Journal of Occupational Safety and Environmental Health
A Publication of the Society for Occupational Safety and Environmental Health
ISSN 2426-8685

RADIOACTIVITY CONCENTRATIONS AND RADIOLOGICAL HAZARDSOF DEGRADED MINE TAILINGS FROM HIGH BACKGROUND RADIATION AREA ON THE JOS- PLATEAU, NIGERIA

***M.U. Said* *D.J. Adeyemo**
*Physics Education Unit, Science Education Division, Institute of Education, Ahmadu Bello University Zaria
**Centre for Energy Research and Training (CERT) Ahmadu Bello University Zaria
E-mail of corresponding Author; muhusaidu@gmail.com

Abstract

The soils of degraded minefield farmland in three Local Government Area; Bokkos, Jos south and Barikin-Ladi of extensive mining of tin on the Jos-plateau were analyzed for radioactivity concentration. $\gamma - rays$ Spectrometry was used for the activity concentration analysis (of ^{40}K, ^{226}Ra and ^{232}Th) and the result was compared with the global standard as reported from UNSCEAR, 2000. The mean activity concentration of K-40 ranged from 86.00±6.58 to 121.31±6.40Bqkg^{-1} (Average 108Bqkg^{-1}) which is far less than the global standard of 420Bqkg^{-1}. Ra-226 mean activity concentration ranged from 39.82±4.01 to 75.4343±4.83 (Averaged 59Bqkg^{-1}) which is greater than the global standard of 33Bqkg^{-1}. Th-232 activity concentration level ranged from 44.46±2.39 to 62.06±2.87Bqkg^{-1} (Averaged 57Bqkg^{-1}) which is greater than the global standard of 45Bqkg^{-1}. The determined average absorbed dose rate, annual effective dose rate andradium equivalent were found to be 67.02nGh^{-1} (higher than the global standard 57nGy/h),82.25μSvy^{-1}(higherthan the global standard 70μSv/h) and 148.53Bqkg^{-1}(less than the global standard 370Bq/kg) respectively. The results show insignificant radiation hazard due to non-uniform distribution of the natural radionuclides in the soil samples The determined average external (H_{ex}) and internal (H_{in}) hazard indices were found to be 0.50 and 0.80 respectively. The radiological hazard indices do not exceed the global standard of unity. The result also revealed that there insignificant potential health risk due to primordial radionuclide in the soil samples from the area studied in this present work.

Key Words; Radioactivity, Radionuclides**,** dose rate NORMS, TENORMS, Radiological Indices, Health hazard

1.0 Introduction

The rock type of the Jos-Plateau is granite rock and according to Strahler and Strahler (1973) most of naturally occurring radioactive materials (NORMs) are now concentrated in the upper granite of the continent. In rocks of the earth's crust, the principal heat producing isotopes are the uranium isotopes(such as U-238, U-235, Th-232 and Ra-226) and K-40 (Adiuku et al 2001). Minerals resources is the most exploited natural resources and involves extraction grinding (processing) ore concentration and dispersal of tailings (Ferreira da Silver at al 2004). The Jos Plateau is known many years of tin miming activities which have left over a legacy of environmental pollution (Jwanbot*et al*,2012).Adiuku*et al* (2001) reported that higher radiation counts were obtained around heaps of mills tailings of the Jos Plateau environment when compared with normal background. *IAEA,(2003) reported a high background of 29,000 Bq/kg of Th-232 for zircon in Nigeria. Due to limitation of arable land in the Jos Plateau, famers cultivate crops on the abandoned or degraded mine tailings. It is fact plants and animal metabolisms do not differentiate between active and non-active isotopes.* The concentration of the NORMs in plants or crops grown on and around the abandoned mine tailings depends on the amount of these NORMs in the soil provided there is no external contamination (INFOSAN, 2011).

Since mining is a kind of technology, the NORMS of the interest in this research is transformed to technologically enhanced naturally occurring radioactive materials TENORMS comprising of the radioisotopes; K-40, (U-238)Ra-226 and Th-232. These are the most hazardous TENORMS that affect the health of individuals by providing both internal (if ingested) and external (in contact) radiation hazard. Excessive exposure to radionuclide causes sudden chromosomal change which could lead to cancerous cells. Shonwald (2004) and Markonvchick *et al* (2003) reported that ingestion of large amount of radioactive potassium could lead to health hazard such as hyperkalemia which strongly influence the cardiovascular system.

