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Correlation of Radiation Doses from Radiometric data and Aero-magnetic Signatures over Parts of Southeastern Nigeria

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Abstract: Ground radiometric and aeromagnetic dataset studies were carried out in some parts of Southeastern Nigeria. The study area is bounded by latitudes 5°00^1 N and 6°30^1 N and longitudes 7°00^1 E and 8°30^1 E, covering an area extent of about 27,225km^2. Acquisition, processing, interpretation and analysis of data from both methods were integrated to better understand the geologic bodies that generated the geothermal source in the study area as different rock types have varying radioelement concentration. Spectrometer (RS 230) was used for radiometric data acquisition and magnetic data was acquired from Nigerian Geological Survey Agency (NGSA). The radiometric data analysis and interpretation revealed that the mean concentrations of the radionuclides Uranium (U), Thorium (Th) and Potassium (K) in the study area are respectively 3.02ppm, 11.22ppm and 0.43% which are within the standard average of 2.973ppm, 11.084ppm and 1.342% respectively. The concentration of the radionuclides in the study area are in the order (U < Th < K) which indicates preferential enrichment of Potassium to both Uranium and Thorium. The absorbed dose rate in the study area varied from 7.5 nGyph^{-1} to 247.10 nGyph^{-1} with an average value of 53.38 nGyph$^{-1.}$ The average absorbed dose rate for the study area is lower than the standard average value of 60nGyph^{-1}. Magnetic result revealed sediment thickness of 2 to 6km within the study area, Curie point depth value of 20.416 to 29.544 km, Geothermal gradient of 16.92 to 26.78 °ckm^{-1} and Heat flow of 42.30 to 66.95mwm^{-2}. The result reveals that the Curie Point Depth varies inversely with heat flow. This shows that heat flow decreases with increases in curie depth.

1. Introduction

1.1. Radiometric method

Radio nuclides 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 (Mohanty *et al.*, 2004). The major sources responsible for exposure are naturally occurring radionuclides in the earth's crust such as ^{238}U, ^{232}Th

and ^{40}K which occur in radiogenic minerals such as monazites and carbonatites. Several studies (United Nations Scientific Committee on Effects of Atomic Radiation UNSCEAR, 2000; Malanca *et al*., 1993; Mohanty *et al*., 2004) have shown that there are few regions in the world, which are known for high background radiation due to the local geology and geochemical effects that cause enhanced levels of terrestrial radiation.

1.2. Basic Principle of Radiometrics

The nuclei of certain elements disintegrate spontaneously emitting energetic corpuscular and electromagnetic radiation and, in doing so, are transformed into nuclei of other elements. The alpha (Helium nuclei) and beta (positron or electron) particles and gamma (γ) radiation are emitted from the process. This phenomenon of spontaneous disintegration and emission of radiation is known as radioactivity. Of the three radiations, the gamma (γ) radiation is successfully used for exploration purposes due to its better penetration power. Although about fifty naturally occurring elements are known to be radioactive, only uranium (U), thorium (Th) and isotope of potassium (K) are found to be important for exploration purposes (IAEA, 2003).

Atoms are the smallest particles of mass with distinctive chemical properties. An atom consists of a nucleus surrounded by electrons. The nucleus consists of positively charged protons, and uncharged neutrons. The diameter of an atom is of the order 10^{-10} m, and the diameter of a nucleus is of the order 10^{-15} m. Protons and neutrons have a mass of 1.67×10^{-27}kg. The mass of negatively charged electrons is 9.11×10^{-31} kg. The elementary charge is 1.602×10^{-19} C. The number of protons in a nucleus of an element, X, is the proton number Z (also called the atomic number). The sum of the protons and neutrons (nucleons) is the mass number, A, of an atom. Atoms of an element having the same atomic number but different numbers of neutrons (i.e. different mass numbers) are called isotopes. Isotopes are denoted by their chemical symbol and their mass number as follows - ^{A}X. Isotopes have identical chemical properties, but different physical properties. Atoms having identical numbers of protons and neutrons are named nuclides. The atomic nuclei of some isotopes have a surplus of energy, are unstable, and disintegrate to form more stable nuclei of a different isotope. This process is accompanied by the emission of particles or energy, termed nuclear radiation. Nuclides with this feature are called radionuclides and the process is called nuclear decay or disintegration. The radioactivity decay law expresses the decrease in the number of atoms of a radionuclide with time:

$$N_t = N_0 e^{-\lambda t} \qquad \textbf{Eqn. 1}$$

Where N_t = the number of atoms present after time t (s);
N_0 = the number of atoms present at time $t = 0$;
λ = the decay constant of a radionuclide (s^{-1}),
A related constant, the half-life $T_{1/2}$ (s), is the time taken for half the radionuclides to decay:

$$T_{1/2} = \frac{0.693}{\lambda} \qquad \textbf{Eqn. 2}$$

The product λN gives the activity (Bq) of the radionuclides. Radioactive decay is independent of other physical conditions.

1.3. Magnetic method

Magnetic method is a geophysical technique commonly used to identify and image subsurface targets in a wide range of applications from archaeological site investigations to regional scale studies (Telford *et al*., 1990). It involves measurements of the direction, gradient, or intensity of the Earth's magnetic field caused by local differences in the magnetization of the subsurface rocks and soils and interpretation of variations in these quantities over the area of investigation. Magnetic surveys can be made on the land surface, from an aircraft, or from a ship. Most exploration surveys made today measure either the relative or absolute intensity of the total field or the vertical component. Measurements of magnetic intensity can be made with simple mechanical balances or with elaborate electronic instruments. With the development in instrumentation and interpretation techniques, many projects have been made for reconfirmation of prospective geothermal areas, analysis of regional relationships among known geothermal areas, and discovery of new geothermal prospects using the creation of a Curie point depth map as an integral part of the exploration.

2. Location of the Study Area

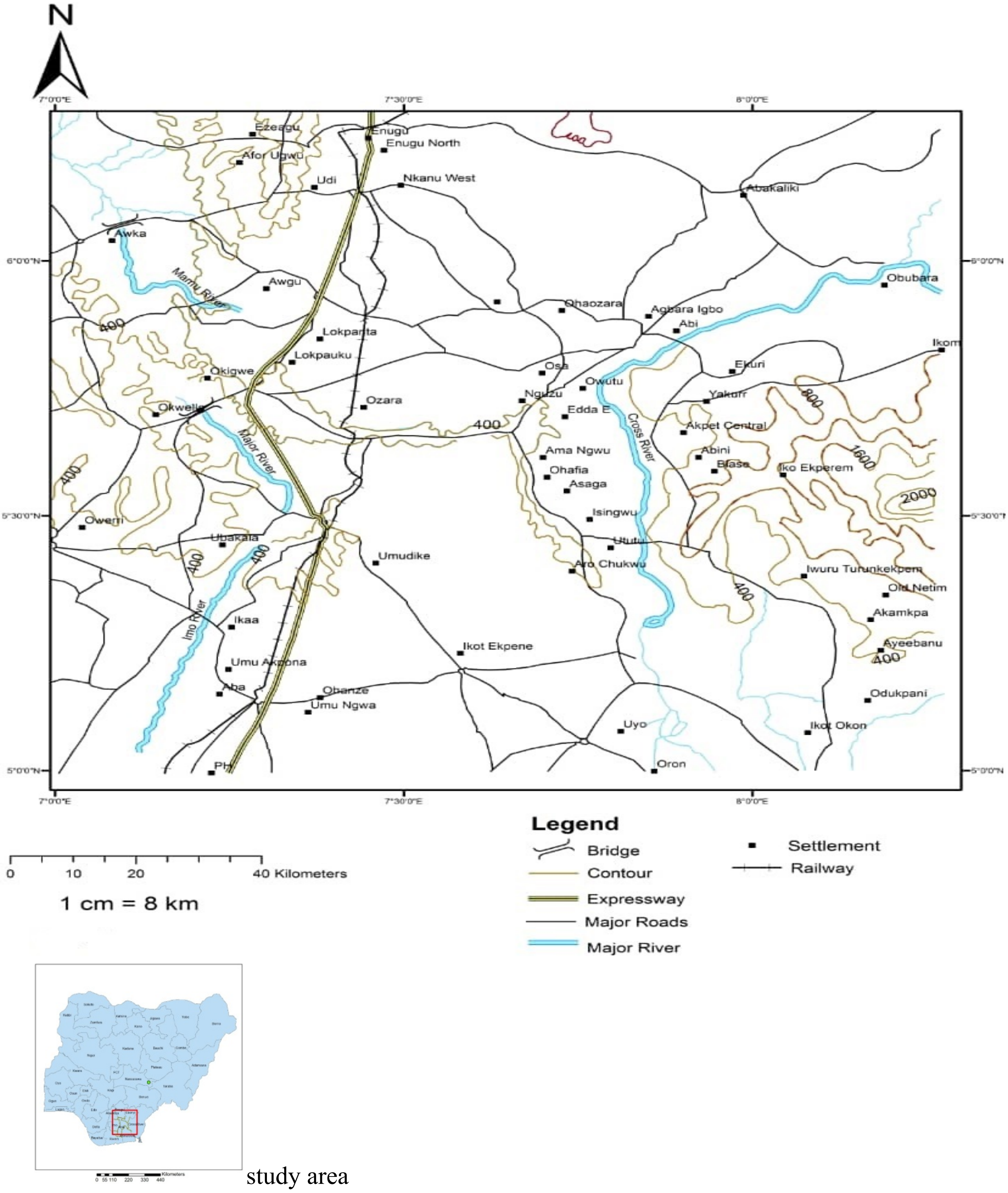
The study area lies between longitudes 7°00'E and 8°30'E and latitudes 5°00'N and 6°30'N (Figure 1). It is within the southeastern Nigerian Cretaceous sedimentary basins which extend from Enugu in the north to Uyo in the south and Orsu and Ikot Ekpene communities in the east and west respectively covering a total area of about 27,225Km^2. The major towns within the area is Abakaliki, Nkalagu and Afikpo in Ebonyi State, Enugu and Udi in Enugu State, Ugep and Odukpani in Cross River State, Ikot Effang and Uyo in Akwa Ibom State, Umuahia and Aba in Abia State, Oru and Okigwe in Imo State and Chokoche and Abara in Rivers State.

