Radiation Protection Dosimetry (2004) Vol. 112, No. 2, pp. 259–265
Advance Access publication 3 August 2004
doi:10.1093/rpd/nch389

A RE-EVALUATION OF THE OCCUPANCY FACTORS FOR EFFECTIVE DOSE ESTIMATE IN TROPICAL ENVIRONMENT

A. M. Arogunjo*, H. O. Ohenhen and S. P. Olowookere
Department of Physics, Federal University of Technology, P. M. B. 704, Akure, Nigeria

Received March 31 2004, amended May 10 2004, accepted June 27 2004

In the estimation of the effective dose to the public, outdoor and indoor occupancy factors have been an important parameter. These factors vary, depending on the prevailing environmental condition in a particular location. The factors have been estimated for the rural and urban areas in Nigeria. An outdoor factor of 0.3 and 0.22 have been estimated for rural and urban dwellers, respectively. The rural outdoor factor is 50% above the value recommended as the world average by the UNSCEAR. The urban outdoor factor is 10% higher than this value. The total outdoor gamma dose rate in the air due to ^{40}K, ^{238}U and ^{232}Th in the soil for some rural population in the southern part of Nigeria is 29.50 ± 3.80 nGy h^{-1} and the average outdoor effective dose has been estimated to be 54.28 ± 6.95 μSv y^{-1} using the present occupancy factor.

INTRODUCTION

In the survey of terrestrial gamma radiation levels of an environment, the knowledge of the outdoor and indoor occupancy factors remain one of the important requirements for calculating the doses to the population[1,2]. In most publications in the area of environmental gamma radiation studies, authors have been employing the outdoor and occupancy factors recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). This assumption, however, may not adequately represent the actual situation in the studied environment. The development of these factors might have been based on the statistics obtained from time budget suiting the working and environmental conditions in the urban and temperate region of the globe, where most activities are carried out indoors. The factor depends, however, on peoples' habits, occupational structure and the prevailing weather conditions, which makes it a location-specific parameter. For example, in the rural and tropical environment the use of the factor might produce large and significant errors, which might either underestimate or overestimate the doses to the population. Interestingly, most publications[3–10] from this section of the globe have been based on the factors by UNSCEAR[2].

In most African countries, over 60% of the total populations reside in the rural areas. In Nigeria, over 66% of the total population are rural dwellers[11]. The major occupation in the continent Africa is farming (including fishing), which takes place outdoors. Most farmers leave their home as early as 6.00 a.m. and will not return until about 7.00 p.m. In urban areas, the majority of the inhabitants are self-employed and most of the works are being carried out in shady places outdoors. Owing to the harsh weather condition, sleeping, which is expected to be done indoors, sometimes takes place outdoors. In view of these situations, which might not properly represent the conditions under which the UNSCEAR values were developed, a more realistic approach to the use of these factors in the environment similar to the above description must be adopted. This work has been designed to obtain an appropriate occupancy factor for use in such environment.

*Corresponding author: arogmuyi@yahoo.com

MATERIALS AND METHODS

Model development

In order to calculate the outdoor and indoor occupancy factors for both the rural and urban areas in Nigeria, a model relating the time budget for various activities of the day to the outdoor and indoor parameters has been developed. The time budget used in this model was evaluated from *a priori* information obtained from various groups of people in both the rural and urban areas. This involved the use of questionnaires particularly developed to retrieve information from workers (of all categories), students, craftmen, job seekers and full-time housewives.

Model assumptions

The following assumptions were made in the development of this model:

- The activities can either be classified as indoor or outdoor.
- The activities are considered as time variables.
- The time budget and the fraction of the time budget for each activity are considered as parameters.

Table 1. Time budget for various activities in the population sub-groups identified in the urban areas.