One of the main health concerns for consumers of food grown on both the active and non-active tailings is the long term effects which result in the development of cancer due to the radiation exposure by the individuals.

The aim of the research is to assess the radioactivity concentration and radiological hazards of the degraded soil of the mine tailing in the selected area. The findings will allow radiological suggestions on whether or not vegetables or other crops grown on the site are radiation free and safe for consumption.

2.0 Materials and methods

Area of Studies

The soil samples for this study were obtained from farmlands were vegetables are grown in three local government areas (Barikin-Ladi,Bokkos and Jos south) within the region of high background radiation figure 1.0 and 2.0

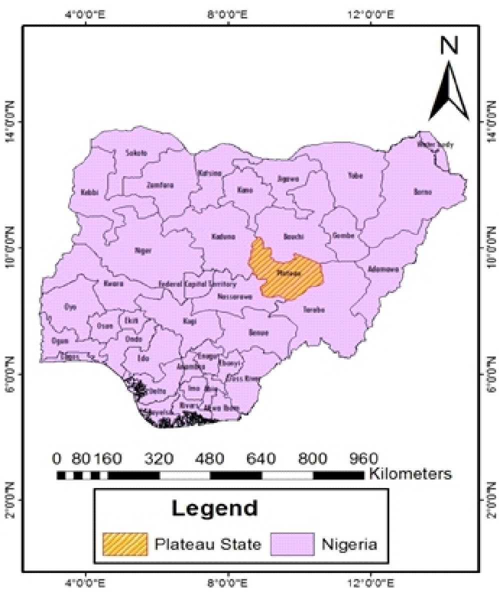

Figure Map of Nigeria showing Plateau State

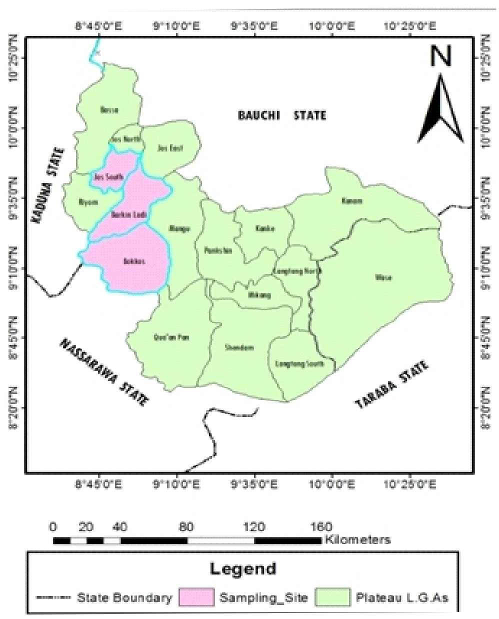

Figure 2 Map of Plateau State Showing Sampling Sites

Source: Modified From Administrative Map of Plateau State (2016).

Sample preparation

Random samplings were applied at each of the three selected local government and for each farmland. The top soil of the farmland was first cleared before the soil was dug and collected from the depth of 0 to 6cmthe rooting depth of vegetables 60mm (Barry, 2003). The soil were mixed properly, collected in labeled polythene bags and exposed to sun to dry for 3days.The prepared Samples were left open in the laboratory for a minimum of 24 hours to dry under ambient temperature. The dried samples were pulverized into a fine powder and passed through a standard mesh (500μm). The homogenized samples were filled into 25g plastic containers which were then hermetically sealed with the aid of PVC tape to prevent the escape of airborne ^{222}Rn and ^{220}Rn from the samples. The samples were stored for a minimum of 24days prior to measurement in order to attain radioactive secular equilibrium between ^{226}Ra and ^{228}Ac and their short lived progeny (>7 half-lives of ^{222}Rn and ^{220}Rn).The samples and the IAEA reference standard materials were mounted on the detector surface and counted for 29,000sec in a low-level gamma counting spectrometer of7.6cm x 7.6cm Sodium iodide NaI(Tl) detector. It was coupled to multichannel analyzer(MCA) through a preamplifier base. The spectral lines and live times of the TENORMS were acquired using MAESTRO software at specific energies.^{40}K was obtained from 1460keV energy peak at energy window between 1380keV – 1550keV.(^{238}U) ^{226}Rawas obtained from the average energy peak 1764keV of ^{214}Bi at energy window between 1620keV – 1820keV. ^{232}Th was determined at channel having energy peak of 26l4.5keV of ^{208}Tlwith energy windowbetween 2460keV – 2820keV (Ibeanu, 1999).

