

## Analysing and Profiling the Magnetic Field Levels in 330 kV Transmission Stations Switchyard

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**Abstract**—The investigation of radiated magnetic field intensity in switchyards is of paramount important, so spot measurement procedure was used to detect the levels of magnetic field by placing the detachable sensor of Extech 480826 Triple-Axis metre on ‘constructed stand’ with three reference heights of 1.0, 1.5 and 1.8 m. Instant coordinates of position was simultaneously recorded at each spot during the process of measurements. The analysis revealed locations significant differences of  $p = 0.027$ ,  $p = 0.016$  and  $p = 0.023$  for the respective reference heights (1.0, 1.5 and 1.8 m). Shiroro and Kainji transmission switchyards mean ELF magnetic field were significant at each height when analysed using least significant differences pairwise comparison. However, non-significant differences between Jebba with Shiroro and also Kainji transmission switchyards were noticed. Further assessment of ELF magnetic field through 2D profiling of height levels in the transmission switchyards display similar drifting path with slight differences and locations with high intensity detected from the plots. The level of instant nonuniformity in mean magnetic field distribution at the switchyards during the duration of the measurements have been revealed by this research and also irregular exposure encountered by workers across height standing at a spot exposed.

*Keywords: Constructed stand, ELF Magnetic field levels, LSD Pairwise Comparisons, Profile distribution and Transmission Switchyards.*

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### 1. Introduction

Electrical energy demand for domestic, commercial and industrial usage has heighten and the main force in the significant level of anthropogenic extremely low frequency (ELF) electromagnetic fields (EMFs) in the environment [1]. The EMFs generated in switchyards decrease much more rapidly in intensity with increasing distance from the sources but limited within the vicinity, hence they are referred to as near-fields [2]. When biological system within the domain of fields is exposed to prolonged and excessive ELF fields, the system becomes charged and conductive in the process [3], and therefore experiences physical force of [4],

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}) \quad (1)$$

This expression is basic in electromagnetic theory and expresses the force that acts on a charge particle,  $q$  in electromagnetic field presence. It is referred to as Lorentz’s force equation with electric field and magnetic field time-varying components that are quasi-static in nature [5]. These fields propagate at perpendicular direction to one another [3], which make their distinctive evaluation and measurement possible. However, the magnetic field component has been found to travels farther away

from the source point and, penetrate through materials and human skin than the electric field component [6, 7]. This has elicited interest of researchers on occupational human safety exposure to ELF magnetic field in the environments [8].

By the assumption that electrostatic field presence in the environment is negligible due to shielding offers by outer layer cables' isolation and soil [4], so that magnetostatics field predominates in the environment, then the biological system will experience a force which depends on velocity,  $v$  in the region and equation (1) reduces to [9],

$$\mathbf{F} = q(v \times \mathbf{B}) \quad (2)$$

The RHS vector product in equation (2) corresponds to  $qvB\sin\theta$ . Hence, magnetic field magnitude is given as,

$$\mathbf{B} = \mathbf{F}/qv \quad (3)$$

This equation shows magnetic field as quantifiable in SI units of newtons per Ampère-metre, often called tesla (T) [5]. Magnetic field is specified in two ways as: magnetic field strength,  $\mathbf{H}$  in Ampère per metre (A/m) and the magnetic flux density,  $\mathbf{B}$  in tesla (T) [9]. However, in terms of biological tissue exposure,  $\mathbf{B}$  and  $\mathbf{H}$  are presumed equal and when it enters the tissue, it is transformed to magnetic flux density,  $\mathbf{B}$ . Both quantities are interrelated in space by the induced magnetic permeability properties  $\mu(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})$  which depends on the medium and expressed as [10]:

$$\mathbf{B} = \mu\mathbf{H} \quad (4)$$

For this reason, magnetic field easily penetrates biological human skin without attenuation due to the resemblance of its permeability with that of human [6]. For typical human experimental research, magnetic field exposure conditions is measured in smaller units of mT or  $\mu\text{T}$  [5].