2.1. Geologic Setting of Southeastern Nigeria

Geological studies (figure 2) in Southeastern Nigeria have been reported widely in literatures by many authors such as (Peters, 1978; Carter *et al*., 1963; Cratchley and Jones, 1965; Offodile,1976) etc. Structural movement in the area began in Coniacian time and culminated during the Santonian. The Benue-Abakaliki Trough was uplifted to form the Abakaliki anticlinorium along some NE – SW axis. The structural inversion was accompanied by the formation of depression on either flank- the small Afikpo Sub-basin on the southeast and the much wider Anambra Basin on the northwest, thus there existed three sedimentary basins from Companian to the Paleocene; the Anambra Basin and the Afikpo Sub-basin separated by the Abakaliki High (Cratchley and Jones, 1965). The stratigraphy and sedimentological history of the study area is well documented by (Peters, 1978). The major controls of sedimentation in the trough resulted from world-wide eustatic changes in sea level and basin tectonics.

3. Methodology

RS – 230 BGO Spectrometer was used for the spectrometric survey. The RS-230 BGO Spectrometer is the industry standard portable handheld gamma ray survey device for geophysical applications. It offers an integrated design with a large detector, data storage, and full weather protection, easy to use and of high sensitivity. Easy to use Bluetooth (BT), Connectivity provides wireless connection to a Bluetooth enabled external GPS receiver, earphone or computer. The survey was carried out along roads and footpath at a station spacing of 500 m. The parameters measured are the uranium, thorium, and potassium. Airborne magnetic data and geologic map of the study area was sourced from Nigerian Geological Survey Agency (NGSA). The 9 data sheets used include 301, 302, 303, 311, 312, 313, 321, 322 and 323.



study area

Figure 1. **Location/Topographic Map of Study Area**

4. Results and Discussion

4.1. Radiometric results and discussion

4.1.1 Uranium concentration

Uranium concentration (Figure 3) is higher around Ayeebam, Akampa, Old Netim and Turunkekpem with values ranging from 3.5 ppm to >4.3 ppm while lower concentration of uranium is observed in the Ezeagu, AforUgwu, Udi, Orumba, Aka Ihobe, Oyi, Nnewi, Orsu, Obaku, Okuku, Owerri, Umuoru and Ntigha with values ranging from 0.5 ppm to 1.7 ppm. High uranium count is also observed within the Southern Benue Trough, around Abakaliki, Ezza North and South, Ezzamgbo, Izzi, Onuba, Agbani and Ohaozara.

