Evaluation of Electric Field Pollution from 132 kVA Power Transmission Lines to Proximity of Infrastructures in Ibadan, Nigeria

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Abstract: Electrical power transmission lines (PTL) generate electromagnetic field while carrying electrical energy from power generating stations to the electrical power distribution systems. Due to increase in population, infrastructure are being built close to or under the power lines; thus, violating the range of the tower setback. This exposes nearby residence to electric field pollution. In this paper, we present an evaluation of the electric field pollution from the 330/132kVA power transmission lines in Ibadan (Ido local government), Oyo state Nigeria. we measured the electric field of the power transmission line of the *closest* proximity to the nearest infrastructure using electromagnetic tester (model 3120-EN-00). Evaluation of spatial distance between the nearest infrastructure and the transmission lines was done by obtaining the spatial position of the transmission tower and the infrastructure using Global *Positioning* System (GPS) receiver (model GPSMAP 78 Series) satellite system. The sets of data obtained were processed in ARCGIS environment and the distance from the transmission tower to the nearest infrastructure was obtained. Also, the range between the tower with reference to a particular tower was obtained using analytical techniques. The ICNIRP standards were used to evaluate the result. The results showed that the electric field strength is below the standard limit. Regulatory bodies like the Power Holding Company of Nigeria (PHCN), Occupational Health and Safety Code (OHSC) and Lagos State Urban and Regional Planning (LSURP) regulations legislated a minimum setback for every infrastructures proximity to power lines. These regulations were used to evaluate infrastructures violating the rules. 12.5% of the infrastructures assecible complied with the PHCN regulation, 56.85% complied with the LSURP regulation and 78.12% compiled with the OHSC regulation.

Keywords: Electric power transmission, ARCGIS, ICNIRP, GPS, Safety distance, Electric field pollution, Occupational and General public exposure

1. Introduction

Electric power transmission and distribution is key to the successful transportation of electrical power from its generation site to the user locations. Electric power transmission lines generate eletric and magnetic field around the *power lines* used to transmit electric power. An electric field is the force that fills the space around any electric charge or group of charges which are caused by electrical forces (James, 2017). Electric fields are analogous to magnetic fields resulting from forces acting upon magnetic substances or magnet poles (Semat and Katz, 1958). Electric fields (Efs) converge and diverge at points of electric charge and can be induced by time-varying magnetic fields. Efs exists whenever positive or negative electrical charges are present, they exert forces on other charges within the field. The higher the voltage, the stronger the electric field at any distance from the wire. The strength of an electric field is typically measured in volts per meter (V/m) or in kilovolt per meter

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(kV/m) (Glover *et al.,* 2012). Increase in population and development within the cities have made people to build houses, workshops, religious centre, schools and farms, close to or under power transmission lines. The development of rural areas to urban communities has social and environmental impact; the growth of urban populations and associated industrialization has resulted in a range of detrimental and often de-humanizing outcomes (Baker, 1974; Olamiju and Oyinloye, 2015). The electric field generated around a wire by the flow of current has adverse biological effects on the human neurological system, causing cardiovascular disorders, low sperm counts and many other effects on workers who regularly service the lines (Aliyu and Ali, 2011; Aliyu *et al.,* 2012). Also, these adverse effects affect people who stay for long periods without shielding near/under power transmission lines. There are simple ways to reduce human exposure. The effects of Electric fields decrease rapidly as human beings move away from the source. This means that increasing the distance between human beings and a source of extremely low frequencies (ELFs) which can be generated from power lines or electrical appliances will easily reduce the level of exposure to ELFs. One of the best ways to reduce exposure is to spend less time close to large sources of ELFs such as places near or under high-voltage transmission lines (hydro corridors) and transformers (Anderson, 1993).

