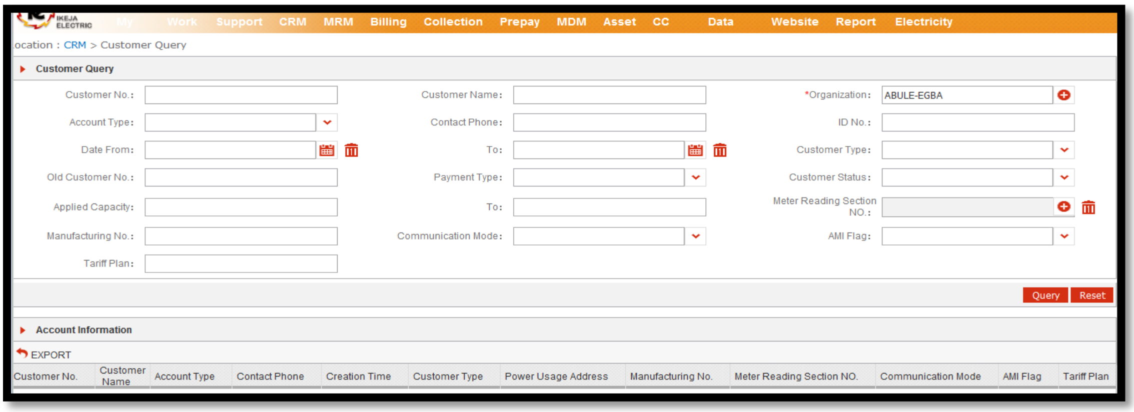

Figure 16: Billing Information Customer Query

Figure 17 shows a sample of billing information containing 1757 customers in Ikeja GRA spooled from the CIS platform paying for power supply. Figure 18a indicates the Billed customers as displayed on the ArcGIS platform whereas Figure 18b shows the legends for electrical asset map interpretation. Figure 19 shows the 228 customers without matching records in the ArcGIS platform after they were related to the billing data from the CIS to indicate the unbilled customers that were not captured originally in the billing dataset.

BU	UT	Account No.	Service Address	Tariff	Account Status	Customer Type	Energy (kWh)	Vat charge (₦)	Current Bill	Current Closing bal.	Last Payment	DT Name
IKEJA	PTC	1E+08	AREA F BARRACKS BLK F2/8 LAGOS	R2SP	Active	MD	149	238	3173.7	3411.73	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	AREA F BARRACKS BLK F2/6 LAGOS	R2SP	Active	NMD	141	225	3003.3	3228.55	4,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	BLOCK F2/6 AREA F BARRACKS IKEJA	R2SP	Active	NMD	137	219	2918.1	3136.96	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	36 MOSHOOD ABIOLA CR 85/S25/068231 IKEJA	R2SP	Suspended	NMD	149	238	3173.7	3411.73	32,000.00	11-PTCINJ-T1-Opebi-ESTAPORT
IKEJA	PTC	1E+08	11A ODUDUWA CRESCENT GRA IKEJA	R2SP	Suspended	NMD	135	216	2875.5	3091.16	5,000.00	11-PTCINJ-T3-General Hospital-ODUDUWA CRESCENT IV
IKEJA	PTC	1E+08	31. MOBOLAJI ANTHONY WAY. MARYLAND.	R2TP	Active	NMD	240	392	5232	5624.4	15,000.00	11-PTCINJ-T2-Awuse-ABULE ONIGBAGBO
IKEJA	PTC	1E+08	AREA F BLK F2/3 IKEJA LAGOS	R2SP	Suspended	NMD	132	211	2811.6	3022.47	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	AREA F BLK F2/4 IKEJA LAGOS	R2TP	Active	NMD	300	479	6390	6869.25	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	AREA F BARRACKS BLK F2/9 LAGOS	R2SP	Suspended	NMD	147	235	3131.1	3365.93	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	AREA F BARRACKS BLK F2/10 LAGOS	R2TP	Suspended	NMD	350	572	7630	8202.25	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	AREA F BARRACKS BLK F2/7 LAGOS	R2SP	Active	MD	135	216	2875.5	3091.16	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	AREA F BARRACKS BLK F3/3 LAGOS	R2SP	Active	NMD	148	236	3152.4	3388.83	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	AREA F BARRACKS BLK F3/4 LAGOS	R2SP	Suspended	NMD	137	219	2918.1	3136.96	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	AREA F BARRACKS BLK F3/1 LAGOS	R2SP	Active	NMD	130	208	2769	2976.68	4,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	AREA F BARRACKS BLK F3/2 LAGOS	R2TP	Active	NMD	312	510	6801.6	7311.72	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	AREA F BARRACKS BLK F3/8 IKEJA LAGOS	R2SP	Active	NMD	135	216	2875.5	3091.16	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	AREA F BARRACKS BLK F3/7 LAGOS	R2TP	Active	MD	335	548	7303	7850.73	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	AREA F BARRACKS BLK F3/6 LAGOS	R2SP	Suspended	MD	149	238	3173.7	3411.73	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE
IKEJA	PTC	1E+08	AREA F BARRACKS BLK F4/2 LAGOS	R2TP	Active	MD	360	589	7848	8436.6	2,000.00	11-PTCINJ-T2-Awuse-ROAD SIDE