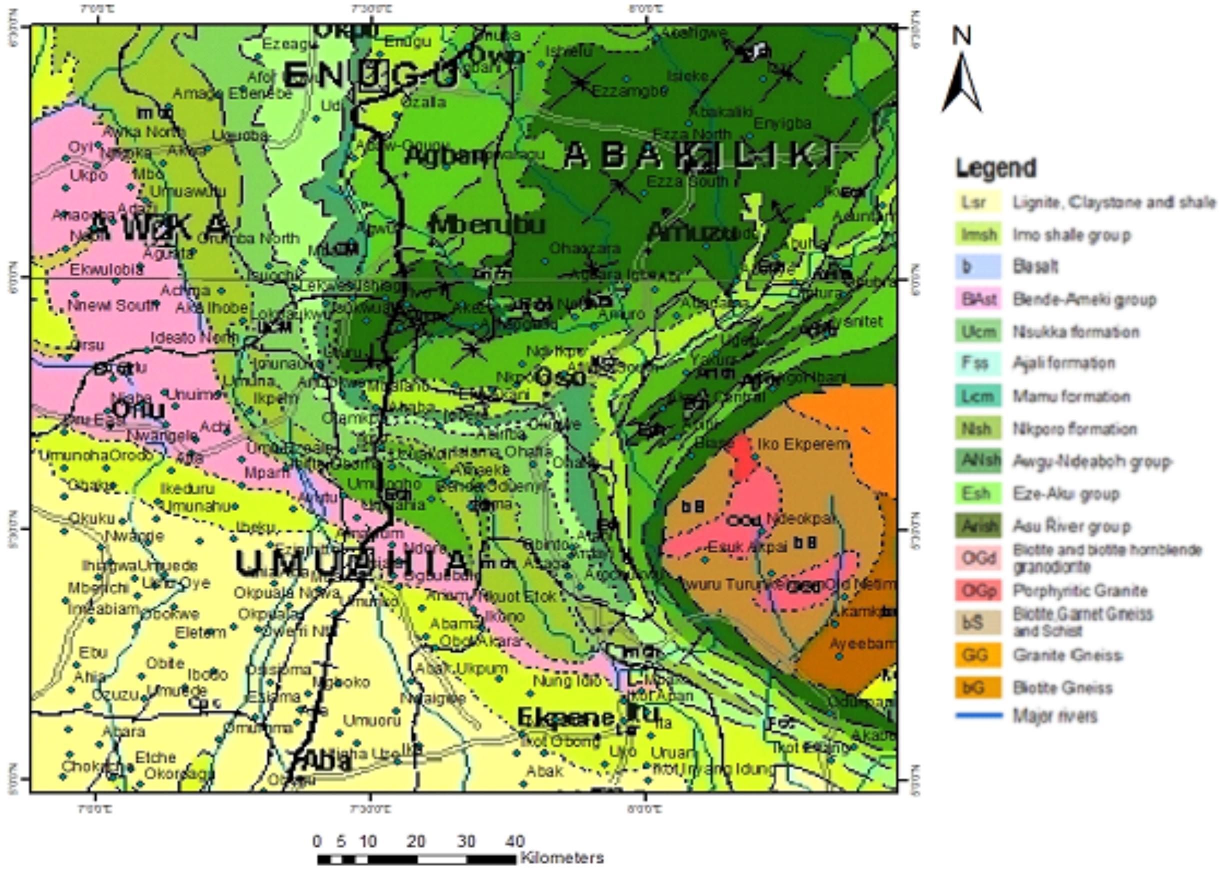


Figure 2. Geology map of the study area

The area around the basement complex at AgoiIbani, Biase, IkoEkperem and Ndeokpai show low uranium concentration. High concentration of uranium is also observed within the Niger Delta Basin, around Imogwa, Etche, Okoroagu, Omoecheigbo, Agbara, Omodema, Ozuzu, Ahia, Ebu and Mberichi with values ranging from 2.8 ppm to 3.9 ppm.Uranium distribution actually results from five main phenomena: partial melting, magmatic differentiation, and late magmatic processes, hydrothermal and meteoric alterations. Uranium and thorium are generally enriched in the youngest, most felsic and most potassic members of igneous rocks, this is observed around Ayeebam, Akamkpa, Old Netim and Turunkekpem. Uranium is a more mobile element than thorium, so if thorium is a very good indicator of the magmatic processes, uranium is a good indicator for the post-magmatic alteration processes. Uranium and thorium are enriched within the Southern Benue Trough. This resulted from hydrothermal and meteoric alterations of Asu River Group Shale and Ezeaku Shale, during the middle Santonian. The areas with intrusive rocks within this area show high potassium count, with generally low uranium and thorium concentration.

4.1.2. Thorium concentration

The thorium map (Figure 4) shows high anomaly within the southern Benue Trough. An anomalous high thorium body is also observed around Ayeebam, Akampa, Old Netim and Turunkekpem with range of about 12 ppm to 18.3 ppm. Anambra, Afikpo and Niger Delta Basin generally shows weak concentration ranging from 3.2 ppm to 6.8 ppm, the intermediate values are observed around Awka, Nobi, Adazi, Ideato, Owerri, Umu Oye, Ngor Okpala, UmuOwa, Nkuot Etok and Abak Ukpum.

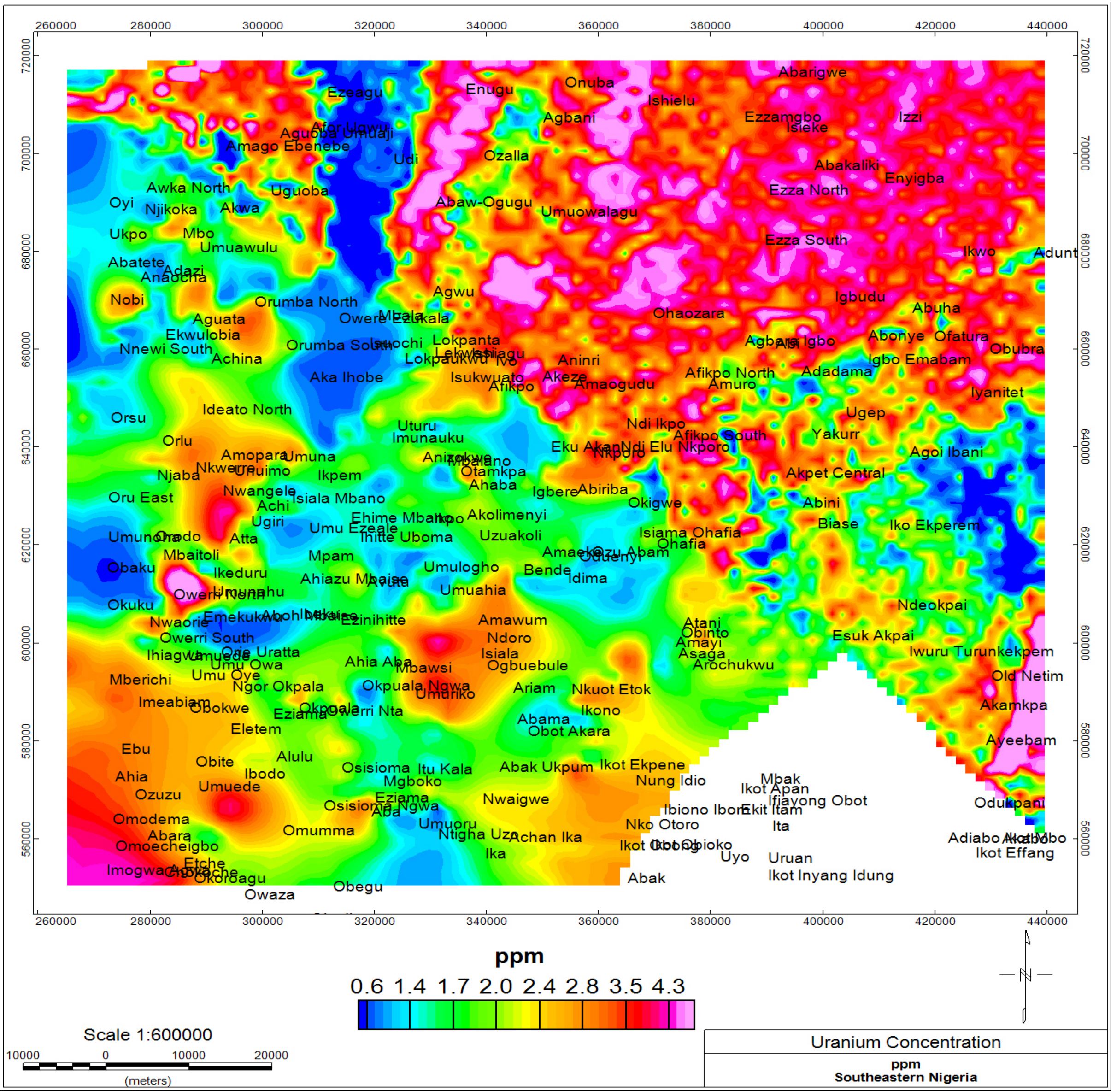


Figure 3. **Uranium concentration (eU) Map of the study area**

The concentration of thorium is higher on high elevated areas as compared to that of uranium as observed around Abakaliki, Ezza North and South, Ezzamgbo, Izzi, Onuba, Agbani and Ohaozara. Thorium (Th) is more resistant to environmental leaching processes than uranium (U) and high Th concentrations are related to high uranium concentration, this is why areas around the Niger Delta Basin has higher uranium concentration than thorium. The sandstone ridge around the Anambra Basin recorded high thorium concentration, high potassium concentration and low uranium as observed around while the low lands has high concentration of uranium.

4.1.3. Potassium Concentration

The potassium map (Figure 5) shows higher concentration of potassium in the basement complex, around Ugep, AgoiIbani, Yakurr, Akpet Central, Abini, Obubra, IgboEmabam, Abuha, Biase, IkoEkperem, and Ndeokpai with range of 0.6 to 1.1 %. This is corresponding to the granitic rocks that are generally potassic within the basement complex. Area around Abakaliki, Ezza, Enyigba, Ezzamgbo, Ohaozara, Lokpaukwu, Lokpanta and Ishiagu also recorded high potassium concentration, and it is interpreted to have resulted from the intrusive rocks occurring within the southern Benue

Trough. The lowest concentrations are observed around Ezeagu, Afor Ugwu, Udi, Amago, Ebenebe, Umuede and Ohafia.