2. Related Work

Several studies have been carried out on the effects/dangers of electric field pollution generated from power transmission lines on lives and property. This section gives an overview of related works in this area.
Petkovic *et al.* (2006) worked on the effect of the electric component of an electromagnetic field of 50 Hz, originating from over ground 110 kV power line, on humans in its immediate vicinity. In their paper, the electric field which penetrates the human body was calculated with the help of a human model. This model, contained blocks which represent different human organs or body parts (e.g. brain, lungs, digestive organs, etc.). Their response to electromagnetic features such as conductivity, electric and magnetic permittivity was obtained. In this case, the distribution of the electric field surrounding humans is given, as well as the values of the field which penetrates humans. In evaluating their results, a comparison was made between calculated values and the values obtained through the usage of adequate software solutions. Aliyu *et*

al. (2012) worked on the Analysis of Electromagnetic Pollution due to High Voltage Transmission Lines. The research work examined the field pollution from 132kV and 330kV lines in Bauchi/Gombo areas in Nigeria as the case study. The evaluation was based on the safety limits recommendations of ICNIRP. When the measurements were being carried out, Tri-field meter was used to measure the fields in the vicinity of the lines with horizontal distance ranging from 0 – 450 m and vertical distance of 1.5m. In the assessment, general public and occupational exposure levels from the power lines were sampled. For the general public, the highest magnetic flux density and electric field strength measured is 45 mG and 130 V/m which is 4.5 % and 2.6 % of the CNIRP, 1998 exposure limit. The highest magnetic flux density and electric field strength measured is 100 mG and 130 V/m respectively which correspond to 2 % and 1.3 % of the ICNIRP (1998) exposure limit for the occupational worker. The result showed that the measured fields are within the required safety limits.

Table 1: ICNIRP (1998, 2010) and Council for European Union (2004) exposure guideline.

Exposure limits	Magnetic Field (μT)	Electric Field (V/m)
Public	100	5000
Occupational	500	10000

A. Electrical power transmission lines

Electrical power transmission lines are wired conductors that carry electric power from generating plants to the substations that deliver power to customers.

B. Interaction of human body with electric and magnetic fields of power lines

Electric and magnetic fields generated by electric power transmission lines are harmful to the human body. Expose to these fields cause damages to the body tissues. For the electric field generated, Ohm's Law relates the current density (J) and electric field (E) (ICNIRP, 1998) as shown in equation (1).

$$J = \sigma E \qquad (1)$$

Rachedi *et al.* (2014) studied the behavior of the of electric field exposure on human beings. They observed that at certain distances human are mostly

likely to experience these health treats: the ground (0 m), exposure of the heart (1, 5m) and brain exposure (1.8m).

3. Material and Methods

In this section we present the materials and methods used to carry out this work.

A. Satellite imagery for the study area

Satellite imagery of high resolution were processed in ARCGIS environment to map out Oyo State from the map of Nigeria. Thereafter, Ibadan which is the study area was mapped out. Fig. 1a shows the map of the study area and the satellite imagery of power transmission lines in Ido local government area is shown in Fig. 1b.

B. Data acquisition and ground truthing

Primary and secondary data were collected for this work. Data that were retrieved from the field work include values of the electric field and GPS points where readings of the electric field were taken down at the power lines as shown in the study area, Fig. 1b.

C. Instruments used for data acquisition

The GPS coordinates (Longitude, Latitude and Height) of the spatial locations were obtained using satellite Global Positioning System (GPS) receiver with following characteristics; model GPSMAP 78 Series and error margin of 3 metres. GPS values of strategic ARCGIS environment were used to map Ibadan metropolis which is the study area of this work. The power lines along the residential areas were mapped out in a straight line and a buffering of 500 m was created along the power lines as shown in Fig. 3.

The electric field strength was obtained using a Field Test Meter with the following specifications: Model 3120-EN-00 as shown in Fig. 2b and measuring capacity from 0.01 V/m to 1999.99 V/m. The electric field strength of strategic points were taken, such as at the infrastructure closest to the left and right side of the power line tower and GPS point under the power line tower itself. The secondary data were used to extract road network information and also to identify infrastructures that were located around the power lines in the study area. The number of infrastructures under power lines were obtained. The GPS device used is shown in Fig. 2a.
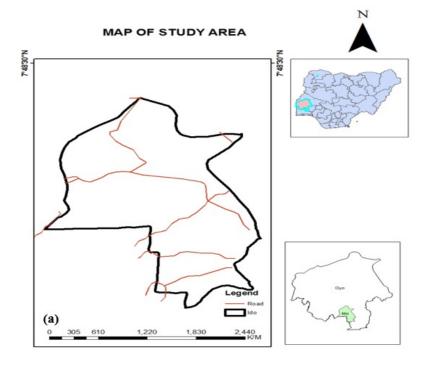
(b)

Figure 1: (a) Map of study area; (b) Satellite imagery of study area showing 330/132 kVA Power Transmission Lines along Ibadan Metropolis.