Figure 17: Sample List of Billed Ikeja GRA Customers

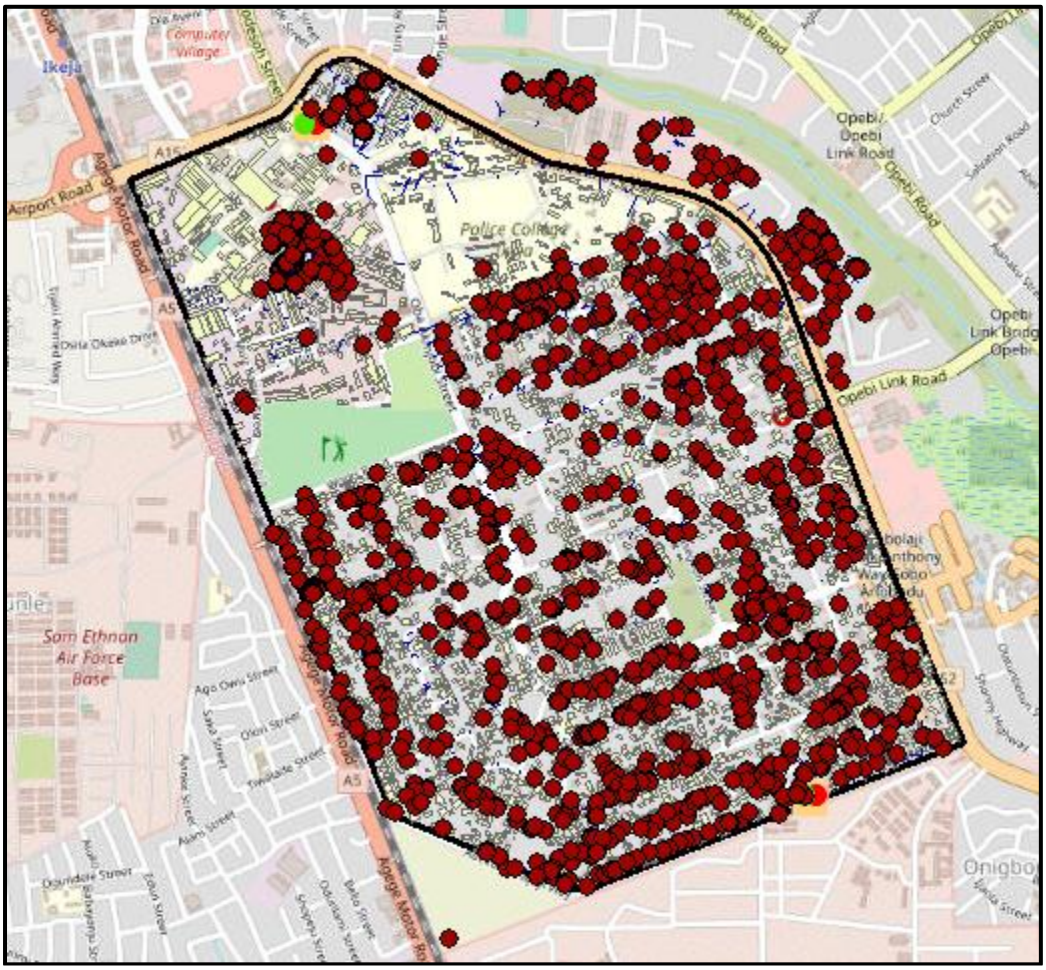

Figure 18(a): Billed Customers in ArcGIS

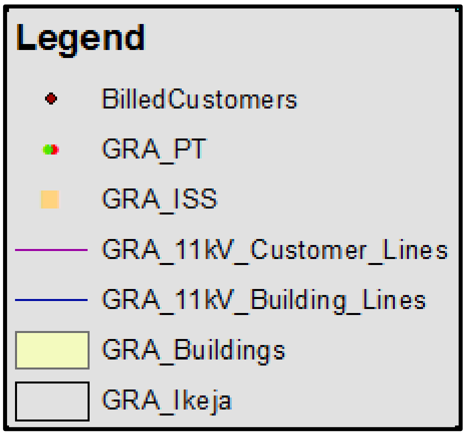

Figure 18(b): Billed Customers Legend in ArcGIS

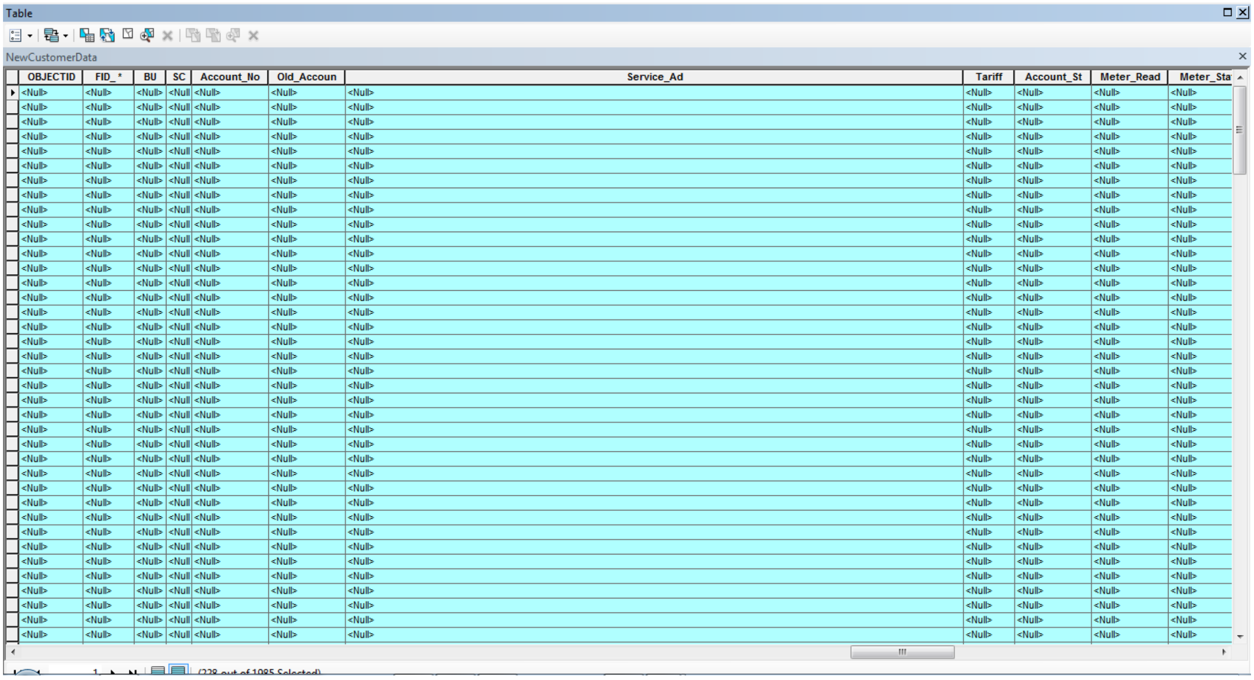

Figure 19: Unbilled Customers (Null results after billing and GIS data are joined)

Figure 20a displays the 228 unbilled customers as presented by the ArcGIS software, while Figure 20b shows the legends for electrical asset map interpretation.