Absorbed Dose rate Air

The mean activity concentration of ^{40}K,^{226}Ra(^{238}U) and ^{232}Th (Bq/Kg) in the soil were used to calculate the absorbed dose rate. This to asses any radiological hazard due the exposure to radiation arising from radionuclides present in the soil(equation 1)

$$D(nGyh^{-1}) = 0.462A_{Ra} + 0.621A_{Th} + 0.0417A_{K} \quad (1)$$

A_{Ra}, A_{Th} and A_K are the activity concentrations of Ra, Th and K respectively.

In this case it is assumed that the contributions of other naturally occurring radionuclides are insignificant. The absorbed dose D is due to gamma radiation in air at 1m above the ground and for uniform distribution of naturally occurring radionuclides the coefficients are in nGyh^{-1}perBq/kg (UNSCEAR, 2000)

Annual Effective Dose Equivalent (AEDE) *(*μSvy^{-1})

The absorbed dose rates in air at 1m above the ground surface does not directly provide the radiological risk to which an individual is exposed (Jibirin, *et al* 2007). The absorbed dose can be considered in terms of annual effective dose equivalent from outdoors terrestrial gamma radiation which is converted from the absorbed dose rate by taking into account the conversion coefficient factor (0.7SvGy^{-1})from absorbed dose in air to and the outdoors occupancy factor (0.2), equation (2)

$$E_{EfD}(\mu Svy^{-1}) = \text{Dose rate } (nGyh^{-1}) \times 24h \times 365.25 \times 0.2 \times 0.7SvGy^{-1} \times 10^{-3} \quad (2)$$

Bashir *et al,* (2013) the values of those parameters used in the UNSCEAR (2000) report

Radium Equivalent Activity (Ra_{eq}

Due to a non-uniform distribution of natural radionuclide in the soil sample the actual activity level of ^{40}K, ^{226}Ra and ^{232}Th in the sample were evaluated by means of a common radiological index called Radium equivalent activity. It is the most widely used index to assess the radiation hazard and can be calculated using equation (3) from UNCEAR, (2000).

$$Ra_{eq}\ (Bq/Kg) = A_{Ra} + 1.43A_{Th} + 0.077A_k \quad (3)$$

A_k, A_{Ra} and A_{Th} are the activity concentration of ^{40}K, ^{226}Ra and ^{232}Th.

Estimation of Radiation Hazard Indices

Radiological hazards of radiation exposure due to Ra-226, Th-232 and K-40 radionuclides could be classified as external and internal. The associated external hazard is defined in terms of external hazard index or outdoor radiation hazard index(H_{ex}) while the internal hazard index (H_{in})explains the internal exposure to carcinogenic radon. This is to limit the natural exposure attributed to natural radionuclides in the samples to the permissible dose equivalent of $1mSvy^{-1}$,equations 4 and 5 respectively

External hazard indices

$$H_{ex} = \frac{ARa}{370} + \frac{ATh}{259} + \frac{Ak}{4810} \leq 1 \quad (4)$$

Internal hazard indices

$$H_{in} = \frac{ARa}{185} + \frac{ATh}{259} + \frac{Ak}{4810} \leq 1 \quad (5)$$

Where ARa, ATh and AK are the activities of radium, thorium and potassium respectively and for values of indices less than unity the radiation hazard will be negligible (UNSCEAR, 2000)

4.0 Results and Discussion

Results

Table 1.0:The Activity of The Soil Samples at Barikin Ladi L.G.A.

S/No	Sample ID	K-40 (Bq/kg)	Ra-226(Bq/kg)	Th-232 (Bq/kg)	TOTAL(Bq/kg)
1	BLDS1	176.5163±9.02	34.9942±2.46	41.7332±2.96	253.2437±14.44
2	BLDS2	98.2893±9.09	29.4322±4.87	43.1015±96	170.8230±7.92
3	BLDS3	89.1135±2.18	55.0406±5.91	50.0570±1.25	194.2111±17.16
Mean	-	121.3060±6.40	39.8200±4.01	44.4640±2.39	206.0926±9.84
Range	-	89.1135- 176.5163-	29.4322- 55.0406	41.73318- 50.0570	170.8230- 253.2437

Table2.0:The Activity of the Soil Sample collected from Bokkos L.G.A.

