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Research Article

Natural Radioelement Concentrations and Dose Rate Assessment Using High-Resolution Aeroradiometric Data of Dapchi and Biriri Areas, Upper Benue Trough, Nigeria

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Abstract

This study investigates the distribution of natural radioelements and the associated radiation exposure levels in the Dapchi and Biriri areas of the Upper Benue Trough, Nigeria, using high-resolution aeroradiometric data obtained from the Nigerian Geological Survey Agency (NGSA). The radiometric dataset was processed and interpreted using Oasis Montaj 8.4 and Surfer 14 to evaluate the concentrations of uranium (U), thorium (Th), and potassium (K), alongside their corresponding dose rates. The results reveal that uranium concentrations range from 1.56 to 2.90 ppm, thorium from 7.8 to 11.9 ppm, and potassium from 0.50 to 0.83%. Spatial analysis shows that the southwestern part of Dapchi exhibits the highest radioelement concentrations, a pattern attributed to the dominance of granitic and metamorphic formations enriched in radiogenic minerals. The computed dose rates vary between 0.402 and 0.472 mSv/year, with an average value of 0.439 mSv/year. Areas with elevated dose rates coincide with regions of high U, Th, and K concentrations, while lower values occur mainly in Biriri, corresponding to sedimentary lithologies such as sandstone and shale. Despite observable spatial variations, all recorded dose rate values remain below the globally recommended natural background radiation limit of 1.0 mSv/year. This indicates that the natural radiological environment within the study area presents minimal health risk to the local population and provides important baseline data for environmental monitoring and geoscientific studies.

Keywords

Dose Rate, Radioelements, Radiation, Upper Benue Trough

1. Introduction

Radionuclides occur naturally on the earth's crust since its origin. They are believed to have been produced when the matter of which the universe is formed first came into existence. The young earth probably contained a large number of elements than they are today. The short-lived radioactive elements decayed leaving those with half-life comparable to the estimated age of the earth. The distribution of these radionuclides on the Earth depends on the distribution of rocks from which they originate and the processes which concentrate them [5]. The major sources responsible for exposure

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are naturally occurring radionuclides in the earth's crust such as 238U, 232Th and 40K which occur in radiogenic minerals such as monazites and carbonatites. The Earth's crust contains naturally occurring radioactive materials which can cause much radiological hazards to the environment and human health [8]. Radiometric concentrations of naturally occurring radioactive materials variation are based on the geological geographical factors like the rock type, soil composition and location [7, 9, 10].

Airborne radiometric surveys are effective tools for mapping the surface distribution of these natural radioelements. They measure gamma-ray emissions from the uppermost layer of the Earth's surface to estimate the concentrations of uranium, thorium, and potassium [4, 11, 12]. These surveys provide valuable information for geological and environmental studies and are widely applied in mineral exploration, geochemical mapping, and radiation hazard assessment [3, 4]. Assessing radiometric concentrations and dose rates is therefore essential for understanding the natural radiation environment and evaluating potential health risks to local populations [6, 13-15]. The aim of this study is to determine the concentrations of uranium, thorium, and potassium, and to estimate the associated dose rates in the Dapchi and Biriri areas of the Upper Benue Trough, Nigeria, using high-resolution aeroradiometric data.

2. Location and Geology of the Study

The study area with the geographical coordinates of latitude 9.5^0 to 10.0^0 North and longitude 11.5^0 to 12.5^0 East with an area extent of approximately 6050 km^2 is located in the Upper Benue Trough. The Upper Benue Trough is part of the Benue Trough of Nigeria and is comprised of three basins: the east-west trending Yola Basin (Yola Arm), the north- south trending Gongola Basin (Gongola Arm) and the northeast- southwest trending Lau Basin (Main Arm). The geological map of Nigeria for the Upper Benue is shown in Figure 1. The earliest Cretaceous sequence is the continental Bima sandstone, which rests unconformably on the undulating PreCambrian Basement. The unit is a thick and widespread series of continental grits, sandstones and clays. In the north, these beds are wholly continental, but in the south, marine shales occur in the lower part of the formation [2].

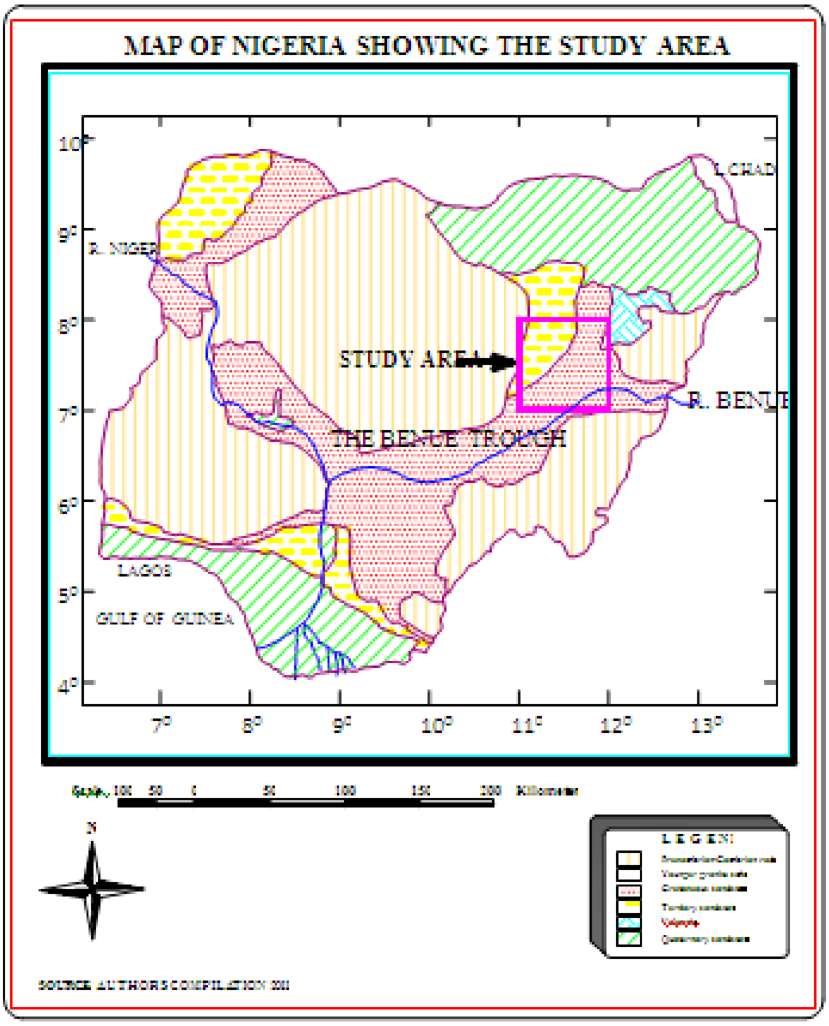


Figure 1. Map of Nigeria Showing the Study Area [1].