Groups	Activities											
	Leisure			Occupation			Rest			Others		
	α_1	β_1	T_1 (h)	α_2	β_2	T_2 (h)	α_3	β_3	T_3 (h)	α_4	β_4	T_4 (h)
Student	0.4	0.6	3.0 ± 0.5	0.2	0.8	10.0 ± 0.1	0.0	1.0	8.0 ± 0.4	0.1	0.9	3.0 ± 0.5
Banking/insurance	0.2	0.8	2.0 ± 0.1	0.1	0.9	11.0 ± 0.1	0.0	1.0	8.0 ± 0.2	0.3	0.7	3.0 ± 0.3
Constructions	0.2	0.8	3.0 ± 0.4	0.6	0.4	9.0 ± 0.5	0.0	1.0	8.0 ± 0.4	0.3	0.7	4.0 ± 0.3
Health	0.2	0.8	1.0 ± 0.3	0.2	0.8	12.0 ± 0.1	0.0	1.0	8.0 ± 0.4	0.4	0.6	3.0 ± 0.4
Civil service	0.2	0.8	4.0 ± 0.4	0.2	0.8	8.0 ± 0.1	0.0	1.0	8.0 ± 0.2	0.4	0.6	4.0 ± 0.1
Military	0.2	0.8	4.0 ± 0.6	0.7	0.3	10.0 ± 0.1	0.0	1.0	8.0 ± 0.5	0.4	0.6	2.0 ± 0.4
Business	0.2	0.8	3.0 ± 0.4	0.4	0.6	9.0 ± 0.7	0.0	1.0	8.0 ± 0.3	0.4	0.6	4.0 ± 0.5
Agro-allied	0.2	0.8	3.0 ± 0.5	0.4	0.6	9.0 ± 0.4	0.0	1.0	8.0 ± 0.5	0.4	0.6	4.0 ± 0.4

- Each activity has a component of indoor and outdoor.
- Every member of the various groups is in a place at a given time.
- The activities are classified as academic/occupation, sleep/rest, leisure and others (miscellaneous).
- Sleep/rest is an indoor activity.

The time spent either outdoor or indoor is a fraction of the time slot for the various activities cosidered in Table 1.

The time spent outdoor by a population sub-group during an activity i is x_i given by:

$$x_i = \alpha_i t_i, \qquad (1)$$

where α_i is a fraction, which is an outdoor weighting parameter, and t_i is the time budget for the activity i.

The time spent indoor by a population sub-group i during an activity i is y_i given by:

$$y_i = \beta_i t_i, \qquad (2)$$

where β_i $(1 - \alpha_i)$ is an indoor weighting parameter.

The total time T_{out} spent outdoor is given as:

$$T_{\text{out}} = \frac{1}{n}\sum_{i}^{n} x_i \qquad (3)$$

and the total time T_{in} spent indoor is given as:

$$T_{\text{in}} = \frac{1}{n}\sum_{i}^{n} y_i, \qquad (4)$$

where n is the total number of the population sub-group.

This model has been represented as shown in Figure 1.

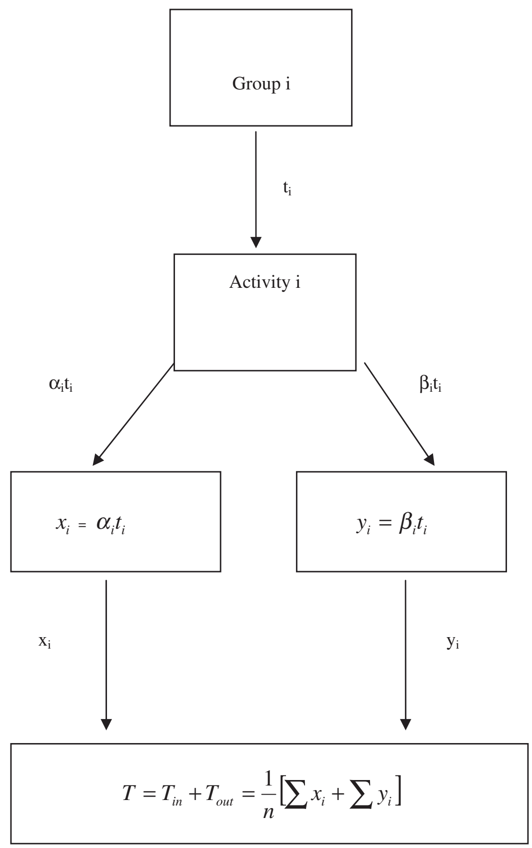

Figure 1. Diagramatic representation of the model for the calculation of occupancy factor.

Implementation of the model

In order to implement this model, specially designed questionnaires, which range between 500 and 1000 depending on the location, were distributed to people in the various population sub-groups (Tables 1 and 2) in order to obtain necessary information needed to estimate t_i, α_i and β_i. The mean values

Table 2. Time budget for various activities in the population sub-groups identified in the rural areas.