(a)   (b)

Figure 2: Measurement devices; (a) GPS Receiver (model GPSMAP 78 Series) and (b) Electromagnetic tester (Model 3120-EN-00).

points were collected for infrastructure closest to the left and right side of the power line tower and under the power line tower itself. All measurements were taken at 1.04m from the ground surface. The measurements taken were recorded into a spread sheet on Microsoft Office Excel. The comparative analysis of the results of electric field strength at nearest infrastructure to right, left and under the tower were recorded into a spread sheet on Microsoft Office Excel. The waveforms for all the results were generated using Microsoft Office Excel tools. After the distances have been recorded, a waveform of the spatial location's distance in metres to nearest Infrastructure from the 330 kVA transmission lines was plotted and another waveform showing the spatial location's distance (m) of nearest infrastructure from the 132 kVA transmission lines was plotted. A graph showing the frequency and percentage of different Infrastructure located close to power lines were plotted.
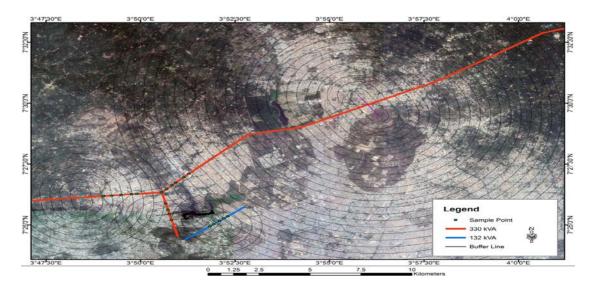
Figure 3: Buffering at 500 m along Ibadan Metropolis.

D. Measurement of electric field from transmission lines to infrastructure

The measurement of electric field strength under the transmission lines were taken with the electromagnetic tester, while that of the left and right side of the transmission line were taken with the use of gauss meter, and the corresponding GPS points of the tower were recorded. All measurements were taken at 1.04m from the ground surface.

The measurements taken were recorded into a spread sheet on Microsoft Office Excel. The comparative analysis of the results of electric field strength at nearest infrastructure to right, left and under the tower were recorded into a spread sheet on Microsoft Office Excel. The waveforms for all the results were generated using Microsoft Office Excel tools. After the distances have been recorded, a waveform of the spatial location's distance in metres to nearest Infrastructure from the 330 kVA transmission lines was plotted and another waveform showing the spatial location's distance (m) of nearest infrastructure from the 132 kVA transmission lines was plotted. A graph showing the frequency and percentage of different Infrastructure located close to power lines were plotted. The range of each point was calculated making the first GPS value where the reading started as the reference point (0 Ref. pt).

The range R was obtained using the equation (2):

$$R^2 = (x_A - x_B)^2 + (y_A - y_B)^2 + (z_A - z_B)^2 \quad (2)$$

The ranges of each point were calculated with equation 3.1 using the first GPS value, where the reading started as the reference point. Therefore, from Table 4.1, $x_A = 591775$, $y_A = 822236$, $z_B = 242$.
where A and B represent two points in the rectangular coordinate system and x, y and z represent the latitude, longitude and altitude (height) of the points. The measurements were recorded into a spread sheet on Microsoft Office Excel. Afterwards, waveforms were generated from the results on the table using Microsoft Office Excel tools.