3. Materials and Methods

3.1. Materials

The materials used for this study include two high resolution aeroradiometric data of Dapchi (sheet 63) and Biriri (sheet 64) which were acquired from Nigerian Geological Survey Agency, Abuja (NGSA). The data obtained from the airborne survey was presented in digital form as a composite grid of 1:100,000 sheets covering the study area. Software applications that were used include: Oasis Montaj 8.4, and Surfer 14 software.

3.2. Methods

Merging and importing of the data to the software

The Uranium, Thorium and Potassium aeroradiometric data sheets of the study area were merged in Microsoft notepad software and imported into the Oasis Montaj 8.4 software for the data analysis.

Gridding of the Data

The data was gridded using the minimum curvature gridding algorithm of the oasis montaj software in order to obtain the Potassium, Thorium, Uranium and Totalcount grid of the study area for the quantitative interpretation.

Radioelement Dose Rate

To estimate the radioelement dose rate $D\,(mSv/year)$ value of the study area. The concentrations of Uranium, Potassium and Thorium were obtained from the geostatistical analysis of the radiometric data using the geostatistical toolkit of oasis montaj software 8.4. After which equation 1 was employed to compute the radioelement exposure rate and dose rate [6, 4].

$$D\,(mSv/year) = 0.0833\ (1.505C_k + 0.287C_{Th} + 0.653\,C_U) \quad (1)$$

where C_K, C_{Th} and C_U are the concentrations of thorium, uranium and potassium respectively. After calculating the dose rate values across the study area using equation 1. Surfer software were employed to produce the contour map of the Dose Rate of the area.

4. Results

4.1. Total Radiometric Anomalies Count Map

Figure 2 is the total count map of the three radioelements (Uranium (ppm), Thorium (ppm) and Potassium (%)) with a count of about 958.1 - 1474.4 cpt. The map shows high concentration of total count values at Dapchi area. There is low concentration of total count values majorly at Biriri areas (blue color).

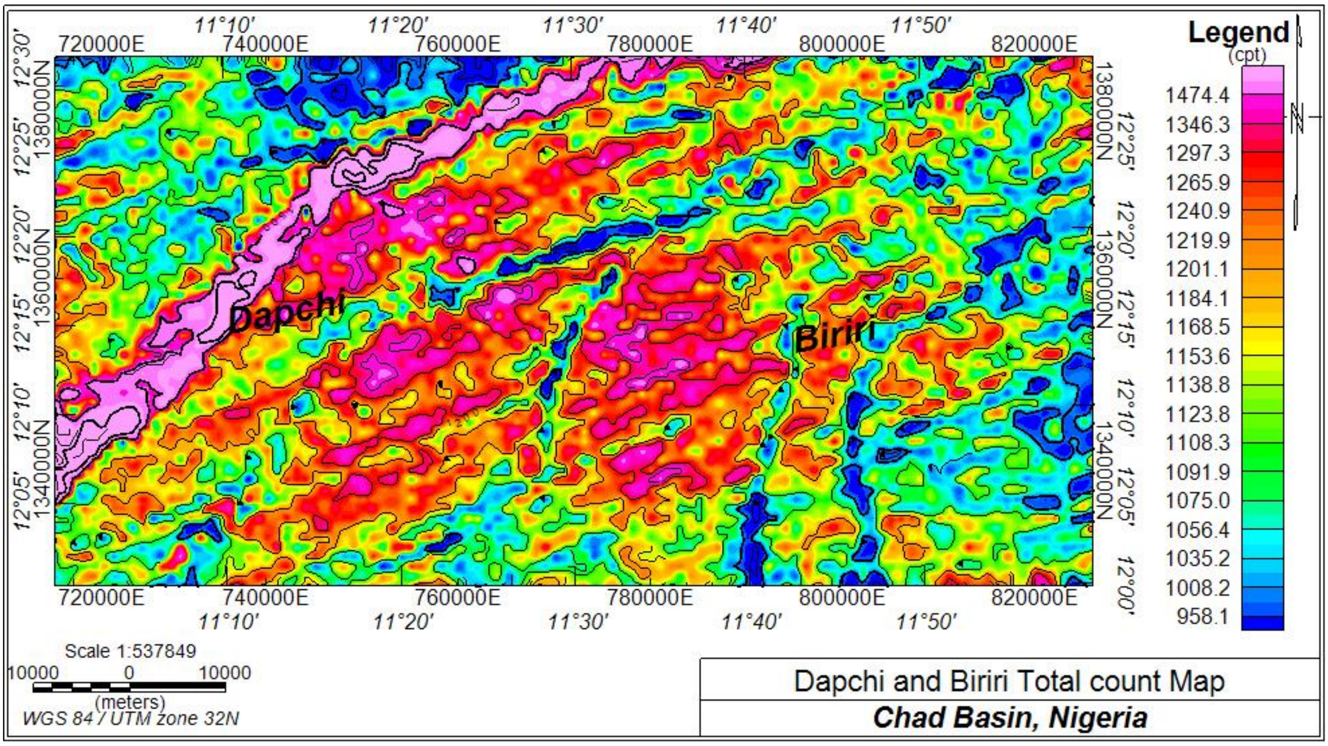


Figure 2. *Total Count Map of the Study Area.*

4.2. Uranium (U) Concentration Map

Figure 3 is the map of Uranium (U) concentrations in the area. Uranium abundances are in the range of 1.56 to 2.90 ppm but there are several zones of relatively high values distributed majorly around western Dapchi area which is represented by the pink color. The area of highly concentrated (pink colour) area roughly related to the presence of acidic igneous rocks such as granite.