Epidemiologic occupational exposure studies have demonstrated that workforce in electrical utility are exposed to high intensities of technogenic sources of ELF magnetic field pollution compare to other professions [11], and reports suggested that persistent and extreme exposure among workforce beyond occupational exposure level of 1000  $\mu\text{T}$  stipulated by the International Commission on Non-Ionising Radiation Protection (ICNIRP) is linked to possible health risk such as reproductive, cardiovascular and neurological disorders [12]. So, the expected impact of transmission switchyards ELF magnetic field is relatively different from those found in other environment due to the intensity, exposure duration and its ability to permeate into the human body without difficulty [6].

This paper, analysing and profiling of the ELF magnetic field levels in the vicinity of transmission switchyards through measured data to assessed the intensity and identified the dangerous locations across the reference heights as an extension of earlier study [1]. The 2D visual spread outline aim at giving insight on zones with high concentrations of ELF magnetic field. This will serve as means of awareness for personnel to avoid dangerous spots, the industry regulators to pay more attention on monitoring and scientists to embark on more study of ELF magnetic field strength within the switchyards' vicinity. The conducive working environment will sustain transmission of electricity to aid socioeconomic development and safeguard workforce against protracted and undue exposure beyond recommended occupational safety limit.

## 2. Materials and Method

The ELF magnetic field measurements study was carried out in three transmission switchyard of hydropower generation stations in Niger state, Nigeria with a handheld Extech 480826 triple-axis EMF metre shown in Figure 1. It has two specifications ( $\mu\text{T}$  & mG) and three different ranges (20, 200, & 200  $\mu\text{T}$ ), resolutions (0.01, 0.1 & 1  $\mu\text{T}$ ) and basic accuracy [ $\pm (4\% + 3d)$ ,  $\pm (5\% + 3d)$ ,  $\pm (10\% + 5d)$ ] and functions on approximate measurement rate of 0.4 seconds and, the GPS coordinates of spots locations obtained using Mapcord compass (version 2.8.6) [5]. The transmission switchyards are Jebba (9.168045°N, 4.821214°E), Kainji (9.861044°N, 4.613103°E) and Shiroro (9.972474°N, 6.830333°E) with respective estimated average power consumption of 165.23 MW, 166.56 MW and 276 MW during the study. The external detachable probe sensor of the metre is usually mounted on 'constructed stand' with three different reference heights (1.0, 1.5 and 1.8 m) corresponding to normal standard heights of human (waist, chest and head) for the measurements of ELF magnetic field levels, and the GPS coordinates of each spot recorded in the process [5].



**Figure 1.** Extech 480826 Triple-axis metre

The calibrated handheld Extech 480826 triple-axis EMF metre meets the standard measurement survey guidelines required for instrumentation set by the IEC 61786 and IEEE 1994-644 [1]. The ELF magnetic field levels spot measurements in the entire switchyard were performed in section because the radiated field concentration is more complex to measure than those found near power lines as a result of many interconnecting points above and underground that also serve as magnetic field sources in the vicinity. However, the measurements were in compliance with the outlined specifications by the Institute of Electrical and Electronics Engineers (IEEE) standards and the vector magnitude of resultant rms unperturbed ELF magnetic field of the measurand was computed by equation (5) in accordance with IEEE 644-1994 standards for measurement technique [5]:

$$\mathbf{B} = (\mathbf{B}_x^2 + \mathbf{B}_y^2 + \mathbf{B}_z^2)^{1/2} \quad (5)$$

where  $\mathbf{B}$  is the rms vector magnitude of ELF magnetic field and,  $\mathbf{B}_x$ ,  $\mathbf{B}_y$  and  $\mathbf{B}_z$  are the rms values of spatial components of the magnetic field [1].