E. Comparative analysis of the electric field based on standards and regulations

There are different regulatory standards on limits of human exposure to electric field resulting to the guidelines which state the minimum distance which an infrastructure can be located close to a power lines. The results of the electric field experienced were obtained and a comparative analysis of all the measurement of electric field strength recorded around the power line based on the guidelines of the Power Holding Company of Nigeria (PHCN), Lagos State Urban and Regional Planning (LSURP), Occupational Health and Safety Code (OHSC) and International Commission on Non-Ionizing Radiation Protection guidelines (ICNIRP) was made. Furthermore, the waveforms to show the comparison were plotted.

Table 2: Percentage of compliance to regulations and standards.

S/N	Organisation	Power Transmission Rating	Regulation and Standards	Compliance
1.	PHCN	330kVA	50 m pathway proximity	12.5%
2.	LSURP	330kVA	22.5m pathway proximity	56.85%
3.	OHSC	230kVA, 500kVA	5 – 7 m pathway proximity	78.12%

Table 3: Infrastructures under power lines.

S/N	Infrastructure	Under Lines	Left to Lines	Right to Lines	Frequency	Percentage
1	Workshop/Shop	4	4	5	13	27.1
2	Church/Mosque	1	2	3	6	12.5
3	Crop Farm	1	0	0	1	2.1
4	House	0	12	11	23	47.9
5	Block Industry	2	0	1	3	6.2
6	School	0	0	2	2	4.2
					48	100%

Table 4: Results of electric field under transmission tower.

Point on Ground surface	Electric field @ Infrastructure H_T (V/m)	Values of GPS @Towers			Range (m) R_{UT}(m)
		X_{UT} (N) Latitude	Y_{UT}(E) Longitude	Z_{UT}(m) Height	
1	1680	591775	822236	242	0(Ref. Pt)
2	707	591517	822221	225	258.99
3	2000	591009	822217	206	767.08
4	2000	590562	822114	216	1219.4
5	2000	590159	822086	202	1623.44
6	2000	593186	821522	218	1581.55
7	2000	593292	821047	220	1927.44
8	2000	593368	820732	223	2190.9
9	2000	593470	820286	204	2583.71
10	2000	592986	822370	207	1218.89
11	2000	594308	823779	210	2958.56
12	2000	594061	823510	200	2617.37
13	2000	593667	823099	207	2079.82
14	2000	593494	822910	225	1846.49
15	2000	593221	822604	216	1492.32
16	934	595341	819790	206	4324.42
17	679	595520	819955	208	4385.1
18	48	595817	820208	193	4522.49
19	2000	596019	820390	204	4628.25
20	1070	596215	820563	207	4744.87

The electric field generated closest to the tower is measured. In Tables 4, 5, 6 and 7, X_{UT}, Y_{UT} and Z_{UT} repesent the values obtained with the GPS device under the tower. Where UT means under tower, LT means left of the tower, RT means right of the tower and X, Y, Z represent the latitude, longitude and height respectively.
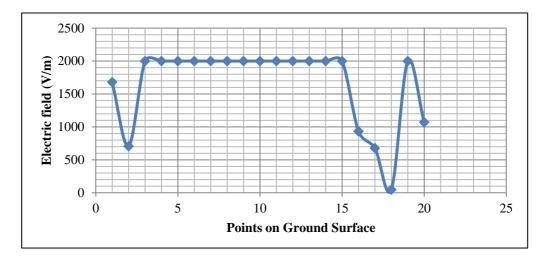

Figure 4: Waveform of the electric field strength under the transmission tower.

Table 5: Results of electric field to nearest ınfrastructure at left side of tower.

Point on Ground surface	Electric field H_{LT} (V/m)	GPS Values left side@ Towers			Range (m) R_{LT}(m)
		X_{LT} (N) Latitude	Y_{LT}(E) Longitude	Z_{LT}(m) Height	
1	379	591754	822285	241	0
2	2000	591524	822251	225	233.04
3	2000	591046	822210	210	712.64
4	175	590548	822169	214	1211.87
5	2000	590165	822113	204	1598.71
6	2000	593194	821559	221	1612.79
7	2000	593315	821063	218	1982.56
8	1609	593380	820740	229	2242.99
9	2000	593496	820292	203	2647.27
10	2000	593016	822333	205	1263.43
11	2000	594324	823762	210	2964.35
12	2000	594088	823497	197	2630.29
13	2000	593684	823076	212	2086.00
14	2000	593502	822877	223	1845.61
15	2000	593216	822578	215	1491.29
16	0	595336	819804	204	4357.46
17	-	-	-	-	-
18	0	595817	820214	192	4560.64
19	25	596015	820394	205	4661.90
20	0	596212	820570	208	4776.62

Figure 5: Waveform of the electric field strength from the left side of transmission tower.