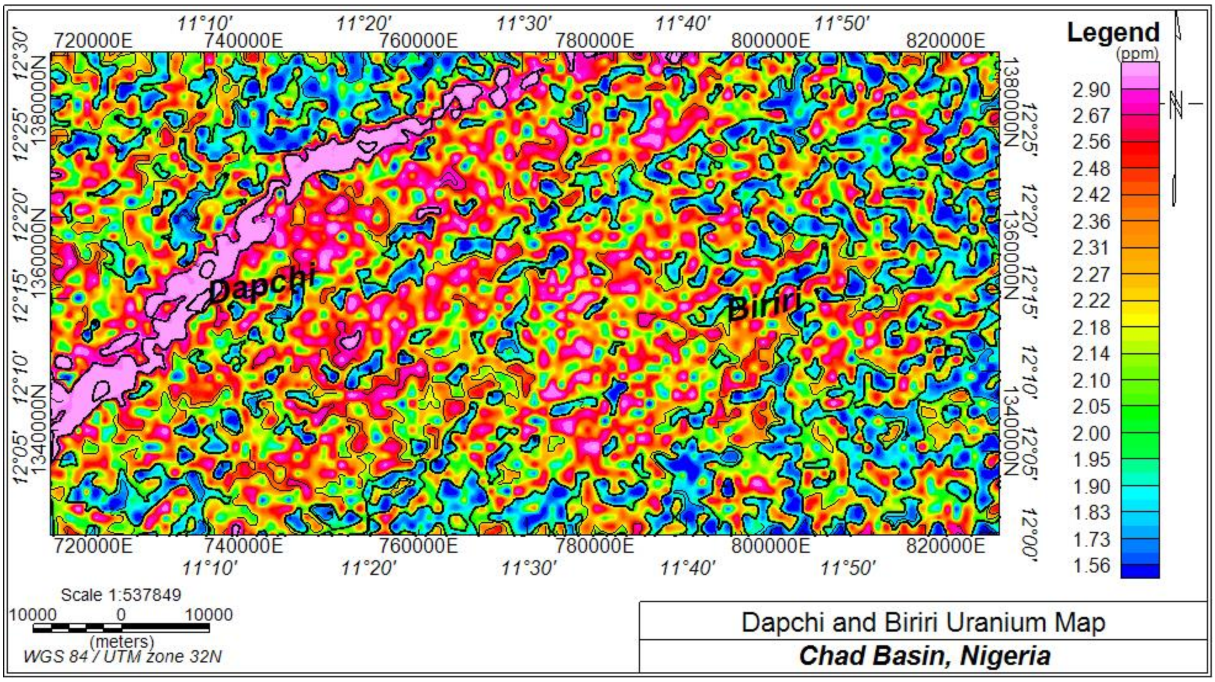


Figure 3. Uranium Map of the Study Area.

4.3. Thorium (Th) Concentration Map

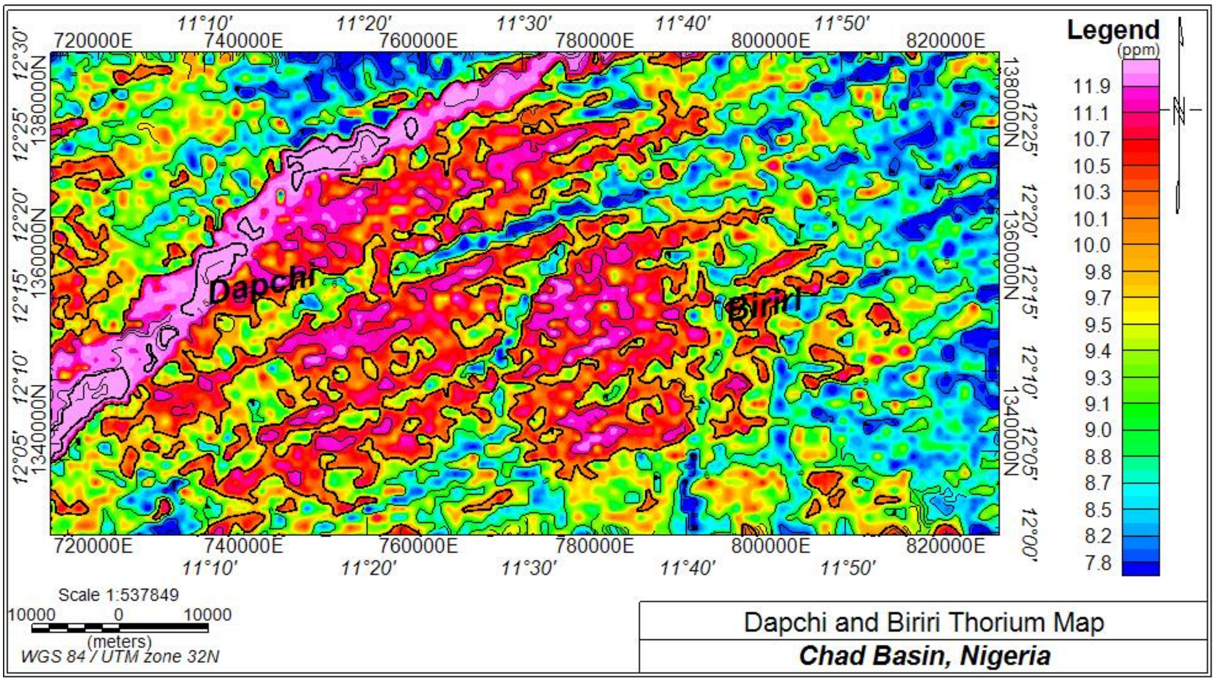


Figure 4. Thorium Map of the Study Area.

Figure 4 is the Thorium abundances are in the range of 7.8 to 11.9 ppm. This reveal that lower values (blue colour) of Thorium abundances are mostly around Biriri area, while the western part of Dapchi area with higher values (pink colour) of Thorium abundances (above 11.1 ppm) are possibly acidic igneous rock such as granite.

4.4. Potassium (K%) Concentration Map

Figure 5 is the map of Potassium (K) concentrations of the study area. The Potassium is in the range of 0.50 to 0.83%. The lower values of around 0.5% (blue colour) of K abundances are likely carbonate sedimentary rock bearing minerals such as shale and sandstone while higher values (pink colour) of K abundances are dominant in western Dapchi and southwestern Biriri areas which are likely metamorphic rock bearing minerals such as Schist.