The Extech 480826 triple-axis EMF metre used operates on the principle that is based on Faraday's law of induction which states that the electromagnetic force is equal to the negative rate of change of the flux,  $\Phi$  in Webers, through the loop [5]:

$$V_{emf} = -\frac{\delta\Phi}{\delta t} = -\frac{\delta}{\delta t} \int_A \vec{B} \cdot \hat{n} d\vec{A} \quad (6)$$

where  $V_{emf}$  is the developed voltage across the loop ends in reaction to the time-rate-of-change in the magnetic field BA,  $\vec{B}$  is the magnetic field,  $\hat{n}$  is a unit vector perpendicular to the cross-sectional area of the probe A and  $d\vec{A}$  is the element of the area [5]. For a free harmonic magnetic field [9],  $\vec{B} = \vec{B}_0 \sin\omega t$ , then

$$V_{emf} = -\omega B_0 A \cos \omega t \quad (7)$$

where  $\omega (2\pi f)$  is the angular frequency and suppose  $\vec{B}$  is perpendicular to loop area for maximum ELF magnetic field detection [9]. Equation (7) confirms that increase sensitivity of sensor probe is proportional to cross-sectional area and estimated as ratio of  $V_{emf}$  to  $B_0$  [5]:

$$Sensitivity = \frac{V_{emf}}{B_0} = 2\pi fNA \quad (8)$$

The same measurements process and measurement duration of 1 minute was applied in taking the readings upon stability of the values at each spot and locations before change in the sensor level across the reference heights and subsequent changes of spot. The 'constructed stand' used in the switchyards helps in precise and reliable measurements above ground at each spot of interest. Recorded field data were subsequently analysed on computer system using One-way analysis of variance (ANOVA) and least significant difference (LSD) in SPSS package (version 23.0) and, the simulation of the ELF magnetic field profile view in the switchyard done with golden software surfer (version 2017) for visualisation of the field distribution pattern within the vicinity.

### 3. Result and Discussion

The highest recorded values of ELF magnetic field in the switchyards for the reference heights (1.0, 1.5 and 1.8 m) were Jebba (13.18, 16.40 and 19.49  $\mu\text{T}$ ), Kainji (11.00, 12.63 and 15.26  $\mu\text{T}$ ) and Shiroro (21.32, 23.73 and 26.48  $\mu\text{T}$ ) respectively. The one-way ANOVA and LSD pairwise comparison based on reference heights above ground level for mean ELF magnetic field of different locations are presented in Tables 1, 2 and 3. The null hypothesis  $H_0$  (the mean different ELF magnetic field is not significant at height 1.0 m or 1.5 m or 1.8 m among the locations), the alternate hypothesis  $H_1$  (at least one of mean ELF magnetic field at 1.0 m or 1.5 m or 1.8 m is significant), and the significance level of ( $\alpha = 0.05$ ) were used for the analysis.

**Table 1.** ANOVA ELF Magnetic Field of Height 1.0 m for Location and Pairwise Comparisons

Sources of Variation	Sum of Square	Mean Square	F <sub>cal.</sub>	Sig.
Location	80.361	40.181	3.637	0.027
Error	5677.861	11.046		
Total	5758.223			
Pairwise Comparison of Location using LSD				
Pair	Mean Difference	Std. Error	Sig.	
Jebba versus Kainji	-0.20090	0.36378	0.581	
Jebba versus Shiroro	0.70474	0.35738	0.051	
Kainji versus Shiroro	0.90564*	0.35404	0.011	

The analysis revealed locations significance value of ( $p = 0.027$ ) based on height. Thus, the null hypothesis,  $H_0$  that mean ELF magnetic field at height of 1.0 m is not significant across locations stand rejected. Hence, at least one of mean ELF magnetic field was significant. Since the null hypothesis has been violated, LSD pairwise comparison was considered to assess the locations based on the height to determine where the difference of ELF magnetic field mean occurs. The LSD comparison shows mean ELF magnetic field was significant with value of  $p = 0.011$  between Shiroro and Kainji switchyards. Meanwhile, there was no statistically significant differences of mean ELF magnetic field observed between Jebba with Shiroro and also Kainji transmission switchyards.