Groups	Activities											
	Leisure			Occupation			Rest			Others		
	α_1	β_1	T_1 (h)	α_2	β_2	T_2 (h)	α_3	β_3	T_3 (h)	α_4	β_4	T_4 (h)
Student	0.6	0.4	4.0 ± 0.6	0.2	0.8	8.0 ± 0.4	0.0	1.0	8.0 ± 0.5	0.6	0.4	4.0 ± 0.6
Farmer	0.7	0.3	1.0 ± 0.7	0.8	0.2	10.0 ± 0.2	0.0	1.0	8.0 ± 0.4	0.4	0.6	5.0 ± 0.6
Trading	0.6	0.4	3.0 ± 0.4	0.7	0.3	9.0 ± 0.3	0.0	1.0	8.0 ± 0.3	0.4	0.6	4.0 ± 0.4
Health Care	0.4	0.6	3.0 ± 0.4	0.3	0.7	10.0 ± 0.1	0.0	1.0	8.0 ± 0.4	0.4	0.6	3.0 ± 0.5
Exten. service	0.4	0.6	4.0 ± 0.6	0.6	0.4	8.0 ± 0.4	0.0	1.0	8.0 ± 0.5	0.4	0.6	4.0 ± 0.6

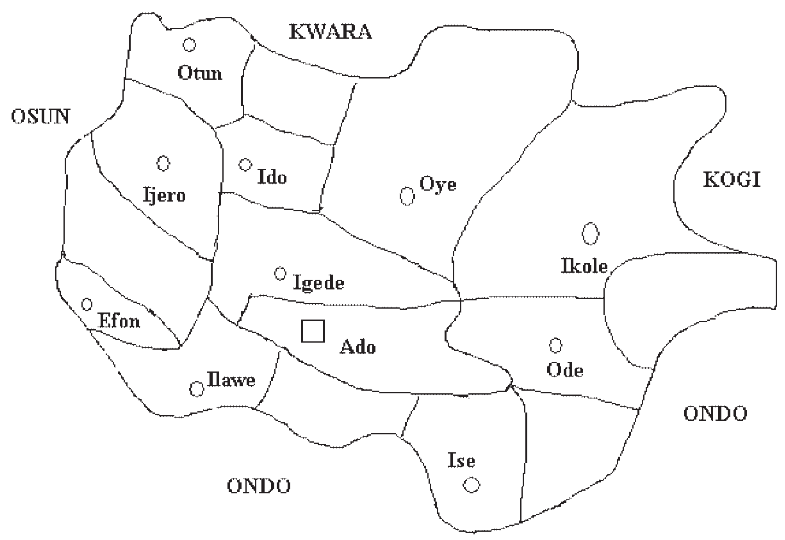

Figure 2. Map showing the sampling locations.

for these parameters in each population sub-group for urban areas are presented in Table 1, while those of the rural areas are presented in Table 2 and the stated errors are the standard deviations.

Activity concentration measurement

Soil samples were collected from some villages in Ekiti State, south western Nigeria (Figure 2). The samples (ranging between 250 and 300 g) were air-dried and sealed in polyethylene bags. Prior to the gamma analysis, the samples were kept for about 3 weeks to allow the gaseous members of ^{238}U and ^{232}Th series to attain secular equilibrium. The spectrometer used consist of a 3×3 in. NaI(Tl) detector with a microcomputer Multi-Channel Analyser (MCA) at the Center for Energy Research and Development (CERD), Ile–Ife. The detector has a resolution of ~8% for the 662 keV gamma line of ^{137}Cs, this is good enough to distinguish the gamma ray energies of natural radionuclides. The ^{40}K activity in the samples was estimated using its gamma line of 1.46 MeV. The gamma lines of 1.76 MeV of ^{214}Bi and 2.614 MeV of ^{208}Tl were used as indicator for ^{238}U and ^{232}Th, respectively. The peaks obtained were reasonably strong and clean, the peak area A for the radionuclides was computed using the algorithm of the MCA, which substracts the background spectrum from the total peak counts. The activity concentrations, A_c (Bq kg^{-1}) of the radionuclides in the samples were estimated using the relation:

$$A_c = \frac{A}{\varepsilon P_r M}, \quad (5)$$

where A is in counts per second, ε is the detector efficiency for a particular gamma energy, P_r is the absolute transition probability of gamma decay and M is the mass (kg) of the sample. The calibration of the activity concentration was achieved by counting a mixed gamma standard soil of known activities of the radionuclides of interest under the same experimental conditions used for the soil samples. The spectra were collected for 36,000 s and the activity concentrations due to the radionuclides of interest in the soil samples were calculated from the concentration ratio between the standard and the sample using Equation 5.