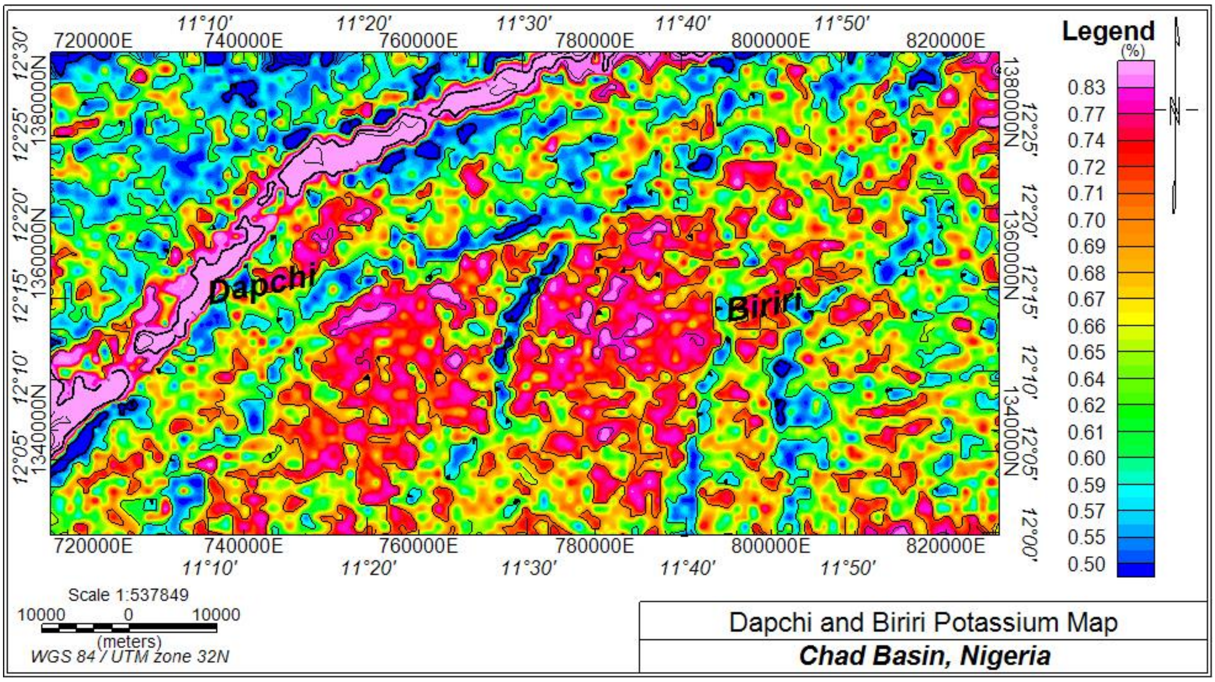
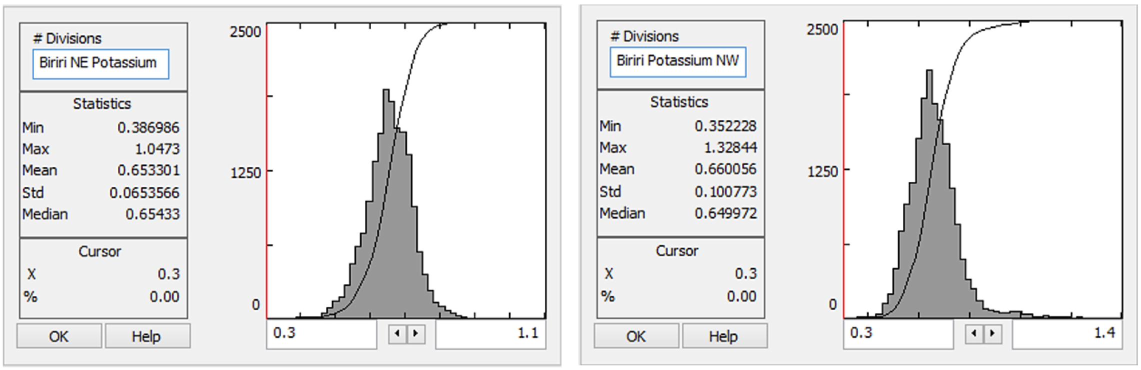


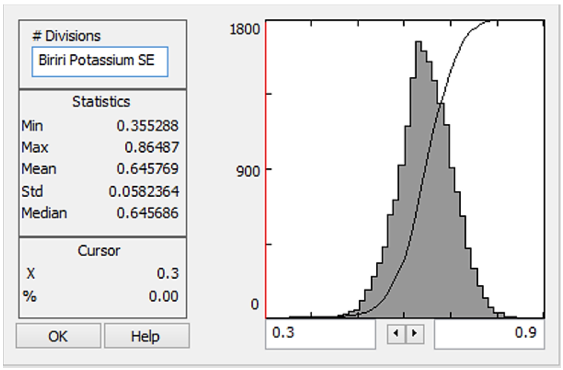
Figure 5. Potassium Map of the Study Area.

4.5. Radioelement Dose Rate Results

Table 1 presents a summary of the results of the analysis of dose rate values across the study area. The concentration of the radiometric elements was obtained from the histogram plots in Figure 6(a-x). The dose rate ranges from 0.402-0.472 mSv/year with an average value of 0.439 mSv/year. The minimum dose rate value of 0.402 mSv/year is observed around NE Biriri area while the maximum dose value of 0.472 mSv/year is observed around SW Dapchi area (Figure 7).