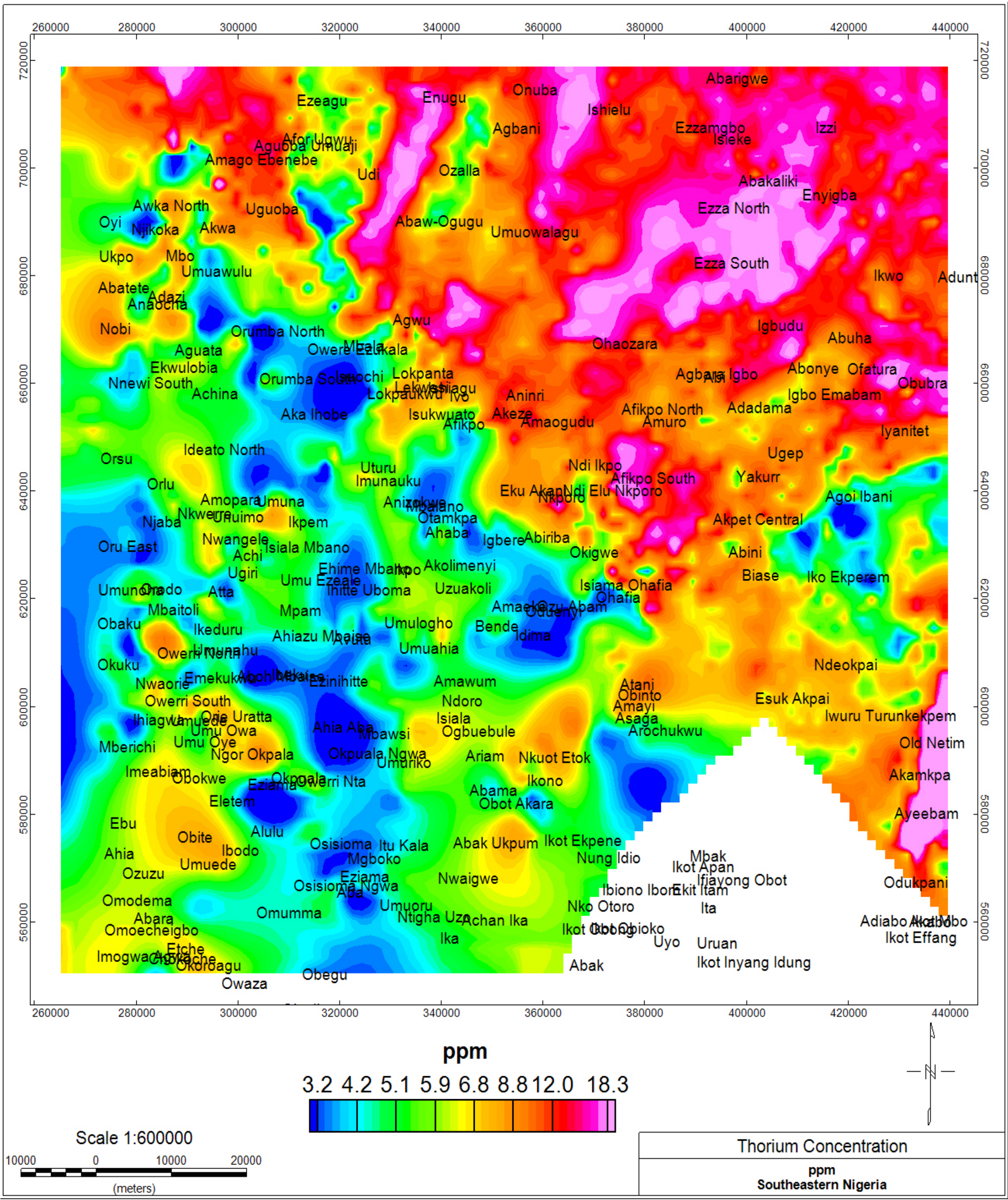


Figure 4. Thorium concentration (eTh) Map of the study area

Potassium radiation essentially comes from K feldspar, predominantly microcline and orthoclase or micas such as muscovite and biotite which are common in felsic igneous rocks (e.g. granite) and are low in mafic rocks (e.g. basalts and andesite) but virtually absent from dunite and peridotites (Manu, 1993). This is associated with the Southeastern Basement Complex rocks around Ugep, Abuha, Obubra, Iyanitet, Yakurr, AgoiIbani, Akpet Central, Abini, Biase, IkoEkperem, Ndeokpai, EsukAkpai, Iwuru, Turunkekpem and Old Netim. The high concentration of potassium within the Niger Delta Basin could be associated with the deposition of materials highly rich in feldspar into the lowlands.

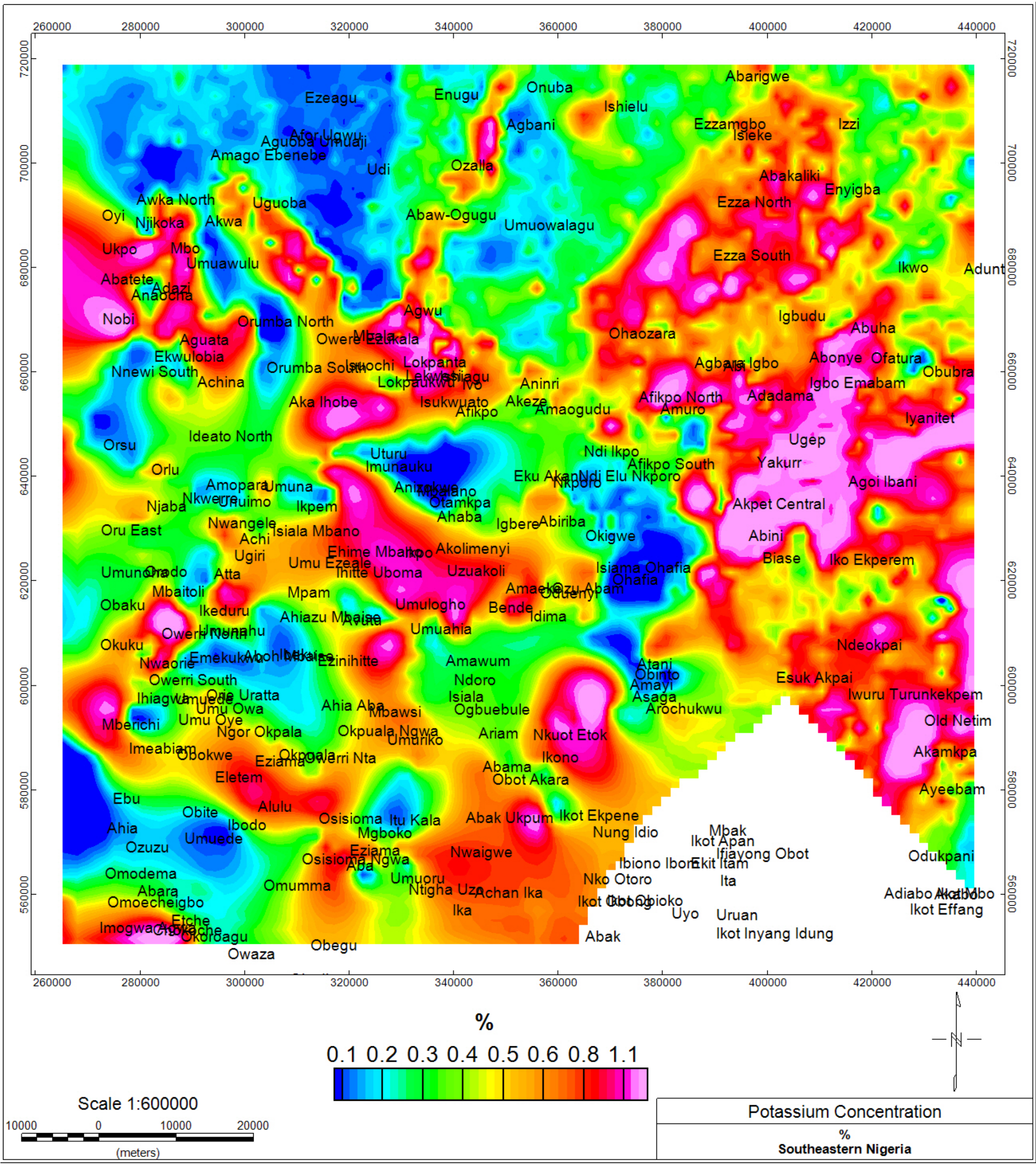


Figure 5. Potassium Concentration (%K) Map of the Study Area

4.1.4. Ternary map

A standard ternary image map presented in (Figure 6) for the radiometric data shows high concentration of the three radioelements (i.e., the white portions) in the Ayeebam, Akampa, Old Netim and Turunkekpem, and within the Southern Benue Trough around Abakaliki, Ezza, Enyigba, Ezzamgbo, Ohaozara, Lokpaukwu, Lokpanta and Ishiagu. High uranium concentration is recorded around Amawum, Ndoro, Isiala, Ogbuebule of the Anambra Basin and Imogwa, Etche, Okoroagu, Omoecheigbo, Agbara, Omodema, Ozuzu, Ahia, Ebu and Mberichi of the Niger Delta Basin. Orsu, Orlu, Ideato North, Amopara, Umuna, Naba, Oru and Atta also recorded high uranium concentration. The Basement complex area at the eastern part of the study area shows high concentration of potassium, with the highest concentration around AgoiIbani and IkoEkperem.