RESULTS AND DISCUSSION

Activity concentration

The activity concentrations obtained for soil samples collected from some rural communities in Ekiti State are presented in Table 5. The activity concentrations of ^{40}K, ^{238}U and ^{232}Th in the soil ranged from 8.9 to 72.4 Bq kg^{-1} with a mean of 43.3 ± 8.5 Bq kg^{-1}, 11.5 to 85.0 Bq kg^{-1} with a mean of 50.1 ± 8.4 Bq kg^{-1} and 2.8 to 13.2 Bq kg^{-1} with a mean of 9.3 ± 1.2 Bq kg^{-1}, respectively, and the stated errors are the standard errors.

The gamma radiation dose D (nGy h^{-1}) to the public from the natural radionuclides in the soil at 1 m above the ground is related to A_c as[12]:

$$D = 0.043A_c^{\mathrm{K}} + 0.429A_c^{\mathrm{U}} + 0.662A_c^{\mathrm{Th}}, \qquad (6)$$

where A_c^i is the activity concentration for a particular radionuclide i. The dose rate values are shown in column 5 of Table 5.

Occupancy factor

The data in Table 3 show that an average city dweller in Nigeria spends ~5.2 h outdoor, which represents 22% of a day. Table 4 shows that an average person in the rural areas spends 8.0 h outdoor representing 33% of a day. The outdoor factor of 0.22 for an average urban dweller in Nigeria is ~10% above the world average factor of 0.2 recommended by the UNSCEAR[2], this is however, not significant. The outdoor factor of 0.3 for the average person in the rural areas is 50% higher than the UNSCEAR factor, which is significant. The increase

Table 3. Time spent outdoor/indoor for various activities in the population sub-groups identified in the urban areas.

Groups	Activities									
	Leisure		Occupation		Rest		Others		Total	
	T_{out}	T_{in}	T_{out}	T_{in}	T_{out}	T_{in}	T_{out}	T_{in}	T_{out}	T_{in}
Student	1.2	1.8	2.0	8.0	0.0	8.0	0.3	2.7	3.5	20.5
Banking/insurance	0.4	1.6	1.1	9.9	0.0	8.0	0.9	2.1	2.4	21.6
Constructions	0.6	2.4	5.4	3.6	0.0	8.0	1.2	2.8	7.2	16.8
Health	0.2	0.8	2.4	9.6	0.0	8.0	1.2	1.8	3.8	20.2
Civil service	0.8	3.2	1.6	6.4	0.0	8.0	1.6	2.4	4.0	20.0
Military	0.8	3.2	7.0	3.0	0.0	8.0	0.8	1.2	8.6	15.4
Business	0.6	2.4	3.6	5.4	0.0	8.0	1.6	2.4	5.8	18.2
Agro-allied	0.6	2.4	3.6	5.4	0.0	8.0	1.6	2.4	5.8	18.2
Mean	0.7	2.2	3.3	6.4	0.0	8.0	1.2	2.2	5.2	18.8

Table 4. Time spent outdoor/indoor for various activities in the population sub-groups identified in the rural areas.

Groups	Activities									
	Leisure		Occupation		Rest		Others		Total	
	T_{out}	T_{in}	T_{out}	T_{in}	T_{out}	T_{in}	T_{out}	T_{in}	T_{out}	T_{in}
Student	2.4	1.6	1.6	6.4	0.0	8.0	2.4	1.6	6.4	17.6
Farmer	0.7	0.3	8.0	2.0	0.0	8.0	2.0	3.0	10.7	13.3
Trading	1.8	1.2	6.3	2.7	0.0	8.0	1.6	2.4	9.7	14.3
Health care	1.2	1.8	3.0	7.0	0.0	8.0	1.2	1.8	5.4	18.6
Exten. service	1.6	2.4	4.8	3.2	0.0	8.0	1.6	2.4	8.0	16.0
Mean	1.5	1.5	4.7	4.3	0.0	8.0	1.8	2.2	8.0	16.0

Table 5. The mean activity concentrations and total absorbed dose rates in air due to ^{40}K, ^{238}U and ^{232}Th for some rural communities.