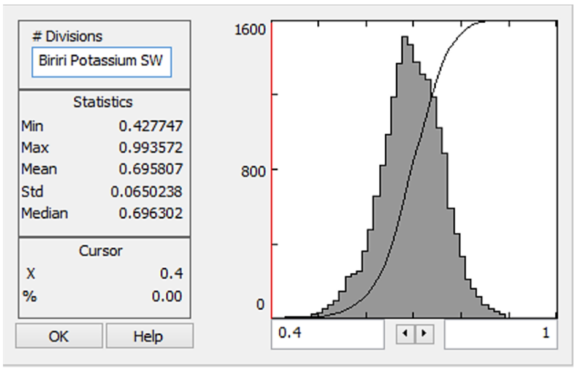


(a) (b)



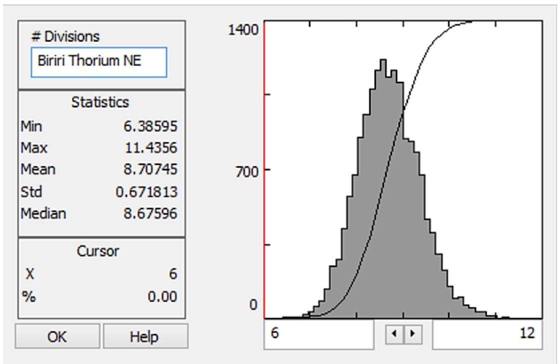
Divisions
Biriri Potassium SE
Statistics
Min 0.355288
Max 0.86487
Mean 0.645769
Std 0.0582364
Median 0.645686
Cursor
X 0.3
% 0.00
OK Help
1800
900
0
0.3
0.9

(c)



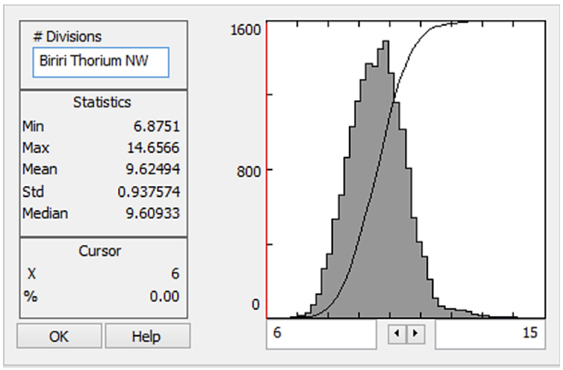
Divisions
Biriri Potassium SW
Statistics
Min 0.427747
Max 0.993572
Mean 0.695807
Std 0.0650238
Median 0.696302
Cursor
X 0.4
% 0.00
OK Help
1600
800
0
0.4
1

(d)



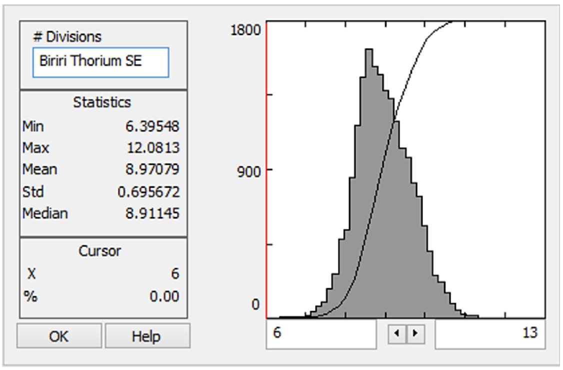
Divisions
Biriri Thorium NE
Statistics
Min 6.38595
Max 11.4356
Mean 8.70745
Std 0.671813
Median 8.67596
Cursor
X 6
% 0.00
OK Help
1400
700
0
6
12

(e)



Divisions
Biriri Thorium NW
Statistics
Min 6.8751
Max 14.6566
Mean 9.62494
Std 0.937574
Median 9.60933
Cursor
X 6
% 0.00
OK Help
1600
800
0
6
15

(f)



Divisions
Biriri Thorium SE
Statistics
Min 6.39548
Max 12.0813
Mean 8.97079
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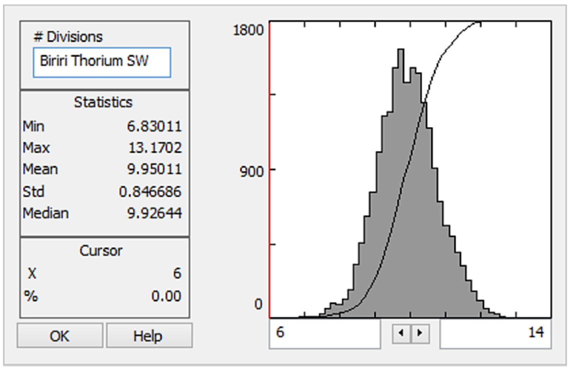
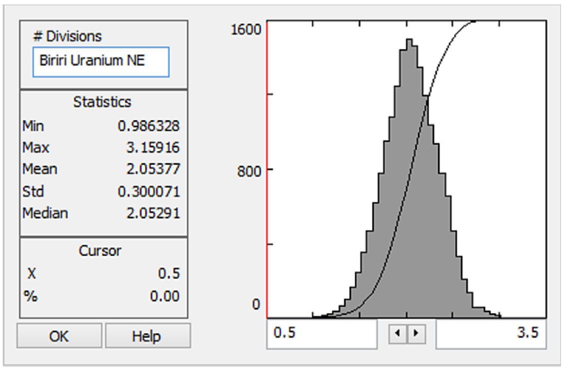
Median 8.91145
Cursor
X 6
% 0.00
OK Help
1800
900
0
6
13

(g)



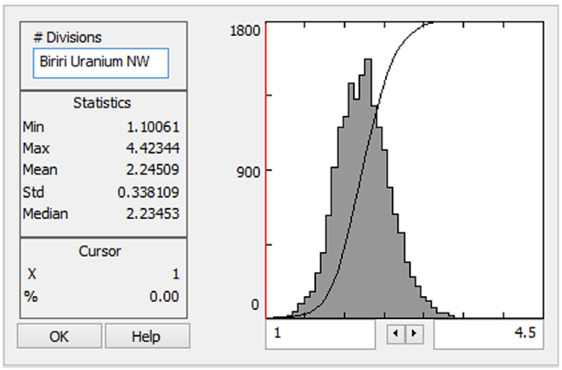
Divisions
Biriri Thorium SW
Statistics
Min 6.83011
Max 13.1702
Mean 9.95011
Std 0.846686
Median 9.92644
Cursor
X 6
% 0.00
OK Help
1800
900
0
6
14

(h)