S/No	Sample ID	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	TOTAL(Bq/kg)
1	$BKKS_1$	109.1750±8.71	46.3500±1.18	52.5660±2.39	208.0910±12.28
2	$BKKS_2$	42.4572±9.02	73.0010±4.40	51.3110±4.78	166.7690±18.20
3	$BKKS_3$	106.3760±2.02	63.9620±7.53	87.571±3.31	257.9090±12.86
Mean	-	86.0027±6.58	61.1043±4.37	63.8160±7.53	210.9230±14.45
Range	-	42.4572-109.1750	46.3500-73.0010	51.3110-87.5710	166.7690-257.9090

Table 3.0:The Activity of Soil Sample collected from Jos -South LG.A.

S/No	Sample ID	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	TOTAL(Bq/kg)
1	JJSS1	116.7960±9.80	75.319±4.17	61.5730±2.39	253.6880±16.36
2	JJSS2	122.2390±8.40	97.6820±4.98	60.2050±1.94	280.1260±15.32
3	JJSS3	110.1090±6.69	53.3020±5.33	64.4080±1.93	227.8190±13.95
Mean	-	116.3813±8.30	75.4343±4.83	62.0620±2.87	253.8777±15.21
Range	-	110.1090-116.7960	53.3020-97.6820	60.2050-64.4080	227.8190-280.1260

Mean Specific Distribution of Radioactivity in soil samples from the three L.G.As

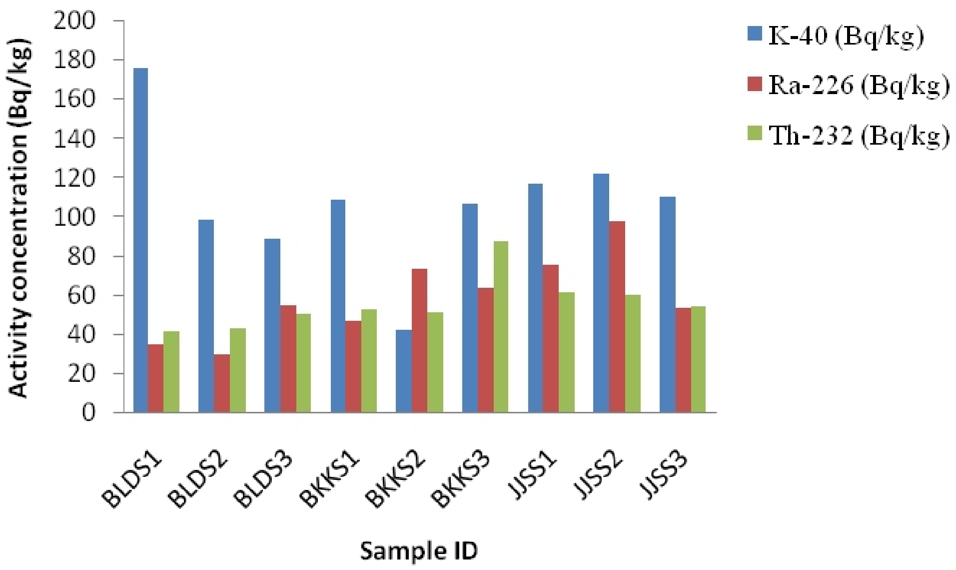

Figure 1.0 Activity Concentration of K-40, Ra-226 and Th-232 of soils

Table 4.0:Average Specific activities of NORMs measured through laboratory-based NaI(Tl) scintillation spectrometer analyses of soil samples compared to Worldwide values

Location	Mean Activity		
	^{40}K (Bqkg^{-1})	^{226}Ra (Bqkg^{-1})	^{232}Th (Bqkg^{-1})
BarikinLadi	121.3060±6.40	39.8200±4.01	44.4640±2.39
Bokkos	86.0027±6.58	61.1043±4.37	63.8160±7.53
Jos South	116.3813±8.30	75.4343±4.83	62.0620±2.87
Average	107.8967±7.07	58.7862±4.40	56.7807±4.26
Worldwide*	**420.0000**	**33.0000**	**45.0000**

*Adapted from UNSCEAR (2000)