Location	^{40}K (Bq kg^{-1})	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	Dose rate (nGy h^{-1})
Otun	72.4 ± 3.1	46.9 ± 7.0	12.9 ± 1.9	31.8 ± 0.7
Oye	20.5 ± 2.9	68.5 ± 4.7	8.5 ± 1.7	35.9 ± 1.2
Ikole	71.4 ± 3.2	11.5 ± 1.6	12.4 ± 2.8	16.2 ± 0.6
Efon	69.3 ± 3.6	59.7 ± 3.5	11.7 ± 1.4	36.3 ± 0.4
Igede	8.9 ± 1.5	58.6 ± 2.4	2.8 ± 1.1	27.4 ± 2.5
Ilawe	33.6 ± 2.1	20.3 ± 6.0	4.7 ± 0.8	13.3 ± 0.8
Ijero	52.7 ± 3.2	85.0 ± 13.0	12.7 ± 2.7	47.1 ± 1.7
Ido	71.5 ± 8.9	53.5 ± 4.1	13.2 ± 2.2	34.7 ± 0.9
Ise	20.4 ± 1.8	14.4 ± 1.9	7.9 ± 1.6	12.3 ± 0.4
Ode	12.3 ± 3.6	82.2 ± 8.6	6.5 ± 1.9	40.1 ± 3.7
Mean ± SD	43.3 ± 8.5	50.1 ± 8.4	9.3 ± 1.2	29.5 ± 3.8

can be attributed to the differences in the occupational and lifestyle habits, which is a function of the prevailing weather conditions. In rural areas, the majority of the people are peasant farmers, most of whom leave home as early as 6.00 a.m. and return between 5.00 and 6.00 p.m. each day except religious and festive days. Adult leisure periods are spent under the shade of trees and shield made with palm leafs. School pulpils also find their way to the farm immediately after school hours and leisure periods are spent playing football either at school during break or at home. Household chores are often carried out in an open yard. Business transactions of goods and services take place in open markets.

The present factors show that the estimated outdoor effective dose to member of the public in a similar situation in Nigeria and indeed Africa must have been underestimated by ~50% for rural settings and 10% for urban settings, thereby overestimating the indoor dose. In an earlier baseline studies of terrestrial outdoor gamma radiation in urban areas in Nigeria(3), the average effective dose value of 98 μSv y^{-1} reported by the authors using the UNSCEAR factor might have been an underestimation of the actual value judging from the present outdoor factor. This value could be as high as 108 μSv y^{-1} for the studied environment, although the difference is not significant. Similarly, the annual effective dose of 31.6 μSv y^{-1} reported for the Delta region of Nigeria(6) using the UNSCEAR factor might have been underestimated by 50%. The oil-producing areas in the country best described a rural dwelling pattern, the UNSCEAR factor was employed because the essential data needed to estimate the factor were not available at that moment. The effective dose to the public in the area should have been 48 μSv y^{-1} using the present outdoor factor, which represents ~68% of the world average (70 μSv y^{-1}) (2). Using the factor 0.7 Sv Gy^{-1} recommended by the UNSCEAR(2) and the outdoor factor

Table 6. Effective dose calculated using the UNSCEAR and the present factors for the rural communities.

Location	Effective dose (μSv y^{-1})	
	UNSCEAR factor	Present factor
Otun	38.94 ± 0.89	58.41 ± 1.34
Oye	44.04 ± 1.43	66.06 ± 2.14
Ikole	19.86 ± 0.72	29.78 ± 1.08
Efon	44.54 ± 0.46	66.80 ± 0.68
Igede	33.58 ± 3.10	50.36 ± 4.64
Ilawe	16.25 ± 0.98	24.37 ± 1.47
Ijero	57.81 ± 2.09	86.71 ± 3.13
Ido	42.61 ± 1.05	63.92 ± 1.57
Ise	15.07 ± 0.50	22.61 ± 0.75
Ode	49.19 ± 4.48	73.79 ± 6.72
Mean ± SD	36.19 ± 4.64	54.28 ± 6.95