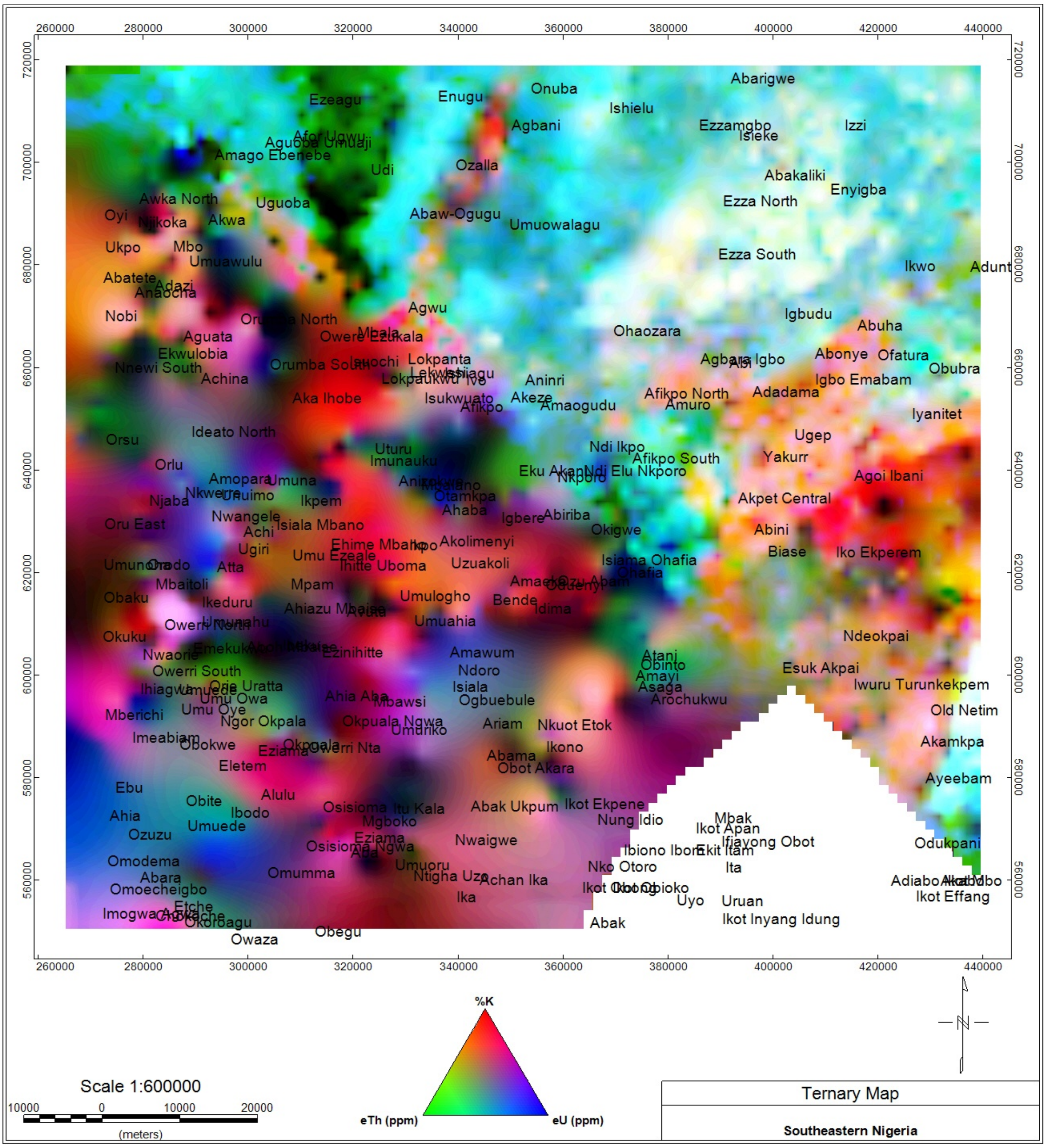


Figure 6. Standard Ternary Map of the Study Area

4.2. Magnetic results and discussion

4.2.1. Depth to bottom of magnetic source surface

Spectral analysis was used to compute the depth to centroid (depth to bottom of magnetic source). The centroid depth was plotted to produce a 2D image of the depth to bottom of magnetic source surface (Figure 7). The deepest depth is observed at the northern part of the study area in Ishielu, Abarigwe, Ezzamgbo, Isieke and Ezeagu. Intermediate depth is observed at Enyigba, Ezza South, Ohaozara, Agwu, Afikpo, Isukwuato, Lokpaukwu, Aka Ihobe, Achina, Awka, Ita, Akpet Central , Abini, Esuk Akpai and Yakurr, with the The shallowest depth to centroid observed around NkuotEtok, Abak Ukpum, Isiala, Abak, Ikot Ekpene, Osisioma, Omumma, Obite, Umuede, Ozuzu, Omoecheigbo and Ariam.