Table 6: Results of electric field strength to nearest infrastructure at right side of tower.

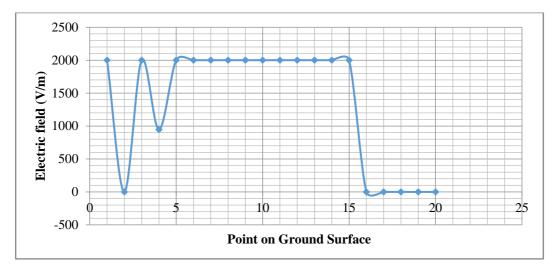| Point on Ground Surface	Electric Field H_{RT} (V/m)	GPS Values at right side @ Towers			Range (R) R_{RT}(m)
		X_{RT} (N) Latitude	Y_{RT}(E) Longitude	Z_{RT}(m) Height	
1	2000	591756	822215	246	0(Ref. Pt)
2	0	591515	822185	223	243.95
3	2000	591041	822143	203	719.90
4	946	590553	822086	215	1219.74
5	2000	590234	822059	205	1539.23
6	2000	593156	821490	216	1576.87
7	2000	593270	821042	217	1773.35
8	2000	593341	820714	224	2183.05
9	2000	593458	820291	206	2569.08
10	2000	592979	822391	211	1236.10
11	2000	594289	823791	208	2983.50
12	2000	594044	823529	200	2638.87
13	2000	593646	823121	208	2096.30
14	2000	593474	822933	225	1862.11
15	2000	593212	822633	216	1515.11
16	0	595500	819964	208	4368.75
17	0	595500	819900	203	4402.11
18	0	595820	820202	192	4535.54
19	0	596037	820386	208	4655.50
20	0	596222	820559	211	4763.26

Figure 6: Waveform of the electric field strength at the right side of transmission tower.

Table 7: Comparative results of electric field strength to nearest infrastructure at right, left and under the tower.

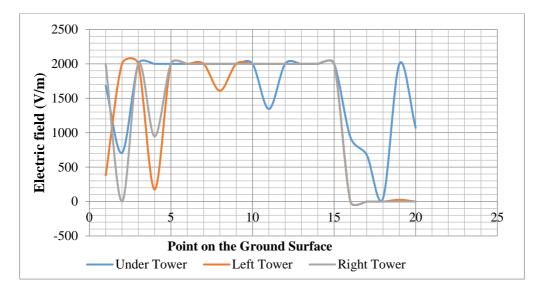| Point on Ground Surface	Electric Field			Range(m)		
	H_T (V/m)	H_{LT} (V/m)	H_{RT} (V/m)	R_{UT}(m)	R_{LT}(m)	R_{RT}(m)
1	1680	379	2000	0(Ref. Pt)	0(Ref. Pt)	0(Ref. Pt)
2	707	2000	0	258.99	233.04	243.95
3	2000	2000	2000	767.08	712.64	719.90
4	2000	175	946	1219.4	1211.87	1219.74
5	2000	2000	2000	1623.44	1598.71	1539.23
6	2000	2000	2000	1581.55	1612.79	1576.87
7	2000	2000	2000	1927.44	1982.56	1773.35
8	2000	1609	2000	2190.90	2242.99	2183.05
9	2000	2000	2000	2583.71	2647.27	2569.08
10	2000	2000	2000	1218.89	1263.43	1236.10
11	1344	2000	2000	2958.56	2964.35	2983.50
12	2000	2000	2000	2617.37	2630.29	2638.87
13	2000	2000	2000	2079.82	2086.00	2096.30
14	2000	2000	2000	1846.49	1845.61	1862.11
15	2000	2000	2000	1492.32	1491.29	1515.11
16	934	0	0	4324.42	4357.46	4368.75
17	679	0	0	4385.10	-	4402.11
18	48	0	0	4522.49	4560.64	4535.54
19	2000	25	0	4628.25	4661.90	4655.50
20	1070	0	0	4744.87	4776.62	4763.26

