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Estimation of Annual Effective Dose Due to Ingestion of Natural Radionuclides in Cattle in Tin Mining Areas of Jos Plateau, Nigeria: Are Large Mammals Really Affected?

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Abstract

We have read with great interest the paper which was published in Natural Science, 2014 issue number 6 titled "Estimation of annual effective dose due to ingestion of natural radionuclides in cattle in tin mining area of Jos Plateau, Nigeria" [1]. The paper motivated us to use state-of-the-art computational technique to investigate the risks of the tin mining activity in Jos-Plateau, Nigeria on large mammals (e.g. cattle). The Tier 2 Erica Tool assessment was used to estimate the total dose rate and risk quotients of these reference terrestrial animals. Our investigation revealed that the expected and conservative risk quotients of large mammals due to internal and external exposure to enhanced level of radioactivity are 0.05 and 0.16, respectively. Since the risk quotients are less than unity, this indicates that there is less than 5% probability that the screen dose rate (10 μGy·h^{-1}) is exceeded. The estimated total dose rate to large mammals is 0.52 μGy·h^{-1} which is not statistically significant. A critical analysis of [1] is presented in the introductory part of this paper.

Keywords

Tin Mining, Radioecology, Biota, Jos, Dose Rate

1. Introduction

The tin mining activities in the suburbs of Jos, Plateau State, Nigeria have resulted in technical enhancement of the background natural radiation as well as higher activity concentrations of primordial radionuclides in the topsoil of mining sites and their environs. In Jos, Nigeria, attempts have been made towards assessing the radiological consequence of mining in several localities [2]-[13]. A summary of the type of samples and results of each of these studies is presented in **Table 1**. Most of the studies on radiological effects of tin mining in Jos, Nigeria have only considered the human health risks.

A recent study by Ademola [1] attempted to measure the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in cattle that were believed to have grazed in the fields around the mining region. The study calculated the effective dose based on the consumption of meat from the cattle in this region. The study reported high activity concentration of ^{40}K in the studied cattle organs. However, there are some deficiencies of the study design and presentation that raise questions concerning the validity of the findings. Although the paper is very well written and deserves to be recognized as a remarkable contribution to the field of natural radiation studies in Nigeria, it has some shortcomings. These shortcomings are highlighted and discussed below.

We have been following studies from this region with technically enhanced background radiation level due to tin mining activities in the suburbs of Jos Plateau State, Nigeria [2] [5]-[9] [13]. The findings of some of these studies have been presented in one of our most recent papers [15] and **Table 1**.

Ademola [1] should have designed a good epidemiological study and the discussions of the results should have been strengthened with robust statistics. The author presented the activity concentrations of primordial radionuclides in the organs of cattle without justifying the results. The study considered just five cattle that were slaughtered in a local abattoir believing the animals had grazed in fields and farmlands that have technically enhanced levels of radioactivity due to mining activities in the region. This is misleading because of the nomadic life style of herdsmen in Nigeria and West Africa. Herdsmen regularly move their cattle to different parts of Nigeria, and in some cases even West Africa, depending on the season's climatic conditions in order to find green fields for their animals [16]. This factor could have resulted in confounding issues that would have biased the results of the study. In a recent study, we have discussed confounding issues in radioecology of the world's high background natural radiation areas [17].

Table 1. Summary of activity concentrations in soil and dose due to tin mining in Jos Nigeria [14].

Study	Activity concentrations of radionuclides (Bq·kg^{-1})					Mine Location	Type of sample
	^{238}U	^{226}Ra	^{232}Th	^{40}K	*In situ* dose measurements (μSv·h^{-1})		
Ibeanu [5]	3779.1	NA	8175.2	NA	NA	Jos tin Mine	Contaminated soil
Ademola [12]	722	NA	1680	Not detected	NA	Jos tin Mine	Tin tailing
Ademola, Farai [13]	NA	66	126	589	NA	Tin mining areas of Bukuru and Bitsichi, Jos	Concrete building blocks
Ajayi [2]	776.0	NA	2.72	35.4	NA	Soil samples	Tin mine in Baukuru-Jos
Arogunjo *et al*. [3]	(8.7 - 51)	NA	(16.8 - 98)	NA	NA	Tin mining area of Bitsichi, Jos	Soil and mineral sands
Funtua, Elegba [4]	NA	NA	NA	NA	(5 - 80)	Tin mines, Bukuru	NA
Jibiri *et al*. [6]	NA	(109 - 163)	(147 - 451)	(466 - 1062)	NA	Bitsichi, Bukuru and Ropp localities, Jos	Farm soil from the three localities
Jibiri *et al*. [7]	(BDL-48)	NA	(BDL-17)	(60 - 494)	NA	Old tin mine of Bitsichi	Food items, soil and local diets
Jibiri, Agomuo [8]	NA	(19 - 30)	(27 - 41)	(83 - 129)	NA	Old tin mine of Bitsichi	Terrestrial food crops
Jibiri *et al*. [9]	NA	(109 - 470.6)	(122.7 - 2189.5)	BDL-166.4	NA	Old tin mine of Bitsichi	Soil
Olise *et al*. [10]	(1.0 ± 40)	NA	(6.0 - 170)	NA	NA	Bukuru, Bitsichi and Kuru	Soil and tailing
Olise *et al*. [11]	BDL-27420	NA	(50 - 35,800)	(30 - 670)	NA	Bitsichi, Kuru and Bukuru	Tailing