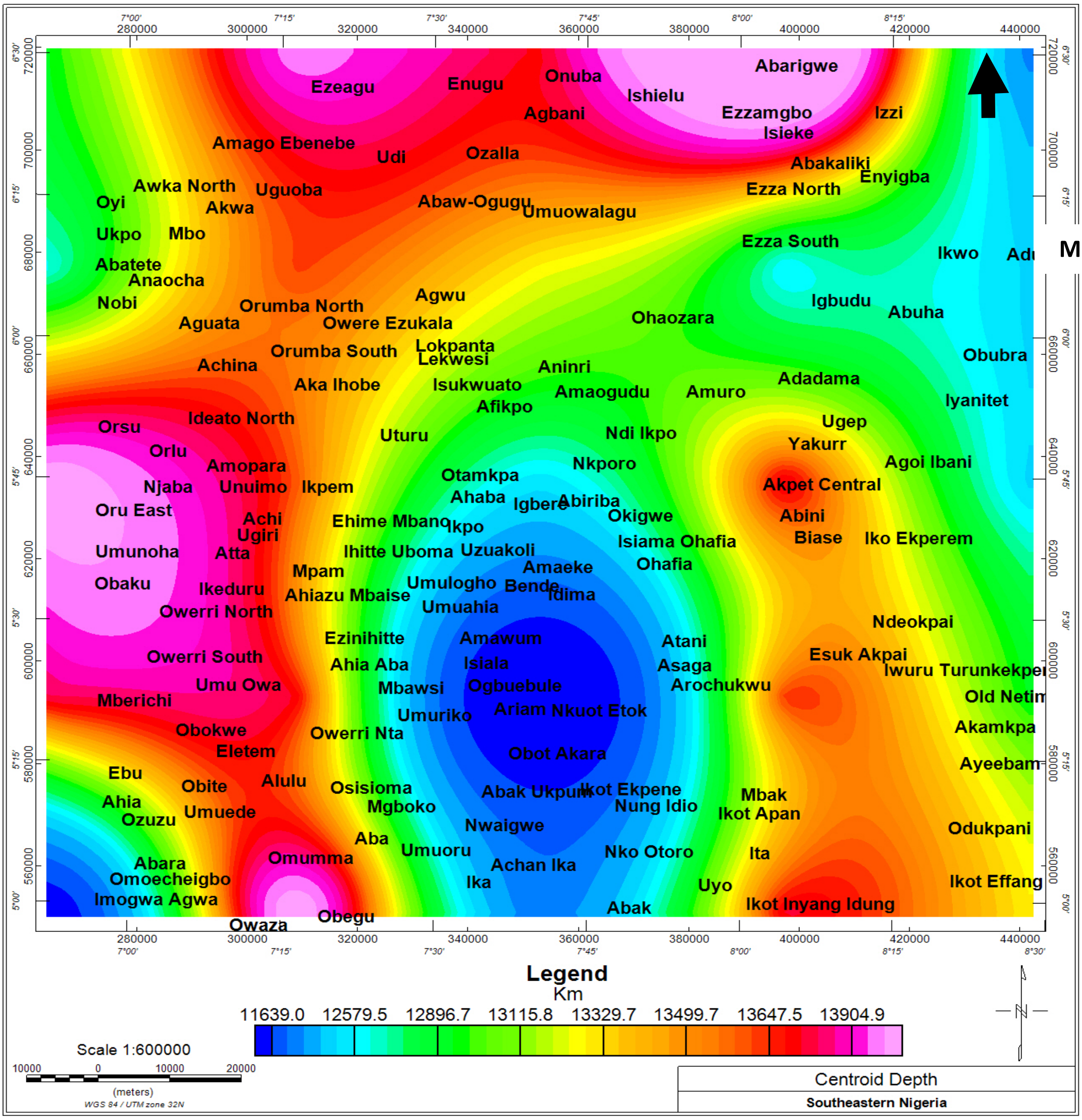


Figure 7. **2D Image of the Basement Surface**

4.2.2. Curie Isotherm Depth

The curie isotherm depths were computed using the depths of the shallowest and deepest sources which were obtained using the spectral analysis method (Bhattacharyya, 1965) and the results are presented in (Table 1). The depths to centroid ranges from 10574 to 15144 m while the depths to the top of the magnetic bodies range from 610 to 868 m. The result obtained was used to generate the Curie isotherm depths map (Figure 8). The Curie depths vary within the study area, ranging from 20416 to 29544 m, shallow curie depth is observed at Imogwa Agwa, Abara, Omoecheigbo, Ariam, Bende, Obot Akara, Abak Ukpum, Abiriba, Uturu, Otamkpa, Ahaba, Uzuakoli, Bende, Ohafia, Iyanitet, AgoiIbani, Iko, Ekperem, IwuruTurunkekpem, Akamkpa and Ayeebam while intermediate depth range is observed at Izzi, Abini, Biase, Aguata,, Osisioma, Omumma, Obite, Ozalla and Alulu, The deeper Curie depth point is observed in the northern part of the study area at Abarigwe, Ezzamgbo, Isieke, Ishielu, Enugu, Ezeagu, and observed also at Njaba, Umunoha, Obaku and Omumma.

Table 1. Calculated Curie point depth, geothermal gradient and heat flow from spectral analysis

longitude (X)			Latitude (Y)			Centroid Depth in metres (Z_0)	Depth to Top Boundary (Z_t)	Curie Point Depth in metres	Curie Point in Km	Geothermal Gradient (^{0}C/Km)	Heat Flow (mW/M^2)
D	M	S	D	M	S						
6	53	0	5	0	0	11223.463	790.338	21656.59	21.65659	26.78169	66.95422
7	18	0	5	0	0	14338.666	700.049	27977.28	27.97728	17.87164	44.67911
7	43	0	5	0	0	12006.218	759.025	23253.41	23.25341	21.50222	53.75555
8	8	0	5	0	0	13746.14	868.081	26624.2	26.6242	18.77991	46.94977
8	33	0	5	0	0	13295.549	712.127	25878.97	25.87897	19.32071	48.30177
6	53	0	5	25	0	13773.547	714.585	26832.51	26.83251	18.63411	46.58528
7	18	0	5	25	0	13725.211	778.043	26672.38	26.67238	18.74598	46.86496
7	43	0	5	25	0	10573.819	731.201	20416.44	20.41644	24.49007	61.22518
8	8	0	5	25	0	13642.814	759.74	26525.89	26.52589	18.84951	47.12378
8	33	0	5	25	0	12937.752	676.321	25199.18	25.19918	19.84191	49.60478
6	53	0	5	50	0	14259.668	723.266	27796.07	27.79607	17.98815	44.97039
7	18	0	5	50	0	13601.438	759.4	26443.48	26.44348	18.90826	47.27064
7	43	0	5	50	0	12523.409	781.918	24264.9	24.2649	20.6059	51.51474
8	8	0	5	50	0	13754.689	808.02	26701.36	26.70136	18.72564	46.8141
8	33	0	5	50	0	12476.103	795.457	24156.75	24.15675	20.69815	51.74537
6	53	0	6	15	0	12658.941	654.373	24663.51	24.66351	20.27287	50.68216
7	18	0	6	15	0	13621.005	719.98	26522.03	26.52203	18.85225	47.13063
7	43	0	6	15	0	13278.515	688.182	25868.85	25.86885	19.32827	48.32067
8	8	0	6	15	0	12578.278	748.387	24408.17	24.40817	20.48495	51.21236
8	33	0	6	15	0	12482.157	609.591	24354.72	24.35472	20.5299	51.32475
6	53	0	6	30	0	12953.041	667.12	25238.96	25.23896	19.81064	49.5266
7	18	0	6	30	0	14075.713	694.519	27456.91	27.45691	18.21035	45.52589
7	43	0	6	30	0	13711.45	760.604	26662.3	26.6623	18.75307	46.88268
8	8	0	6	30	0	15144.674	745.273	29544.08	29.54408	16.92387	42.30967
8	33	0	6	30	0	12090.99	665.023	23516.96	23.51696	21.26125	53.15314

4.2.3. Geothermal gradient

Curie-point temperature of 550ºC (Curie point temperature of 580ºC minus surface temperature of 30ºC) and calculated curie isotherm depths were used to compute the geothermal gradient variations within the study area (Ofor & Udensi, 2014) (Table 1 and Figure 9). The result obtained in the study area shows that geothermal gradient varies between 16.92 to 26.78 ºC/km. Within the basement complex rock at the eastern part of the study area, geothermal gradient ranges from >19.1 ºC/km. Southern Benue trough recorded geothermal gradient ranging from 19.8 to 20.8 ºC/km, with the highest values observed around Ikwo, Ezza South, Igbudu, Abakaliki, Enyigba, Ishiagu and Obubra and lowest values occurring around Ezzamgbo, Abarigwe and Ishielu areas. Anambra Afikpo Basin recorded similar geothermal gradient as that of Southern Benue Trough, with Awka, Ukpo, Oyi, Abatete, Amawum, Isiala, Afikpo, Uzuakoli, Okigwe, Abiriba and Ohafia area; while the lower values within the basin is recorded at Enugu, Ezeagu, Udi, Ozalla, Agbani, Onuba and Abaw Ogugu. Niger Delta Basin recorded variation in geothermal gradient ranging from 20.3 to as high as 26ºC/km, higher values are recorded at Abak, Ika, Achan Ika, NkoOtoro and Nung Idio Ozuzu, Omoecheigbo, Etche and Isiala and lower values within Omumma and Obegu.