of 0.3 obtained for rural dwellers in this work, which suggests that an average individual stays ~8.0 h outside daily, the total absorbed dose rate values given in column 5 of Table 5 were converted into the outdoor annual effective dose. Table 6 shows the effective dose values calculated using the UNSCEAR and the present outdoor factors for the purpose of comparison. Figure 3 shows the comparison between the effective dose obtained using the present outdoor factor for rural dwellers and the UNSCEAR factor. The indoor effective dose was not evaluated because the essential data on average build-up of radon gas in the indoor atmosphere were not available.

CONCLUSION

The outdoor and indoor occupancy factors for the urban and rural dwellers in Nigeria have been estimated. The factors suggest that the effective dose due to the terrestrial gamma radiations to the public in

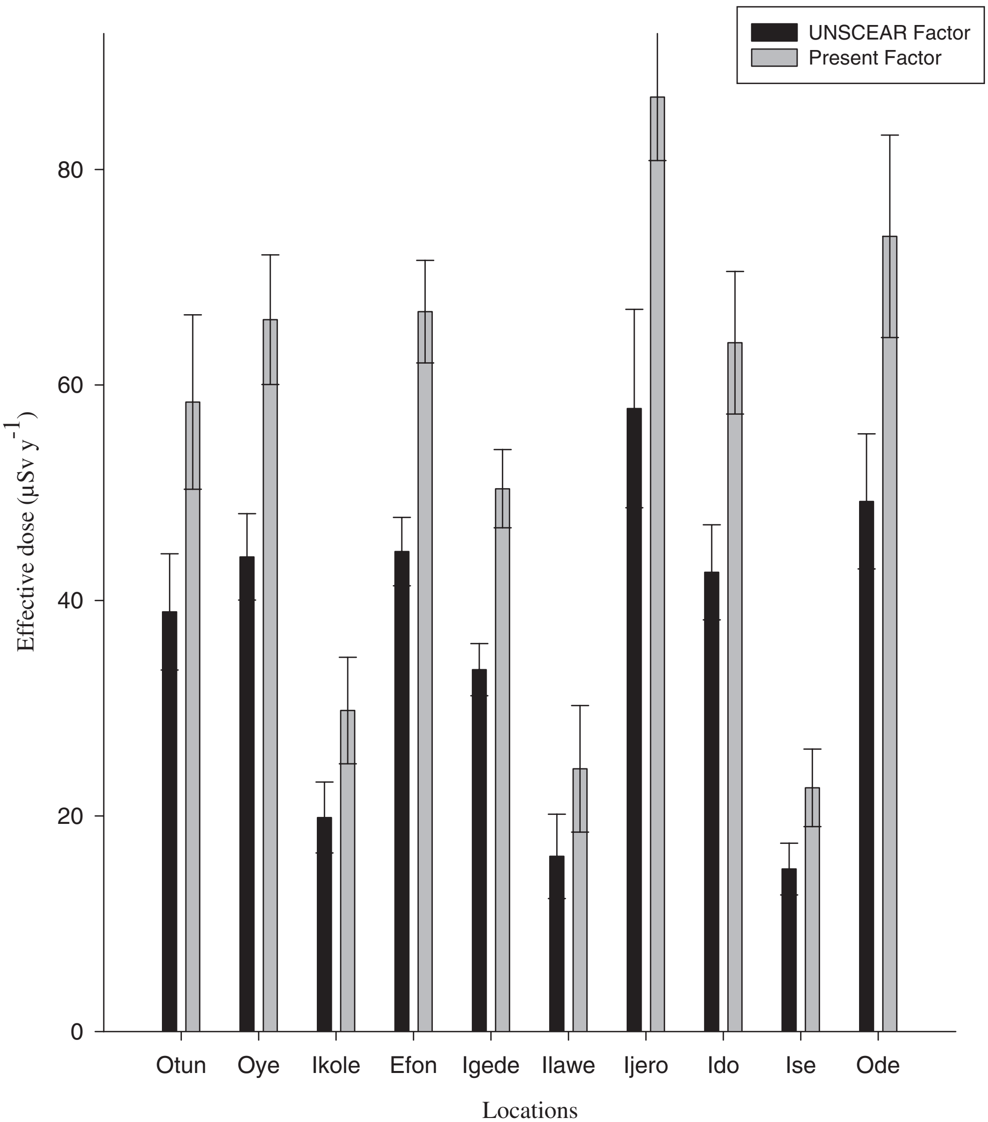

Figure 3. Comparision between the effective dose using the UNSCEAR and the present factors