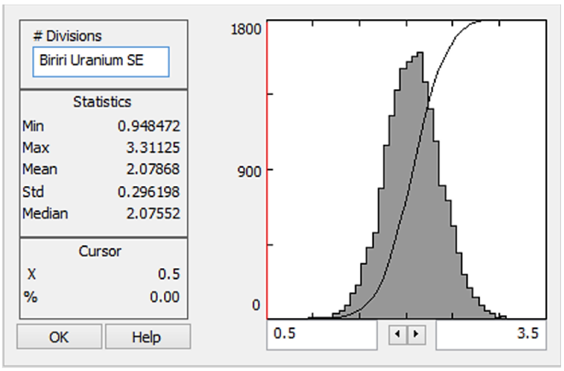
Divisions
Biriri Uranium NE
Statistics
Min 0.986328
Max 3.15916
Mean 2.05377
Std 0.300071
Median 2.05291
Cursor
X 0.5
% 0.00
OK Help
1600
800
0
0.5
3.5

(i)

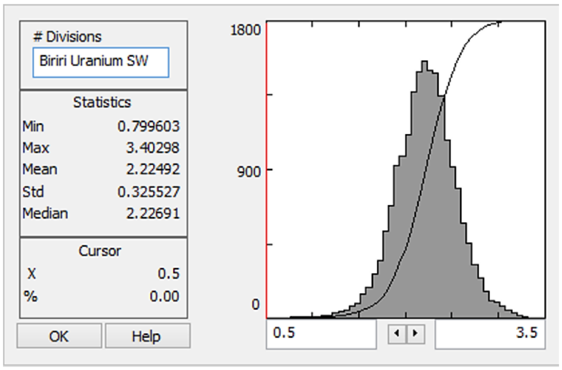


Divisions
Biriri Uranium NW
Statistics
Min 1.10061
Max 4.42344
Mean 2.24509
Std 0.338109
Median 2.23453
Cursor
X 1
% 0.00
OK Help
1800
900
0
1
4.5

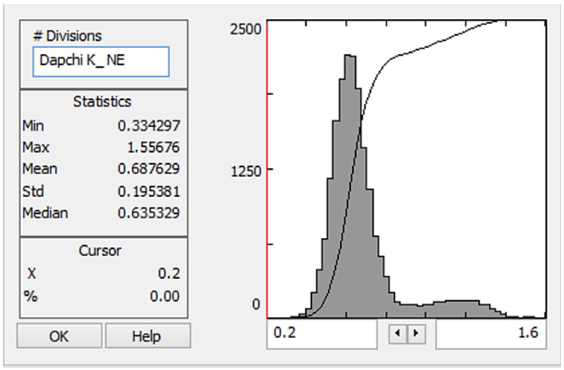
(j)


Divisions
Biriri Uranium SE
Statistics
Min 0.948472
Max 3.31125
Mean 2.07868
Std 0.296198
Median 2.07552
Cursor
X 0.5
% 0.00
OK
Help
1800
900
0
0.5
3.5

(k)


Divisions
Biriri Uranium SW
Statistics
Min 0.799603
Max 3.40298
Mean 2.22492
Std 0.325527
Median 2.22691
Cursor
X 0.5
% 0.00
OK
Help
1800
900
0
0.5
3.5

(l)


Divisions
Dapchi K_NE
Statistics
Min 0.334297
Max 1.55676
Mean 0.687629
Std 0.195381
Median 0.635329
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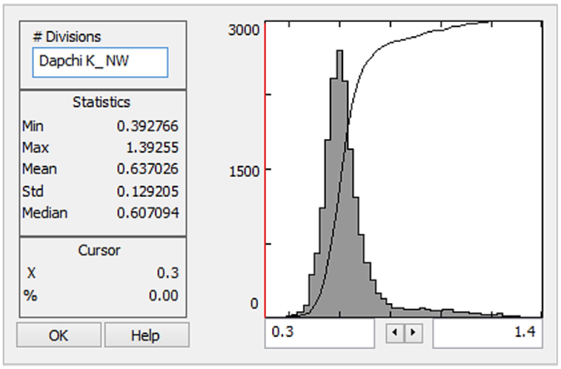
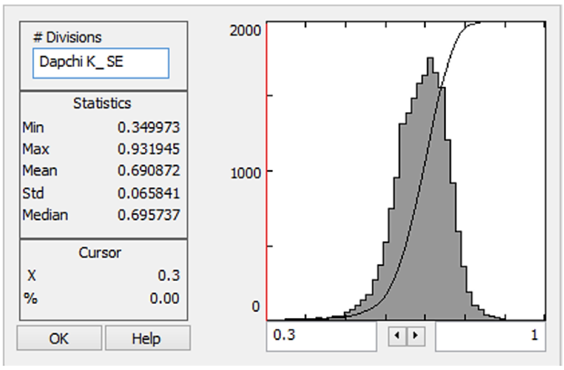
% 0.00
OK
Help
2500
1250
0
0.2
1.6

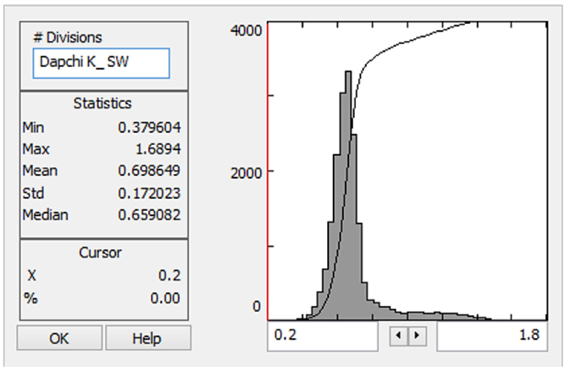
(m)


Divisions
Dapchi K_NW
Statistics
Min 0.392766
Max 1.39255
Mean 0.637026
Std 0.129205
Median 0.607094
Cursor
X 0.3
% 0.00
OK
Help
3000
1500
0
0.3
1.4

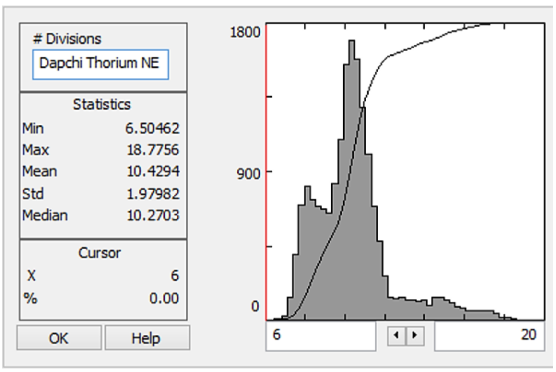
(n)