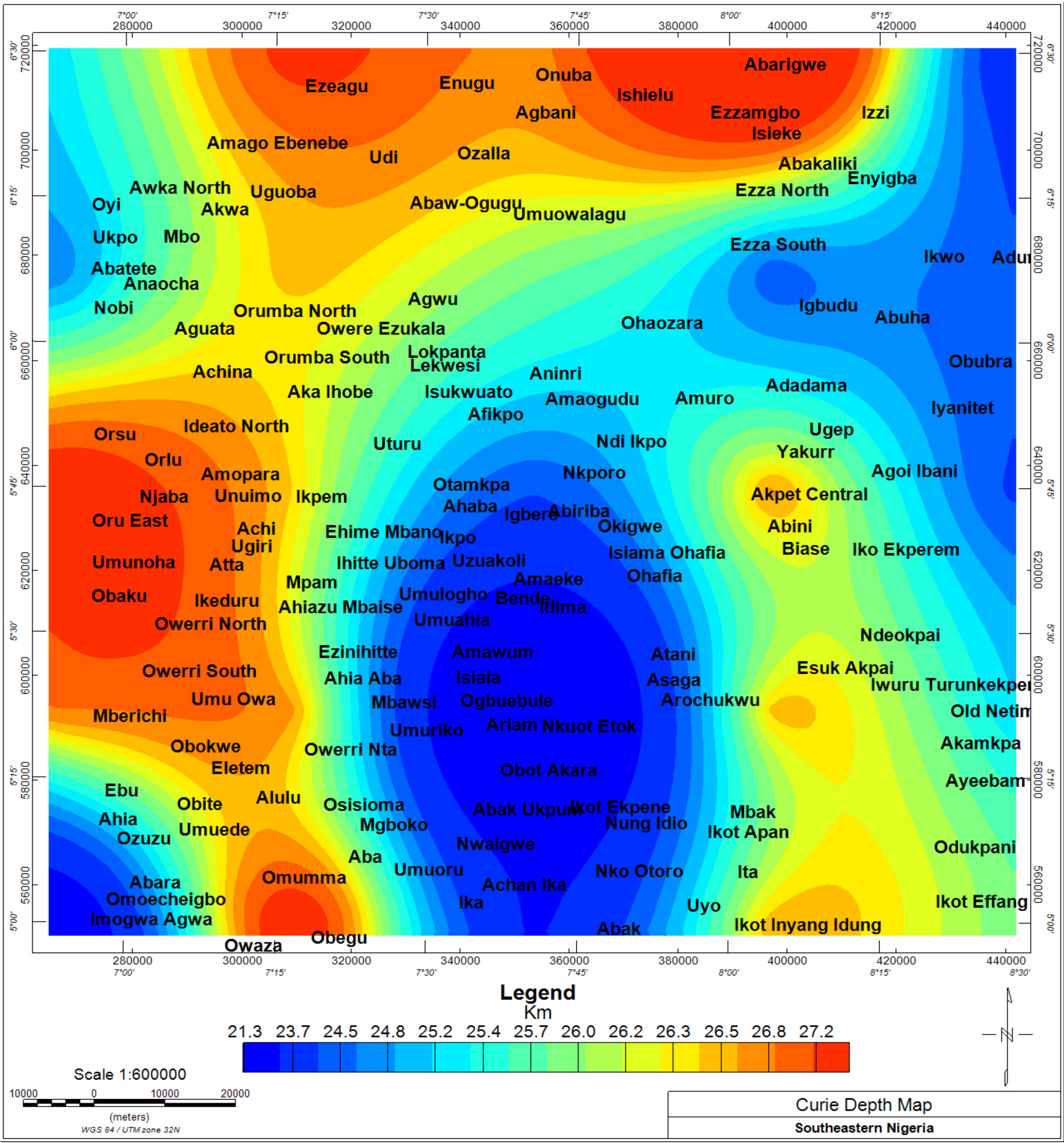


Figure 8. Curie Isotherm Depth Map of the Study Area

4.2.4. Heat flow

The values of geothermal gradients and thermal conductivity of 2.5 $Wm^{-10}C^{-1}$ (Nwankwo *et al.*, 2009) were subsequently used to calculate the corresponding heat flow anomalies in the study area (Table 1 and Figure 10). Heat flow of the study area ranges from 42.30 to 66.95mWm^{-2}. High heat flow greater than 49.5 mWm^{-2} is observed at Imogwa Agwa, Abara, Omoecheigbo, Ariam, Bende, Obot Akara, Abak Ukpum, Abiriba, Uturu, Otamkpa, Ahaba, Uzuakoli, Bende, Ohafia, Iyanitet, AgoiIbani, Iko, Ekperem, IwuruTurunkekpem, Akamkpa and Ayeebam while intermediate heat flow range of 47.8 to 49.4 mWm^{-2} is observed around Izzi, Abini, Biase, Aguata, Osisioma, Omumma, Obite, Ozalla and Alulu.

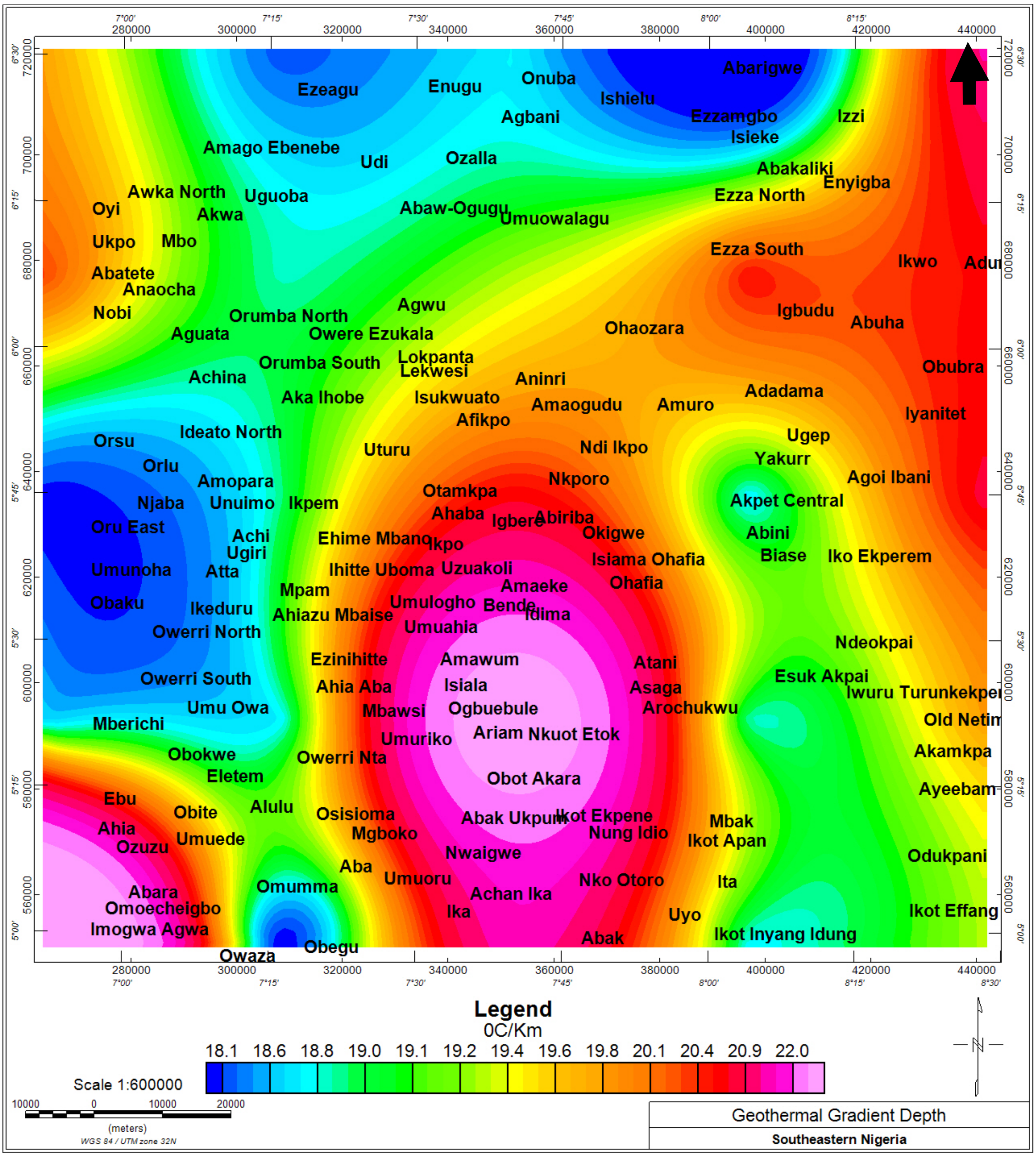


Figure 9. **Geothermal Gradient Map of the Study Area**

The low heat flow value of less than 45.2 mWm^{-2} is observed in the northern part of the study area at Abarigwe, Ezzamgbo, Isieke, Ishielu, Enugu, Ezeagu, and observed also at Njaba, Umunoha, Obaku and Omumma.