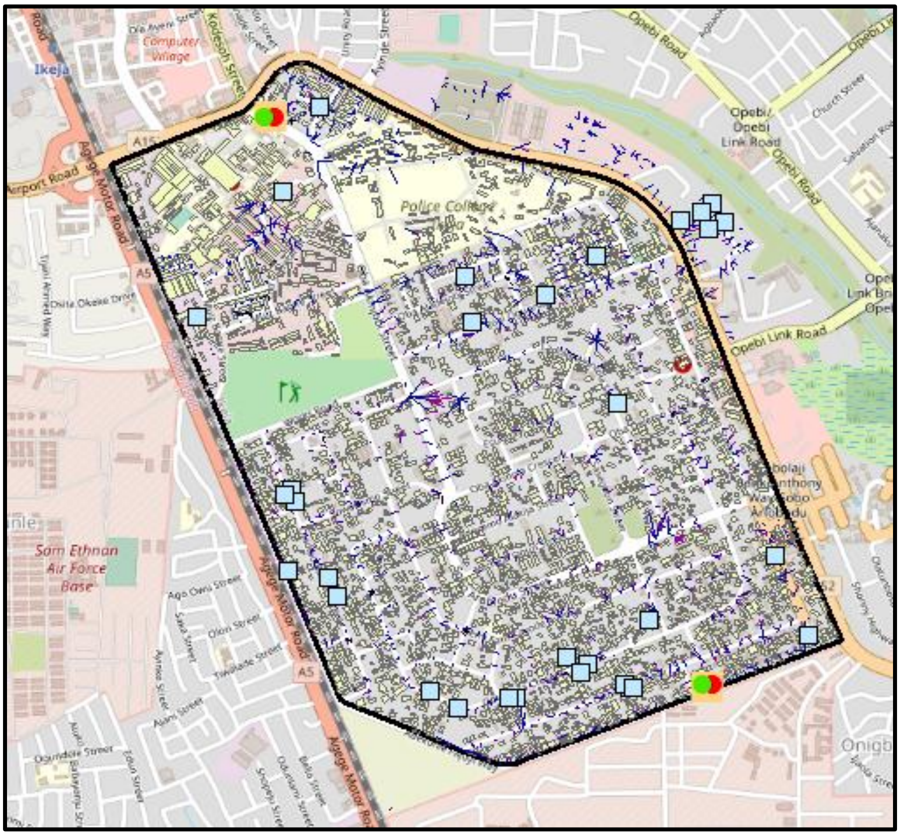

Figure 20(a): 228 Unbilled Customers on ArcGIS

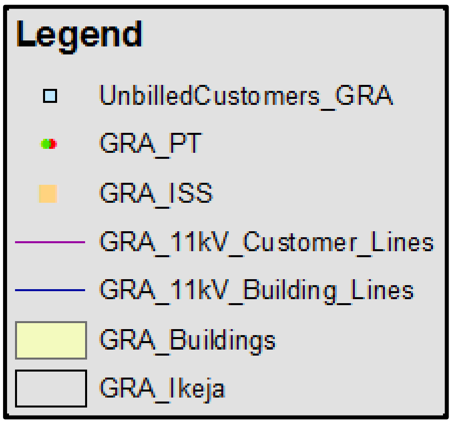

Figure 20(b): Unbilled Customers Legend in ArcGIS

c. COMPARATIVE ANALYSIS OF UNBILLED CUSTOMERS AND BILLED CUSTOMERS

This analysis identified consumer geo-coded connection points that were not currently in the billing data gotten from CIS used in IE monthly billing cycle to charge customers for services rendered. The implication of this is that the identified unbilled customers are directly connected to the revenue loss which is what the distribution company cannot account for in terms of their energy accounting and audit.

When this is subjected to further investigations the difference between the consumers connected to the grid 1985 and customers that pay monthly for power supply 1757, a total of 228 customers were discovered to be unbilled. Figure 21 represents the count of unbilled customers per tariff class recognized from this comparison.

TARIFF_C_1	Count_TARIFF_C_1
R2SP	198
R2TP	30

Figure 21: Unbilled Customers by Tariff Class

To further validate this analysis, the 228 customers were pinpointed to be residential non-maximum demand (non-MD) customers with a load assessment ranging from 0.25kW for a single phase to 0.5kW for three-phases for each customer per hour, which is 5kwh (single-phase) to 12kwh (three-phase) a day which is 150kwh (single-phase) to 360kwh (three-phase) per month. Subsequently, with IE's weighted average tariff (WAT) of ₦27.30 this amounted to ₦4,095 (single-phase) to ₦9,828 (three-phases) monthly.