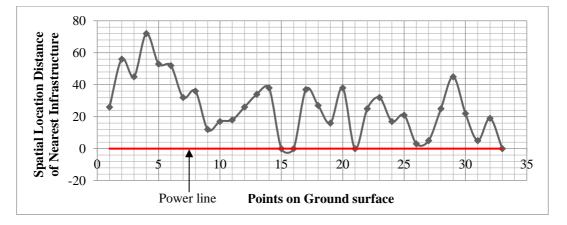**Figure 7:** Comparative analysis of values of the electric field strength.

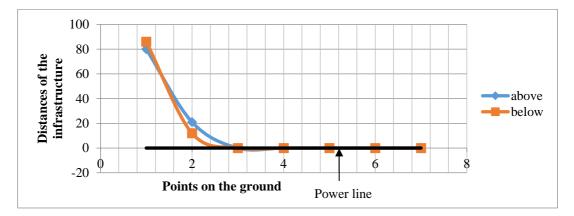**Figure 8:** Spatial location's distance (m) of nearest ınfrastructure from 330 kVA transmission lines.

Figure 9: Spatial location's distance (m) of nearest ınfrastructure from 132 kVA transmission lines.
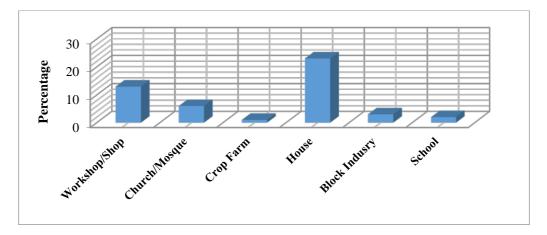
Figure 10: Percentage of the frequency of different Infrastructure located close to power lines.
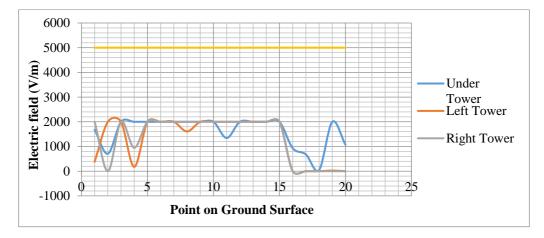

Figure 11: Comparative analysis of all measurements of electric field recorded around the power line based on ICNIRP.
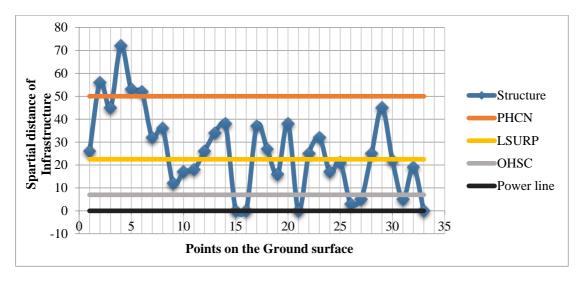

Figure 12: Comparative analysis of all measurements of electric field recorded around the power line based on power standards and regulations.