**Table 2.** ANOVA ELF Magnetic Field of Height 1.5 m for Location and Pairwise Comparisons

Sources of Variation	Sum of Square	Mean Square	F <sub>cal.</sub>	Sig.
Location	124.028	62.014	4.190	0.016
Error	7607.845	14.801		
Total	7731.873			
Pairwise Comparison of Location using Least Significant Difference (LSD)				
Pair	Mean Difference	Std. Error	Sig.	
Jebba versus Kainji	-0.39211	0.42109	0.352	
Jebba versus Shiroro	0.77023	0.41368	0.063	
Kainji versus Shiroro	1.16234*	0.40981	0.005	

The result of Table 2 shows that mean ELF magnetic field for locations based on height was significant with value of  $p = 0.016$ . Therefore, the null hypothesis,  $H_0$  that mean ELF magnetic field at height of 1.5 m is not significant for locations was violated and stand rejected. This shows that, at least one of the locations was significant in mean ELF magnetic field exposure level. To determine where the difference exist, LSD pairwise comparison was considered for the assessment. The significant difference of  $p = 0.005$  was demonstrated as mean ELF magnetic field between Shiroro and Kainji switchyards at height 1.5 m. Whereas, no statistically significant differences of mean ELF magnetic field were notice between Jebba with Shiroro and Kainji transmission switchyards.

**Table 3.** ANOVA ELF Magnetic Field of Height 1.8 m for Location and Pairwise Comparisons

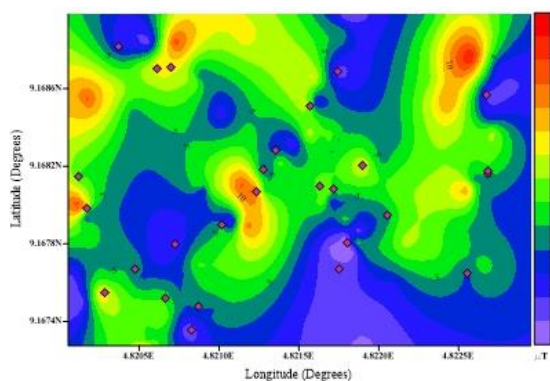
Sources of Variation	Sum of Square	Mean Square	F <sub>cal</sub>	Sig.
Location	149.712	74.856	3.821	0.023
Error	10069.845	19.591		
Total	10219.261			

Pairwise Comparison of Location using Least Significant Difference (LSD)			
Pair	Mean Difference	Std. Error	Sig.
Jebba versus Kainji	-0.58786	0.48445	0.226
Jebba versus Shiroro	0.71189	0.47593	0.135
Kainji versus Shiroro	1.29976*	0.47148	0.006

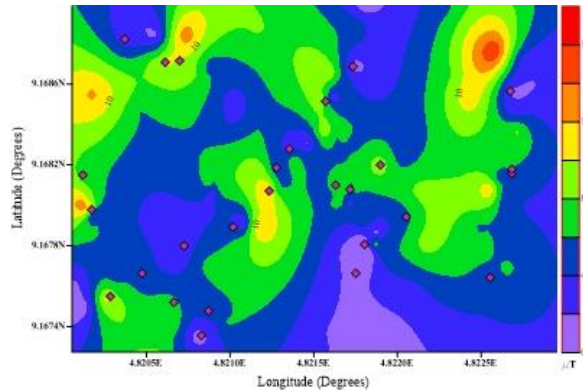
The analysis of Table 3 revealed that the significance value of the *F* test (Sig. = 0.023) based on height is less than level of significance ( $\alpha = 0.05$ ). Thus, the null hypothesis,  $H_0$  that average ELF magnetic field at height of 1.8 m is not significant across locations stands rejected. Thus, at least one of mean ELF magnetic field was different. Since null hypothesis is violated, further analysis of pairwise comparison of average ELF magnetic field among the locations based on the height of 1.8 m were performed. The result of LSD revealed, the mean ELF magnetic field at height 1.8 m for Shiroro switchyard performed significantly lower than Kainji switchyard with *p*-value of 0.006. Meanwhile, no statistically significant difference occurs between Jebba switchyard with Kainji and Shiroro switchyards.