Nigeria and similar environment in the continent Africa would either be underestimated by 10% for outdoor or overestimated by 2.5% for indoor in urban areas using the world average values by the UNSCEAR. These percentage differences, however, are not significant and the use of the UNSCEAR factors for the effective dose assessment in the urban areas in Nigeria and the larger African continent would not introduce large errors. For the rural environments, however, the percentage difference between the present outdoor factor and the one given by the UNSCEAR has been estimated to be 50%. This implies an underestimation of the outdoor effective dose by 50% and an overestimation of the indoor effective dose by 12.5%. The increase in the outdoor factors over the UNSCEAR value have been attributed to the differences in lifestyle of the people in tropical Africa and those in the temperate region of the globe, which the estimation of the UNSCEAR value might have been based upon. Apart from this, the differences in occupational practices between the developed and the developing countries could be a major contribution. In the estimation of the outdoor effective dose from terrestrial gamma radiation to the rural areas surveyed in the southern part of Nigeria using the outdoor factor of 0.3, the mean outdoor annual effective dose is 54.3 ± 6.9 μSv y^{-1}, which is 77% of the world average value of 70 μSv y^{-1} [(2)].

ACKNOWLEDGEMENTS

The authors are grateful to Dr A. Giussani of the Dipartimento di Fisica–Sezione di Fisica Medica, Universita degli Studi di Milano for his useful discussions and kindness to proofread the original manuscript of this work and also to the Fisica Medica group for the use of their facilities. The first author is particularly grateful to the ICTP TRIL programme, Trieste Italy for granting the fellowship, which enables him to have unlimited access to information used for the final preparation of this work.

REFERENCES

1. Brown, L. *National Radiation Survey in the U.K.: indoor occupancy factors*. Radiat. Prot. Dosim. **5**, 203–208 (1983).
2. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). *Ionizing radiation: sources and biological effects. Report on the General Assembly* (New York: UN) (1988).
3. Farai, I. P. and Jibiri, N. N. *Baseline studies of terrestrial outdoor gamma dose rate levels in Nigeria*. Radiat. Prot. Dosim. **88**, 247–254 (2000).
4. Farai, I. P. and Ademola, J. A. *Population dose rate due to building materials in Ibadan, Nigeria*. Radiat. Prot. Dosim. **95**, 69–73 (2001).
5. Jibiri, N. N. and Farai, I. P. *Assessment of dose rate and collective effective dose equivalent due to terrestrial gamma radiation in the City of Lagos, Nigeria*. Radiat. Prot. Dosim. **76**, 191–194 (1998).
6. Arogunjo, A. M., Farai, I. P. and Fuwape, I. A. *Dose rate assessment of terrestrial gamma radiation in the delta region of Nigeria*. Radiat. Prot. Dosim. **108**, 73–77 (2004).
7. Arogunjo, A. M. and Farai, I. P. *Dose assessment due to terrestrial gamma radiation in Ibadan, South-western Nigeria*. Glob. J. Pure Appl. Sci. **9**, 393–398 (2003).
8. Abbady, A. G. E. *Estimation of radiation hazard indices from sedimentary rocks in upper Egypt*. Appl. Radiat. Isot. **60**, 111–114 (2004).
9. Ajayi, I. R., Oresegun, M. O. and Babalola, I. A. *Absorbed dose rates in air due to U, Th and K in a part of South-western Nigeria*. Nig. J. Phys. **8s**, 38–40 (1996).
10. Ajayi, I. R. and Kuforiji, O. O. *Natural radioactivity measurement in rock samples of Ondo and Ekiti States in Nigeria*. Radiat. Meas. **33**, 13–16 (2001).
11. National Population Commission of Nigeria. *Provisional population census results* (1992).
12. Beck, H. L., De Campo, J. A. and Gogolak, C. V. *In situ Ge (Li) and NaI (Tl) gamma-ray spectrometry*. USAEC Report HASL-258 (1972).