4. Results and Discussion

The results obtained from the experiment is shown in Tables (1-7), from the waveform plotted for the electric field strength values recorded under the tower at the left and right side of the tower, it was observed that the electric field strength is approximately 0 V/m at 132 kVA and higher at 330 kVA. Meanwhile, more infrastructure particularly residential houses are located directly under the 132 kVA transmission power lines. Also, in comparison to the guidelines set by International Commission for Non-Ionizing Radiation Protection (ICNIRP) on the exposure limit of human being to electric field, the results clearly showed that the values are still very low and in the safe limits of exposure. Lastly, it was observed that many infrastructures violate the minimum distance given for buildings to be situated near the electric power line. The results obtained within the study area indicate that 12.5% infrastructure complied with the PHCN regulations, 56.85% compiled with Lagos State Urban and Regional Planning regulations and 78.12% compiled with Occupational Health and Safety Code (OHSC) regulation. The summary of the data collected is shown in Tables 4, 5, 6 and 7 respectively. The percentage of compliance of our obtained results to the regulations and standards of the PHCN, LSURP and OHSC are shown in Table 2, the data obtained for the electric field under the transmission tower is shown in Table 4 and its waveform is shown in Fig. 4, while that of the electric field of the nearest infrastructure to left side of tower is shown in Table 5 and its waveform is shown in Fig. 5. The electric field strength of the nearest infrastructure to right side of tower is shown in Table 6 and the waveform is shown in Fig. 6. Comparison of the results of electric field strength at nearest infrastructure to right, Left and Under the Tower is given in Table 7and the waveform is shown in Fig. 7. The Spatial Location's Distance (m) of Nearest Infrastructure from the 330 kVA Transmission Lines and from 132kVA are shown in Fig. 8 and Fig. 9 respectively. The number of infrastructures under power lines is shown in Table 3. The plot of the percentage of the frequency of different Infrastructure located close to power lines is shown in Fig. 10 obtained from the result of Table 3. Comparative analysis of all the measurement of electric field recorded around the Power line based on Power Standard and Regulations such as PHCN, LSURP and OHSC is represented in Fig. 12 while the plot of the comparison based on the ICNIRP standard is shown in Fig. 11.

5. Conclusions

In this paper, the magnitude of electrical field pollution in the vicinity of 132 kVA and 330 kVA have been analyzed for the general public and also the occupational exposure using ICNIRP, 1998 standard and the regulations of the PHCN, LSURP and OHSC. The analysis showed that 12.5% of the infrastructure complied with the PHCN regulations, 56.85% compiled with Lagos State Urban and Regional Planning (LSURP) regulation and 78.12% compiled with Occupational Health and Safety Code (OHSC) regulation. These results are compared with the ICNIRP standard.

References

Aliyu, O. I. and Ali, H. (2011). Analysis of Magnetic Field Pollution due to 330kVA and 132kVA Transmission Lines, Abubakar Tafawa Balewa University Bauchi, *Nigeria Journal of Technology and Educational Research*, 4(20), 87-93.

Aliyu, O., Maina, I. and Ali, H. (2012). Analysis of Electromagnetic Pollution due to High Voltage Transmission Lines, *Journal of Energy Technologies and Policy,* 2(7). 1-10.

Anderson, J. G. and Short, T. A. (1993). Algorithms for Calculating of Lightning İnduced Voltages on Distribution Lines, in *IEEE Transactions on Power Delivery*, 8(3), 1217-1225.

Baker, P. H. (1974). Urbanization and Political Change: The Politics of Lagos, London: *University of California Press*, 1917-1967.

Glover, J. D., Sarma M. S. and Overbye, T. (2012). Power System Analysis and Design, *5th Edition*, Scamford, USA: Cengage Learning, 850p.

ICNIRP (1998): Guidelines for Limiting Exposure to Time-varying Electric, Magnetic, and

Electromagnetic Fields ''Quantities and Units'' p. 495.

James, D. D. (2017). A Gestalt Aether Theory on the Nature of Light and Related Phenomena: A New Physics, *Educreation Publishing*, p. 350.

Olamiju, I. O. and Oyinloye, M. A. (2015). Characteristics and Vulnerability of Houses under Overhead High-Tension Powerline in Akure, Nigeria, *World Environment*, 5(3), 121-133.

Petkovic, D. M., Krstic, D. D. and Stankovic, V. B. (2006). The Effect of Electric Field on Humans in the Immediate Vicinity of 110 kVA Power Lines. *Facta Universitatis-Series: Working and Living Environmental Protection, 3*(1), 63-72.

Rachedi, B. A., Babouri, A. and Berrouk, F. (2014). A Study of Electromagnetic Field Generated by High Voltage Lines using COMSOL MULTIPHYSICS, *International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM)*, Tunis, pp. 1-5.

Semat, H. and Katz, R. (1958). Physics, Chapter 29: The Magnetic Field, *Robert Katz Publications*, p. 153.