Figures 2 to 4 are the respective 2D simulated profiles views of the ELF magnetic field spread in Jebba, Kainji and Shiroro 330 kV transmission switchyards using surfer software. The purple spots indicate some of the spots where the ‘constructed stand’ with mounted sensor of the metre was placed for field detection in the switchyards. For better visualisation of the ELF magnetic field spread, distinct profiling of the reference heights (1.0, 1.5 and 1.8 m) above the ground level corresponding with exposures at the waist, chest and head were performed.



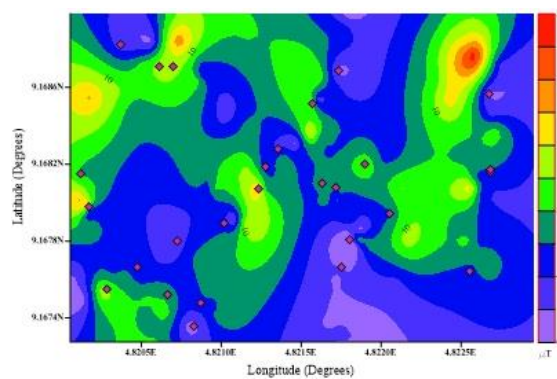
**Figure 2a.** Jebba magnetic field profile distribution at height 1.0 m

Figure 2a is the profile view of the measured ELF magnetic field at height of 1.0 m in Jebba transmission switchyard. There are five spots with relative high intensity presence but the highest peak was reached at the top right corner from the simulated. The field drift from lowest value of 0  $\mu\text{T}$  at contour interval of 2  $\mu\text{T}$  to reach peak value of 14  $\mu\text{T}$  against the selected spots.



**Figure 2b.** Jebba magnetic field profile distribution at height 1.5 m

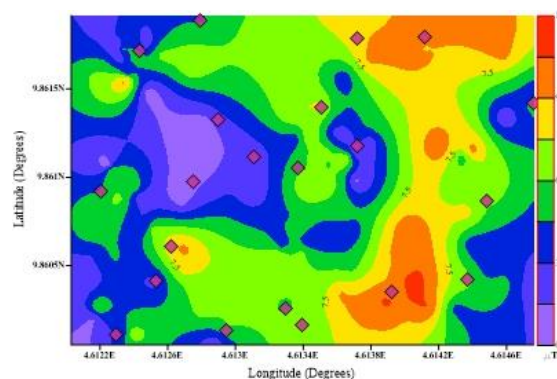
The profile view of Figure 2b is the measured ELF magnetic field at height of 1.5 m in Jebba transmission switchyard. The highest peak was attained at the top right location. The field trend starts from value of 0  $\mu\text{T}$  to peak value of 18  $\mu\text{T}$  at contour interval of 4  $\mu\text{T}$  against selected spots.



**Figure 2c.** Jebba magnetic field profile distribution at height 1.8 m

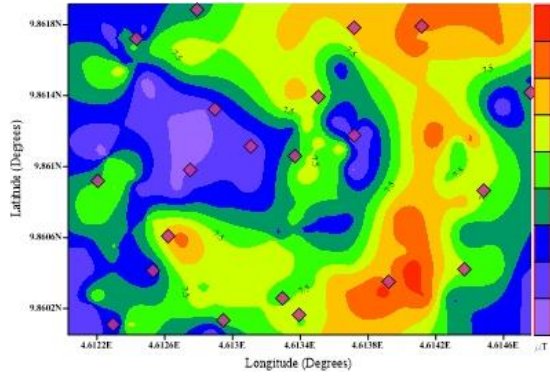
Figure 2c is the simulated profile of ELF magnetic field measurements at height of 1.8 m in Jebba transmission switchyard. The field trend against selected spots from least value of 0  $\mu\text{T}$  at contour interval of 4  $\mu\text{T}$  to reach maximum value of 20  $\mu\text{T}$ .