This, therefore, accounted for energy as well as the non-technical losses for the 198 R2SP customers of tariff ₦21.30 as ₦632,610 in addition to the 30 R2TP customers of tariff ₦21.80 as ₦235,440 resulting in a total of ₦868,050 as the revenue loss which directly impacts the commercial and collection losses. Figure 22 visualizes the unbilled and billed customer's data as seen on the ArcGIS desktop application to know exactly where these customers are located whereas Figure 22b shows the legends for electrical asset map interpretation. Figure 23 gives the chart representation of these customers based on their meter type – single phase and three phases as well as the revenue lost monthly.

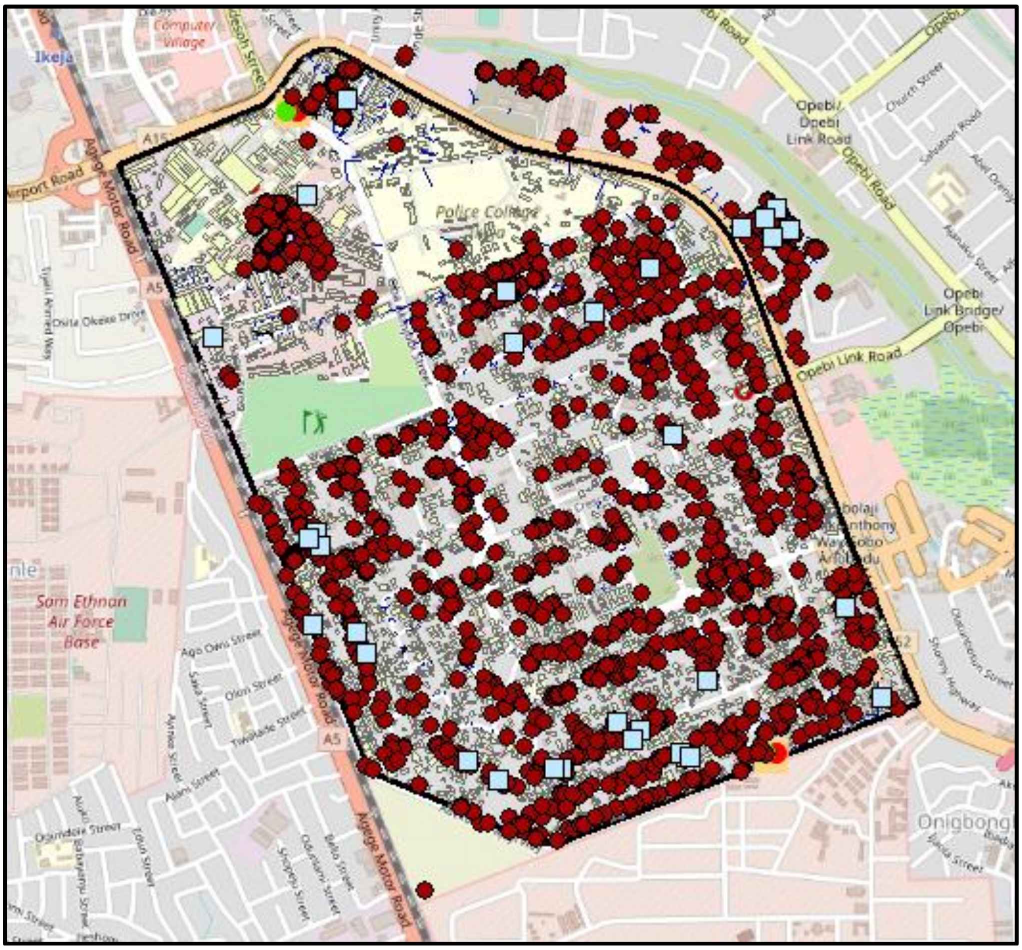

Figure 22: Billed and Unbilled Customers

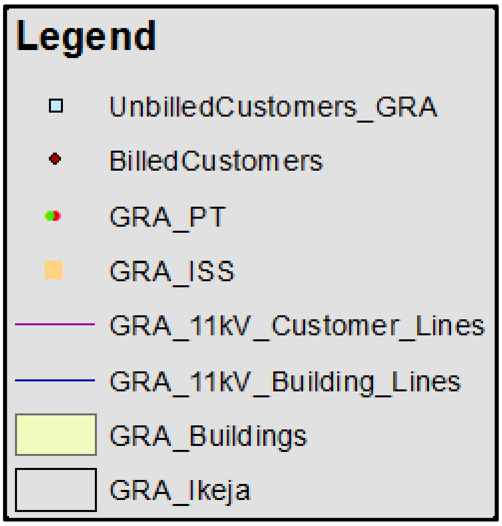

Figure 22: Billed and Unbilled Customers Legend

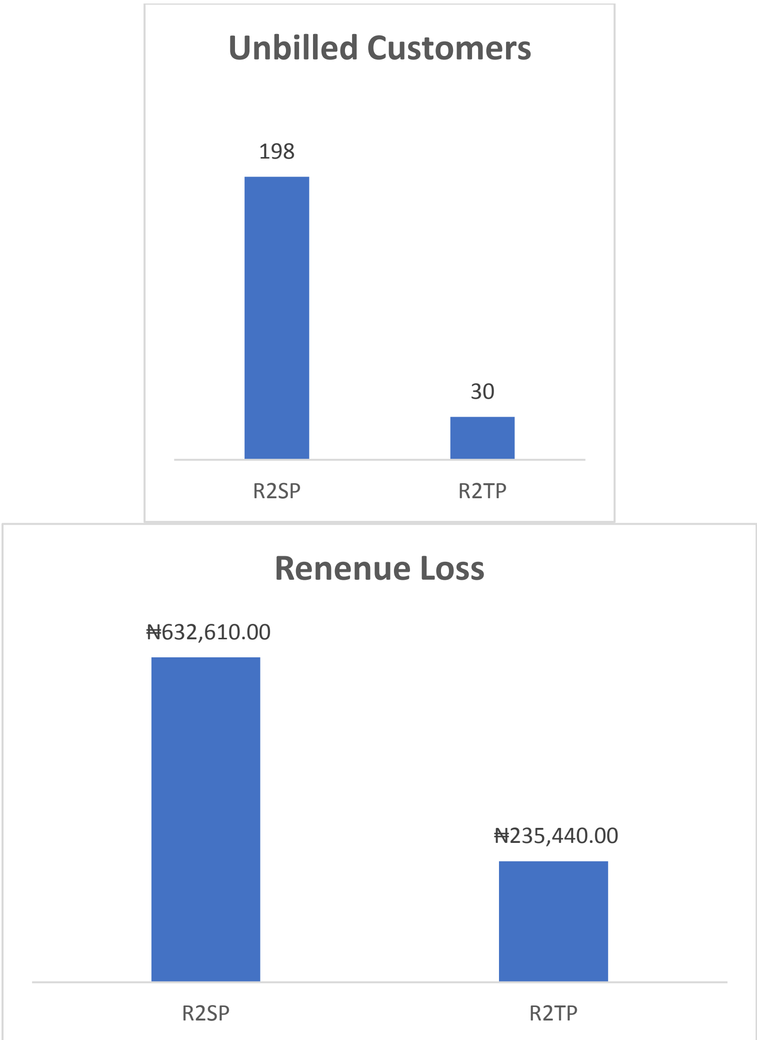

Figure 23: Customers Count and Amount of Revenue Lost from Unbilled Customers

IV. CONCLUSION

This contribution has explored the impacts of GIS in identifying unbilled customers to ensure that all the energy delivered to customers is effectively accounted for. This will inevitably boost the profitability of the distribution companies so that they can recoup the revenue for the energy bill which is used to start new projects and procure new equipment.

The study has shown the capability of a spatially enabled information system in managing the Ikeja GRA electricity distribution network and has been demonstrated to meet the objectives set out ab initio. The products delivered were: (i) a spatially-aware database using a desktop GIS mapping application featuring tools that showcase the locations of customers and assets within Ikeja GRA, (ii) the identification of the total number of billed customers as obtained from the CIS database, (iii) the revenue loss due to the recognition of the unbilled customers when the spatial data is compared with the billing data.

This system is being deployed to the six (6) business units within Ikeja Electric Plc, where currently a further roll-out to the undertaking offices is being examined. It is therefore recommended that the system, once deemed to be satisfactory, can be implemented in other distribution companies in Nigeria.

This GIS solution coupled with other systems will enhance infrastructure and customer management as well as revenue management.

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