Table 5.0:Comparism between Averages absorbed dose rate, effective dose rate, radium equivalent external hazard and internal hazard of the soil with the average worldwide values

Location	Mean	Computed	Values	Radiological	Indices
		Effective	Radium	External	Internal
	Dose rate	Dose rate	Equivalent	Hazard	Hazard
	(nGyh^{-1})	(µSvy^{-1})	(Bqkg^{-1})	(H_{ex})	(H_{in})
BarikinLadi	51.3790	63.0548	113.4613	0.3293	0.8188
Bokkos	71.4463	87.6824	158.9834	0.4816	0.7146
Jos South	78.2443	96.0253	173.1444	0.6187	0.9332
Average	67.0232	82.2542	148.5297	0.4765	0.8220
Worldwide*Mean	**57.0000**	**70.0000**	**<370.0000**	**<1.0000**	**<1.0000**

*Adapted from UNSCEAR (2000)

The activity concentration measurements in the study area are presented in tables 1, 2, 3 and figure 1. In the analyzed soil samples, the activity concentration of K-40 varies between 42.46±9.02Bqkg^{-1} (BKKS2) and 176.52±9.02Bqkg^{-1} (BLDS1) The Ra-226 activity concentration in the soil varies between 29.43±4.87Bqkg^{-1} (BLDS2) and 97.68±4.98Bqkg^{-1}(JJSS2) The activity concentration of Th-232 ranged from 41.73±2.96Bqkg^{-1}(BLDS1) to 87.57±3.31Bqkg^{-1}(BKKS3)

The activity concentration of K-40 was more in BarikinLadiarea and small in Bokkos. The activity concentration of Ra-226 is high in Jos south and small in BarikinLadi. Higher activity concentration of Th-232 was measured in Bokkos and small in BarikinLadi

The results show that all the soil samples predominantly contain K-40 than Ra-226 and Th-323. This is due to the fact that chemical fertilizer is applied in the farmland for the vegetables farming exercise and potassium is an essential element for their growth. Thus K-40 is more localized in the soil because the biochemistry of plants metabolism cannot distinguish ^{39}K from either ^{40}K or ^{41}K as well as other radionuclides (Andreas and Hans, 2012). Mining exercise and the variation of geological structure influenced the measurement of higher concentration level of the TENORMs The determined mean activity concentration, dose rates and radiological indices are presented in tables 4 and 5. The average activity concentration level of the soil over the whole area for K-40 was 107.70±7.07Bqkg^{-1}(low compared with global standard of 420.00Bqkg^{-1}), for Ra-226 was 58.79±4.40Bqkg^{-1} (more compared with global standard of 33.00Bqkg^{-1}) and for Th-232 was 56.78±4.26Bqkg^{-1} (more compared with global standard of45.00Bqkg^{-1}.The absorbed dose rate ranged from 51.38 nGyh^{-1}(BarikinLadi) to 78.24 nGyh^{-1} (Jos south). The annual effective dose ranged from 63.06μSvy^{-1}(BarikinLadi) to 96.02μSvy^{-1} (Jos south). The radium equivalent ranged from 113.46Bqkg^{-1}(BarikinLadi) to 148.53Bqkg^{-1} (Jos south). The external hazard index ranged from 0.33(BarikinLadi) to 0.62(Jos south) and the internal hazard index ranged from 0.82(BarikinLadi) to 0.93 (Jos south)

The results revealed higher average values of absorbed dose rate of 67.02nGyh^{-1} (more compared with global standard of 57.00) and annual effective dose equivalent of 82.25 μSvy^{-1}(compared to global standard of 70.00 μSvy^{-1}). However the acceptable annual effective dose for members of the public without constraints should not exceed 1mSv/year and under radiological constraints for an adequate protection for potential users 0.5mSv/year is recommended (ICRP, 1990) The radium equivalent 148.53Bqkg^{-1} is small compared to global standard of 370.00Bqkg^{-1} and hence there is no significant radiation hazard due to non-uniform distribution of the natural radionuclides in the soil samples. The external health hazard index (0.48) is lower than unity and hence it was below recommended safe limit value