At Jebba, the ELF magnetic field spread patterns across heights in the switchyard as illustrated on Figures 2(a, b & c) followed similar distribution path with slight visible variations. However, intensity exposure levels differ across heights.



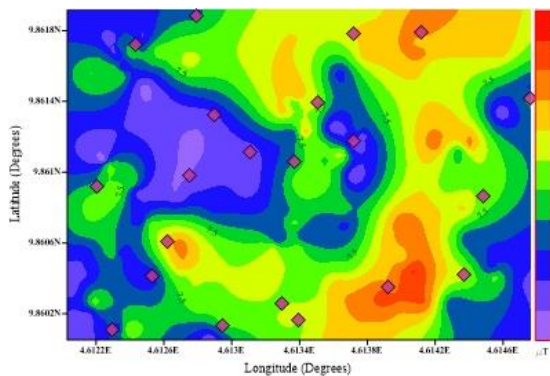
**Figure 3a.** Kainji magnetic field profile distribution at height 1.0 m

Figure 3a is the 2D visual profile of ELF magnetic field measurements at height of 1.0 m in Kainji transmission switchyard. The field trend from least value of 0  $\mu\text{T}$  at contour interval of 3  $\mu\text{T}$  to reach maximum value of 12  $\mu\text{T}$  against the selected spots.



**Figure 3b.** Kainji magnetic field profile distribution at height 1.5 m

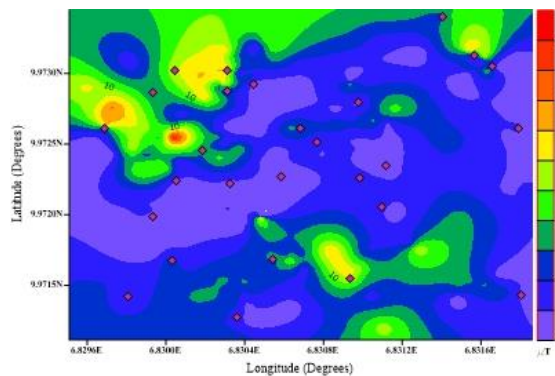
The ELF magnetic field 2D visual profile is shown on Figure 3b for measurements taken in Kainji transmission switchyard at height of 1.5 m. The field drift from minimum value of 0  $\mu\text{T}$  at contour interval of 3  $\mu\text{T}$  to reach maximum value of 13.5  $\mu\text{T}$  against the selected spots.



**Figure 3c.** Kainji magnetic field profile distribution at height 1.8 m

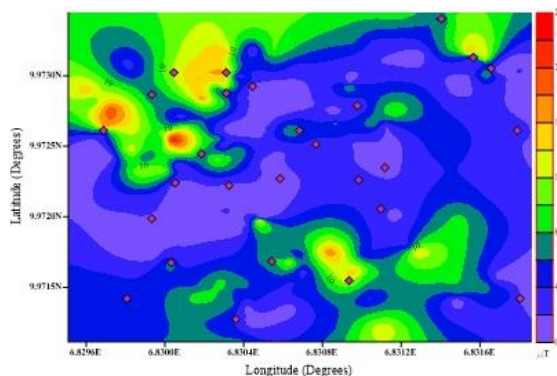
Figure 3c is profile view at height 1.8 m of measured ELF magnetic field in Kainji transmission switchyard. The field trend against the selected spots, from minimum value of 0  $\mu\text{T}$  at contour interval of 3  $\mu\text{T}$  to maximum value of 16.5  $\mu\text{T}$ .