The variation of heat flow within the study area indicates random distribution of magma conduits. The heat flow result obtained is compared favourably with other works on heat flow within Nigeria's inland basins (Onwuemesi, 1997; Nur *et al.,* 1999; Nkwankwo *et al.,* 2009; Kasidi and Nur, 2012 & 2013; Akpabio and Ejedawa, 2001 & 2010; Emujakporue and Ekine,2014; Anakwuba and Chinwuko, 2015). The average heat flow obtained within the sedimentary basin in the study area is 47.4 mWm^2, this may be considered as typical of continental crust (Jessop *et al.,* 1976). It can be inferred that the geothermal prospect areas in this study may be areas with thick layer of thermally insulated sediments cover, basement rocks and volcanic activities as observed around Ogbuebule, Ariam,Isiala, Afikpo, Okigwe, Oyi, Abak, and NkoOtoro. The measured geothermal gradient within Niger Delta Basin (average of 38°C/km) is slightly above the thermal gradient average of 23.56 °C/km measured from nineteen (19) exploration wells within the Eastern Niger Delta Basin by (Emujakporue and Ekine, 2014).

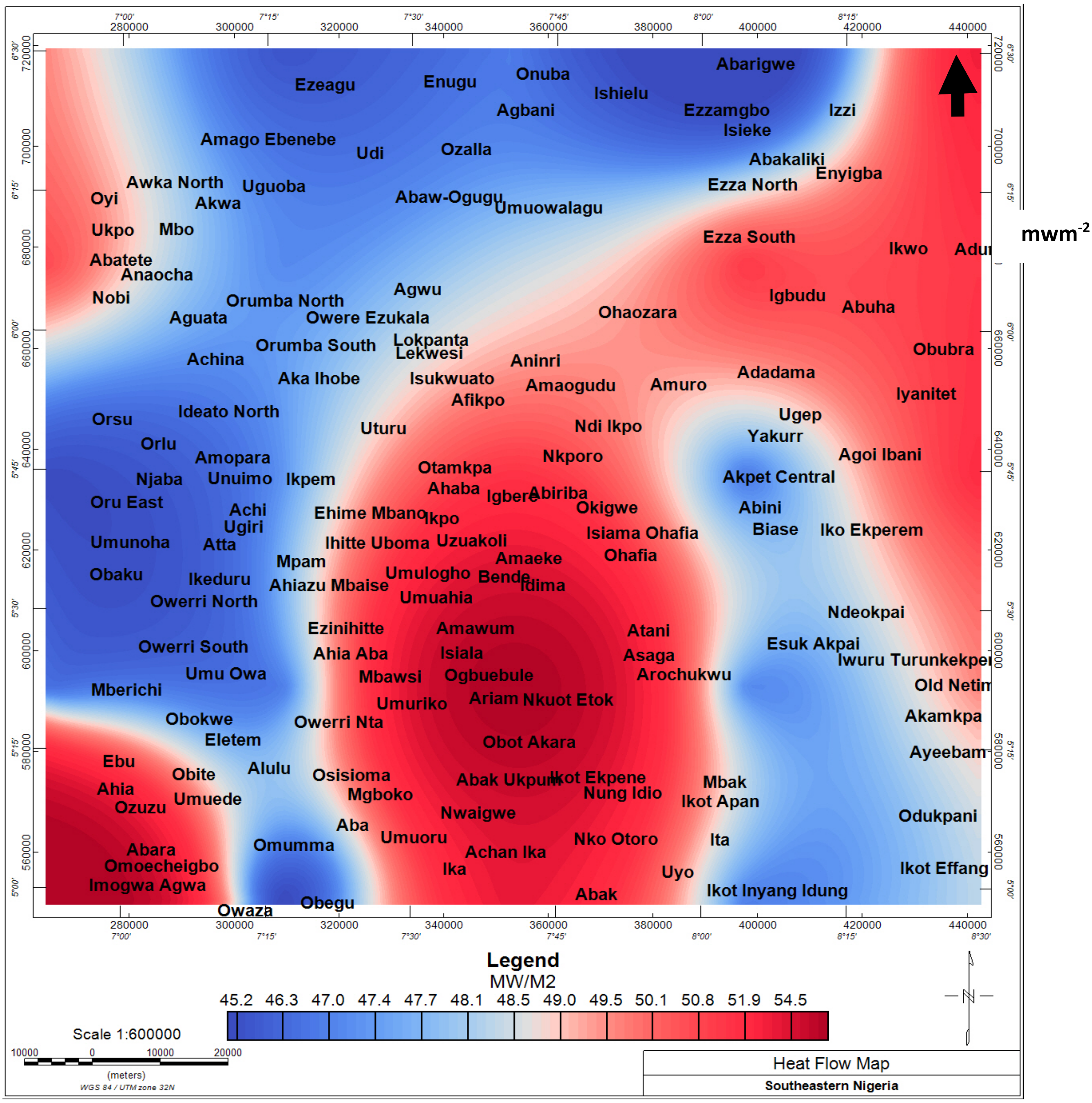


Figure 10. Heat Flow Gradient Map of the Study Area

4.3. Integration of radiometric and magnetic methods analysis in order to establish the relationship between heat flow and radioelement concentration in the study area.

Integration of radiometric and magnetic methods analysis was done by relating heat flow to radioelement concentrations within the study area. The high heat flow within the southern Benue Trough (>49 mW/m^2 to 50.8 mW/m^2) recorded high absorbed dose rate of (>48.04 nGyh^{-1}). The directly proportional relationship between high radioactive elements and high heat flow within the

Southern Benue Trough (Ezza South, Iyanitet, Ikwo, Igbudu, Abuha, Obubra etc) is attributed to the enrichment and mobilization of radioactive nuclides absorbed dose rate by thermal activities of the Santonia age. The increase in temperature and the emplacement of radioactive minerals (e.g. Lead, pyrite) by hydrothermal fluid therefore resulted in the increase in heat flow. The high heat flow could also have resulted from the shallow curie depth within the Southern Benue Trough (< 21 Km). Ogbuebule, Obot Akara Amawum, Okigwe, Otamkpa, Abiriba, Okigwe, Amaeke, Nwaigwe, and Achan Ika with their environs also recorded high heat flow (>50.8 mW/m^2) but moderate to low radioactive nuclide absorbed dose rate, this indicates that the high heat flow did not result from shallow curie depth (< 23.6 km) and not as a result of radioactive heat. Note that moderate aborbed dose rate within these areas resulted from hyperbesal rocks that are generally quarried within these areas. Within Ebu, Ahia, Ozuzu, Abara and Imogwa Agwa recorded high heat flow (>50.8 mW/m^2) and moderate absorbed dose rate (31.81 to 48.03 $nGyh^{-1}$). Low heat flow and high absorbed dose rate around Enugu, Ishielu, Awgu, Amago Ebenebe and Ugwuoba (Anambra Basin) resulted from the Ajali Formation, hence it is regarded as high dose rate resulting from shallow sources. Note that absorbed dose rate is synonymous to radioelement concentration.

5. Conclusion

Radiometric survey analysis of most part of the study area is not available and this study has successfully generated the radiometric analysis of the area during ground radiometric survey. The parameters measured are the uranium, thorium, potassium and dose rate. The investigation revealed that:

- **i.** The mean concentrations of the radionuclides uranium (U), thorium (Th) and potassium (K) in the Study area are respectively 3.02 ppm, 11.22 ppm and 0.43 % which are within the world average value.
- **ii.** The concentration of the radionuclides ^{238}U, ^{232}Th and ^{40}K in the study area are in the order (U < Th < K) which indicates preferential enrichment of potassium to both uranium and thorium.
- **iii.** The study revealed that the area generally has a less natural background radiation but few places like Ayeebam, Akamkpa, Olde Netim and Turunkekpem in Southeastern basement complex, Enugu, Ozalla, Udi, Abawogugu, Awgu in Anambra basin, and Abakiliki, Ezza north and south, Ishielu and Ohazara in Southern Benue have high radioelements concentration.
- **iv.** Geothermal energy Potential production zones within the study area are Imogwa Agwa, Omoecheigbo, Abara, Ozuzu, Ahia, Nkuot Etok, Obot Akara, , Ogbuebule, Isiala, Amawum, Amaeke, Bende, Idima, Ikwo, Ezza South, Igbudu, Abuha, Obubra, Iyanitet, Turunkekpem, Olde Netim, Akamkpa, Ayeebam, Oyi, Ukpo,etc.

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