Divisions
Dapchi K_SE
Statistics
Min 0.349973
Max 0.931945
Mean 0.690872
Std 0.065841
Median 0.695737
Cursor
X 0.3
% 0.00
OK
Help
2000
1000
0
0.3
1

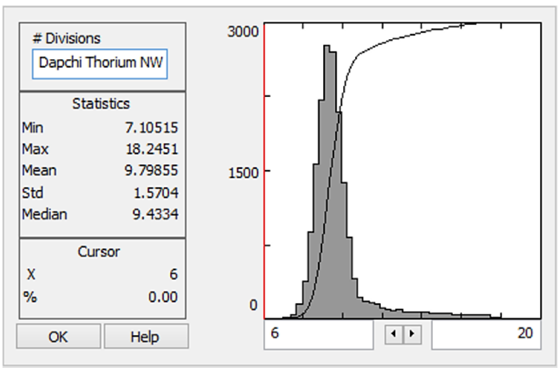
(o)


Divisions
Dapchi K_SW
Statistics
Min 0.379604
Max 1.6894
Mean 0.698649
Std 0.172023
Median 0.659082
Cursor
X 0.2
% 0.00
OK
Help
4000
2000
0
0.2
1.8

(p)


Divisions
Dapchi Thorium NE
Statistics
Min 6.50462
Max 18.7756
Mean 10.4294
Std 1.97982
Median 10.2703
Cursor
X 6
% 0.00
OK
Help
1800
900
0
6
20

(q)


Divisions
Dapchi Thorium NW
Statistics
Min 7.10515
Max 18.2451
Mean 9.79855
Std 1.5704
Median 9.4334
Cursor
X 6
% 0.00
OK
Help
3000
1500
0
6
20

(r)

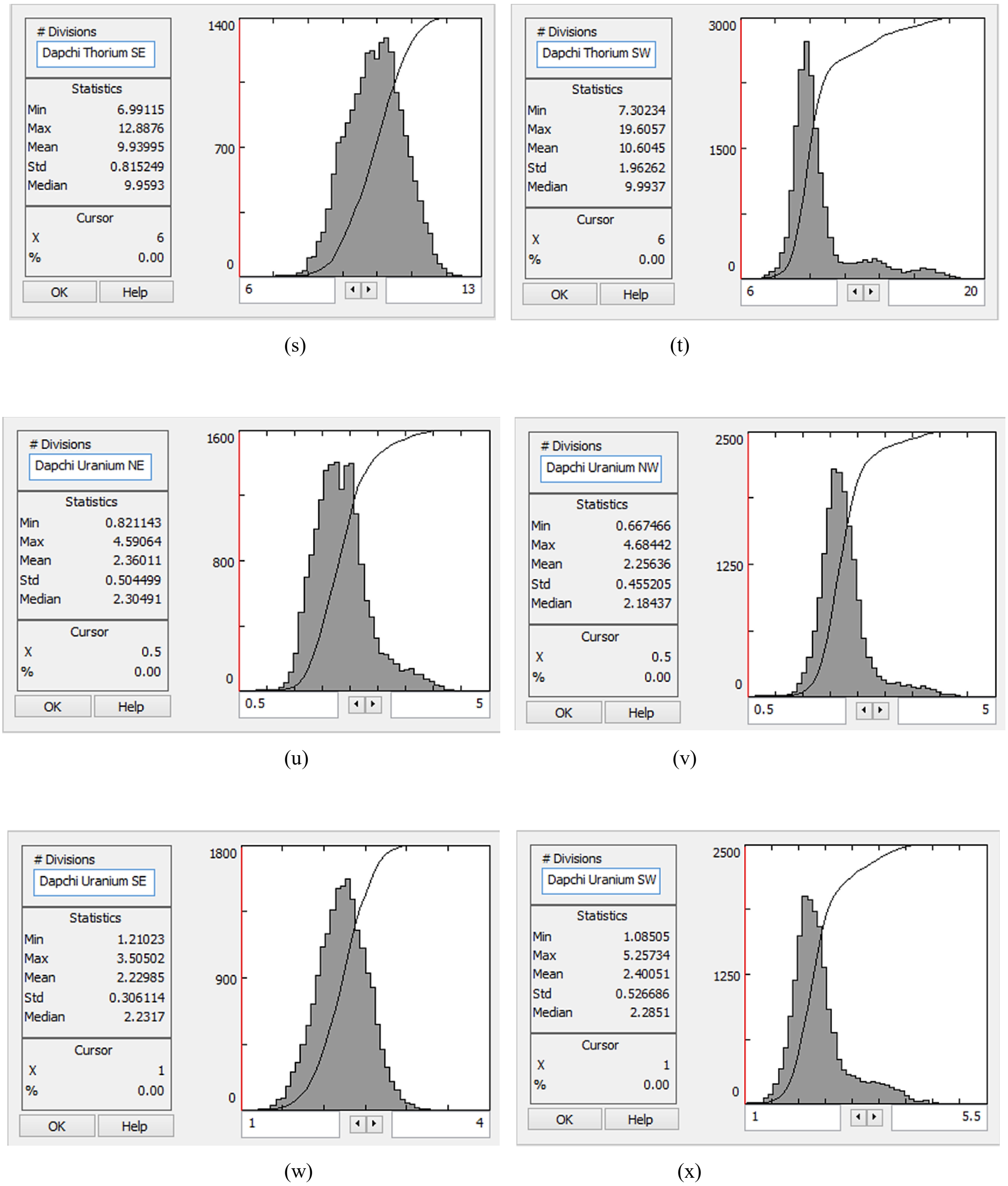


Figure 6. *(a): Biriri NE Potassium Histogram Plot; (b): Biriri NW Potassium Histogram Plot; (c): Biriri SE Potassium Histogram Plot; (d): Biriri SW Potassium Histogram Plot; (e): Biriri NE Thorium Histogram Plot; (f): Biriri NW Thorium Histogram Plot; (g): Biriri SE Thorium Histogram Plot; (h): Biriri SW Thorium Histogram Plot; (i): Biriri NE Uranium Histogram Plot; (j): Biriri NW Uranium Histogram Plot; (k): Biriri SE Uranium Histogram Plot; (l): Biriri SW Uranium Histogram Plot; (m): Dapchi NE Potassium Histogram Plot; (n): Dapchi NW Potassium Histogram Plot; (o): Dapchi SE Potassium Histogram Plot; (p): Dapchi SW Potassium Histogram Plot; (q): Dapchi NE Thorium Histogram Plot;(r): Dapchi NW Thorium Histogram Plot; (s): Dapchi SE Thorium Histogram Plot; (t): Dapchi SW Thorium Histogram Plot; (u): Dapchi NE Uranium Histogram Plot; (v): Dapchi NW Uranium Histogram Plot; (w): Dapchi SE Uranium Histogram Plot; (x): Dapchi SW Uranium Histogram Plot.*