Conclusion

The results show that all the soil samples predominantly contain K-40 than (U-238)Ra-226 and Th-323. The crops disability of elemental isotropic differentiation makes K-40 to be more localized in the soil that is enhanced by fertilizer application. The high values of the radioactivity concentration level of the TENORMS are due to the mining exercises and the geological structure of the soil. The average annual effective dose of 82.25μSvy^{-1} is lower than the average world recommended value of 1mSv/year (although under radiological constraints for an adequate protection of potential users 0.5mSv/year is recommended). Also the average value of radium equivalent of 148.53Bqkg^{-1}is lower than the recommended safe limit of <370Bqkg^{-1} implies insignificant radiation hazard due to non-uniform distribution of the natural radionuclides in the soil samples. The external hazard index (0.48) in table 5 which is of greater interest for radiological health purposes is lower than unity. It can be concluded that the radiological health risk in the soil of the farmland of the area studied in this present work is insignificant.

Acknowledgment

The authors wish to acknowledge the contribution of Prof T.C. Akpa of NNRA Abuja and Prof. S.P. Mallam of Energy Commission of Nigeria Abuja also Prof. G.I. Balogun,Prof. I.G.E. Ibeanu, and Mal. Bappa A.ofCentre for Energy Research and Training (C.E.R.T) Ahmadu Bello University Zaria. The contribution of Dr. B.C. Kim, Jos Plateau state – Nigeria is also highly acknowledged.

References

Adiuku M.E., Brown A.E. and Ogzie A.E. (2001) Radiation Level of Cassetterite Tailings in Jos Plateau State, *Journal of Environmental Sciences* 4 (1), pp 8-12.

Andreas, B. and Hans, K. (2012) Functions and Significance of Potassium for Human Body-Possible Consequences of Enhanced Intake of Radioactive Potassium-40 retrieved from www.currentconcern.

Barry, Smith (2006) T*he farming hand book*; African indigenous vegetables in urban Agriculture, University of Kwazulu-Natal press, South Africa pp340-350.
Bashir, M., Ibeanu, I.G.E., Y.I. Zakari and U. Sadiq (2013) Assessment of Radiological Risk in flooded soil samples in Kudenda Kaduna state Nigeria,*International journal of engineering science invention* vol; 2, 69-74

Berekta, J. and Mathew, P.J. (1985) Natural radioactivity of Australian building materials, industrial wastes and by- products, *Health Physics* 48, 87-95

Chang, B. U., Koh, S.M., Kim, Y. J,.Seo, J. S.,Yoon, Y. Y.,Raw, J. W.and Lee, D.M. (2008) Nationwide survey on the natural radionuclide in industrial raw minerals in South Korea.*Journal of Environmental Radioactivity*99,455-460**.**

Girgisu, S., Ibeanu, I.G.E., Adeyemo,D.J., Onoja R. A., Bappa, I.A. and Okoh S. (2013) Assessment of Radiological Level in Soil from Artisan Gold Mining exercise at AwwalKebbi state Nigeria. Online Programmes in Management Technology and Public Health master, Maxwell's science publication 2013, 1-9.

ICRP (1990) Recommendations of the International Commission on Radiological Protection (ICRP Publication No. 60).

INFOSAN (2011) International Food Safety Authority Network, INFORMATION on Nuclear Accident and Radioactive Contamination of Foods 30th March 2011 pp1-7

International Atomic Energy Agency I.A.E.A. (2003), Extent of Environmental Contamination by Naturally Occurring Radioactive Material (NORM) and Technological Options for Mitigation, Technical Reports Series No. 419, *(NORM VII)* STI/DOC/010/419 (ISBN: 9201125038) *, p 84*

Jibiril, N.N., Farai, I.P. and Alausa, S.K (2007) Estimation of annual effective dose due to natural radioactive element in ingestion of food stuff in tin mining are of Jos-Plateau al *Journal of Environmental Radioactivity.*Volume 94 pp 34 –40.
Sconwald,S. (2004) "potassium chloride permanganate." Medical Toxicology,
Lipincott Williams and Wilkins p903-905.Spectrum Analysis.*Nucl.Inst.Methods*, **193**, 147-155.

Strahler, A.N. and Strahler A.H, (1973) *Environmental Geosciences,* John Willey & Sons Inc. p 511.

United Nation Scientific Committee on the Effect of AtomicRadiation UNSCEAR,(2000); "*Sources and Effects of Ionizing Radiation"* UNSCEAR 2000 Report Vol. 1 to the General Assembly with Scientific Annexes 16; United Nation Sales Publications , United Nation New York.