At Kainji, the spread pattern across the reference heights of ELF magnetic field in the switchyard as illustrated on the Figures 3(a, b & c) have comparable spread with minor distinctions. Though, the exposure levels differ with increase height.



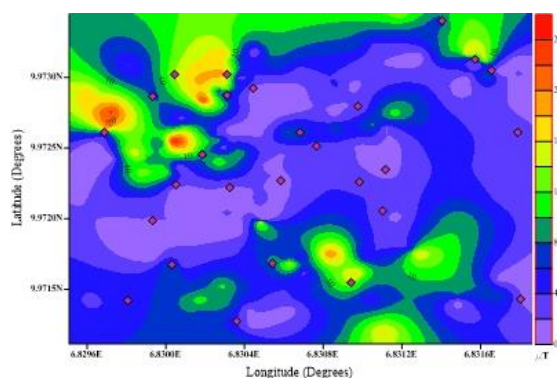
**Figure 4a.** Shiroro magnetic field profile distribution at height 1.0 m

The visual profile of ELF magnetic field measurements at height of 1.0 m in Shiroro transmission switchyard is illustrated on Figure 4a. The field trend from lowest value of 0  $\mu\text{T}$  to attain peak value of 30  $\mu\text{T}$  against the selected spots at contour interval of 4  $\mu\text{T}$ .



**Figure 4b.** Shiroro magnetic field profile distribution at height 1.5 m

Figure 4b is the profile view of measured ELF magnetic field at height of 1.5 m in Shiroro transmission switchyard. The designated spots field drift from minimum value of 0  $\mu\text{T}$  at contour interval of 4  $\mu\text{T}$  to attain maximum value of 24  $\mu\text{T}$ .



**Figure 4c.** Shiroro magnetic field profile distribution at height 1.8 m

Figure 4c is the plotted profile view of ELF magnetic field measurements at 1.8 m height in Shiroro transmission switchyard. The least value of field was 0  $\mu\text{T}$  and trend at contour interval of 4  $\mu\text{T}$  to attain maximum value of 26  $\mu\text{T}$  against the selected spots.

At Shiroro transmission switchyard, the pattern of spread of ELF magnetic field across heights are slightly different as shown on Figures 4(a, b & c) but the trend are similar. However, the exposure levels vary with rising height.

In summary, from all observations the magnitude of the ELF magnetic fields varies from one spot to the other but increases with respect to height level. Hence, irregular ELF magnetic field spread within the switchyard's vicinity. This variation pattern also corroborated prior study by [13], that in switchyard radiated magnetic fields are diverse. And is due to varying current and load on the buses and conductors in the switchyards.

More intense ELF magnetic field were generally recorded at 1.8 m height compare to other heights with values of 19.49  $\mu\text{T}$ , 15.26  $\mu\text{T}$  and 26.48  $\mu\text{T}$  as highest obtained during the measurements in Jebba, Kainji and Shiroro transmission stations switchyard respectively. Though the values are instantaneous and significantly low when compared to 1000  $\mu\text{T}$  occupational stipulated limit by ICNIRP. But the study has given clue on the intensity of magnetic field radiated across levels in the switchyards. Thus, from all indication the head region will likely experience unwarranted ELF magnetic field exposure than the chest and waist regions.

#### **4. Conclusion**

The pairwise comparative study of mean ELF magnetic field generated in hydropower transmission switchyards based on height has been analysed. Significant differences of mean magnetic

field were noticed between some locations, while nonsignificant differences occur between others. Furthermore, the 2D profiling gives better visualisation of magnetic field spread pattern within the vicinity of switchyards. These illustrate the nonuniformity of the distributions in switchyards but across the height, spread trend were similar with slight variations upward. The highest recorded value in the study locations was at height 1.8 m in Shiroro transmission switchyard station and is 2.65 % of the reference level of 1000  $\mu\text{T}$  stipulated by the ICNIRP for personnel occupational safety. Further studies that are based on hourly or daily monitoring of field levels should be understudy for better insight of fields intensity of the study locations.

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