Table 1. *Summary Results of Dose Rate Values of the Study Area.*

S/N	Locations	Long (o)	Lat (o)	K (%) Mean	Th (ppm) Mean	U (ppm) Mean	Dose Rate (mSv/year)
1	SW Dapchi	11.1	12.1	0.699	10.605	2.401	0.472

S/N	Locations	Long (o)	Lat (o)	K (%) Mean	Th (ppm) Mean	U (ppm) Mean	Dose Rate (mSv/year)
2	SE Dapchi	11.4	12.1	0.691	9.940	2.230	0.446
3	SW Biriri	11.6	12.1	0.696	9.950	2.225	0.446
4	SE Biriri	11.9	12.1	0.646	8.971	2.079	0.409
5	NW Dapchi	11.1	12.4	0.637	9.799	2.256	0.437
6	NE Dapchi	11.4	12.4	0.688	10.429	2.360	0.464
7	NW Biriri	11.6	12.4	0.660	9.625	2.245	0.435
8	NE Biriri	11.9	12.4	0.653	8.707	2.054	0.402
	Average						0.439

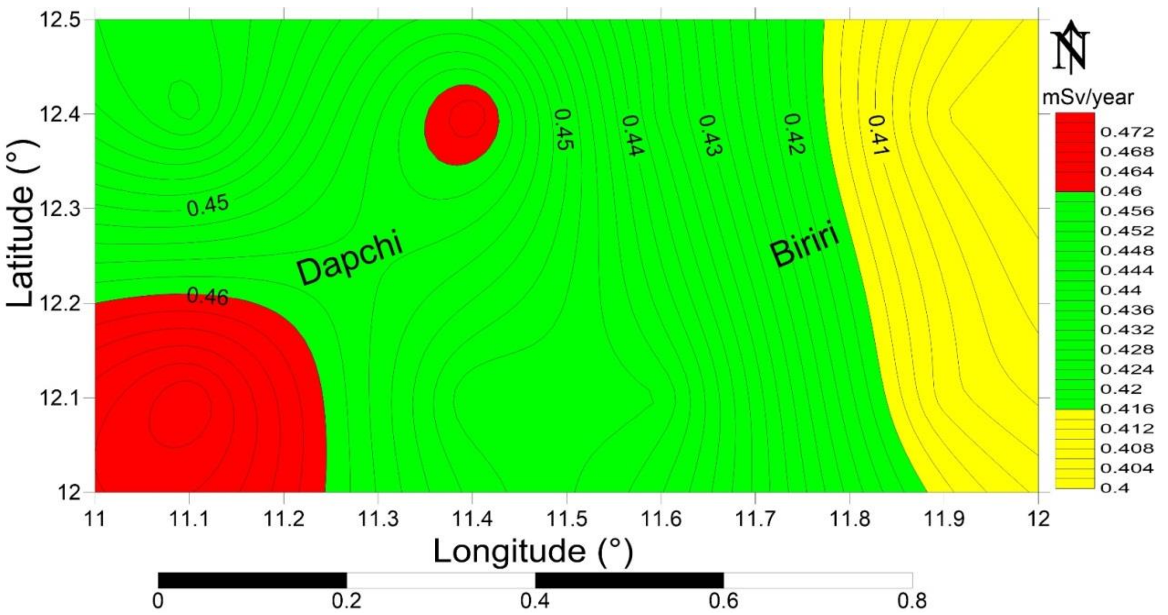


Figure 7*. Radiometric Dose Rate Map (Contour 0.002).*

5. Discussion

The radiometric data analysis reveals spatial variation in the concentrations of Uranium, Thorium, and Potassium across the study area. The western part of Dapchi consistently shows higher values of all three radioelements, which correlates with the presence of acidic igneous rocks such as granite. Potassium concentrations in the range of 0.50-0.83% also suggest the influence of metamorphic formations, particularly schist in southwestern Biriri and Dapchi. The dose rate map (Figure 7) further affirms this observation, with the highest values centered around the SW Dapchi area. This region recorded a dose rate of 0.472 mSv/year. These values, although higher than other parts of the study area, remain below the internationally recommended safety threshold for natural background radiation of 1.0 mSv/year [4, 6, 8]. Lower radiation levels were observed in NE Biriri (0.402 mSv/year), likely due to the dominance of sedimentary formations such as shale and sandstone, which typically have lower natural radioelement content. Generally, the average dose rate for the area (0.439 mSv/year) indicates a low radiation risk environment.

6. Conclusion

This study successfully evaluated the distribution of natural radioelements and the corresponding radiation dose rates in the Dapchi and Biriri areas of the Upper Benue Trough, Nigeria, using high-resolution aeroradiometric data. The results revealed distinct spatial variations in Uranium, Thorium, and Potassium concentrations across the study area, reflecting the influence of underlying lithological and structural features. High concentrations of Uranium (1.56-2.90 ppm), Thorium (7.8-11.9 ppm), and Potassium (0.50-0.83%) were observed predominantly in the southwestern part of

Dapchi, which corresponds to granitic and metamorphic rock formations known for their higher radiogenic content. The computed dose rates ranged from 0.402 to 0.472 mSv/year, with an average value of 0.439 mSv/year. These values are below the internationally recommended exposure limit of 1.0 mSv/year for the general public [4, 8], indicating that the natural background radiation in the study area poses no significant radiological health risk.

Acknowledgments

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Author Contributions

Nwobodo Anthonia Ndidi: Conceptualization, Funding acquisition, Resources, Supervision, Writing – review & editing

Uduma Ifeanyi Awa: Conceptualization, Funding acquisition, Writing – original draft

Nnamani John Friday: Funding acquisition, Project administration, Writing – original draft

Abangwu Uchenna Johnson: Formal Analysis, Methodology, Resources, Software, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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