Another issue is the very small sample size and the inability of the author to include proper controls. The author should have also considered cattle that were from non-mining areas of Jos. This would have helped the author in justifying the assumption that the dumping of mine tailings and the dispersion of excavated soil with enhanced radioactivity to some locations around the mining field would have influenced the activity concentrations in cattle from mining areas.

Another crucial factor that was overlooked by Ademola [1] was the age of the animals. This would provide insight as to whether the older animals had accumulated more radionuclides than the younger ones. This is hypothetically justifiable as older animals should have grazed on these "contaminated" fields the most. The author's failure to compare her results with earlier studies that were conducted in the study area is also a major limitation. For instance, [8], [7] and [9] have presented data on the activity concentrations of natural radionuclides in food samples from the same area.

Ademola [1] could have been enhanced if the author had considered if there was a relationship between radionuclide concentrations in the blood and any of the organs of interest. This is because ^{226}Ra is soluble in water and highly mobilizable [10] [18] [19]. This study could have also considered the radioecology of the studied animals which is also known to have important consequences for radionuclide uptake and deposition. For example, a simple run of the ERICA Tool [20]-[22], a state-of-the-art-software for assessing the impacts of exposure to ionizing radiation on non-human biota should have addressed this. Some of the contributing authors of this Letter have used ERICA for preliminary impact assessments of the Fukushima nuclear accident on non-human biota [23] [24] and for environmental impact assessments of the new nuclear power plant in Nigeria [25]-[27].

It is our opinion that given the small sample size, the lack of controls, and an incomplete radioecological analysis, the suggestion that mine tailings are the underlying cause of higher activity concentration of ^{40}K cannot be justified. In Nigeria, cattle graze on harvested fields and on byproducts of farming that are not needed by the peasant farmers for food. The application of inorganic fertilizer which is made of elements like NPK (Nitrogen, phosphorus, potassium) will influence the activity concentration of ^{40}K in the cattle feeds and hence their organs. The radioactivity of NPK fertilizer is well documented in the literature [28]-[30] and this is likely the cause of the reported findings. We understand that some of the highlighted deficiencies could be attributed to lack of funding but we hope the author will take some of our comments into consideration in any future study.

Several studies have considered the radiological human health risks of the mining activity; however, to our knowledge no documented study has investigated the radiological impacts on biota. Hence, an attempt is made to cover this information gap using published data from the literature and the ERICA Tool. Such a study is both timely and relevant given the growing international interest in the biological impacts of low dose radiation in the environment.

2. Material and Methods

Published data on the activity concentration of 238U, and 232Th in soil and tailings from Bukuru, Kuru and Bitsichi were used to conduct a Tier 2 ERICA Tool impact assessment to estimate the dose rate and risk quotients for the reference terrestrial species. The universal screening dose rate criterion of 10 μGy·h^{-1} was used for the assessment procedure. Such a level is often assumed to result in negligible environmental risks [31]. This methodology has proven useful for the assessment of impacts to biota due to exposure to Fukushima-derived radionuclides in marine, freshwater and terrestrial ecosystems [32] [33]. In order to follow regulatory standards, the upper bound of the reported range value for 238U and 232Th that have been reported by Ibeanu [5] were used as these two studies considered all mining areas (**Table 1**).

Brief Description of ERICA Tool

There are three elements of the ERICA integrated approach, which are to aid decision-making related to the environmental effects of ionizing radiation; the elements have been combined into the ERICA Integrated Approach. These are assessment of environmental exposure and effects using the ERICA Tool, risk characterization, and management of environmental risks [29] [34].

Tier 1: is designed to be simple and conservative, requiring a minimum of input data and enabling the user to exit the process and exempt the situation from further evaluation, provided the assessment meets a predefined screening criterion. Here the predefined screening dose is used to calculate the environmental media concentration limit (EMCL) for all reference organism/radionuclide combinations.

In Tier 1, the risk quotient (RQ) is then obtained by comparing the input media concentrations with the most restrictive EMCL for each radionuclide. These are defined by Equation (1).

$$RQ_n = \frac{AC_n}{EMCL_n} \tag{1}$$

where, AC is the measured activity concentration in the medium for a specific radionuclide n.

If $RQ < 1$, then the probability of exceeding the benchmark is acceptably low ($<5\%$) and this serves as the justification for terminating risk calculations at this stage. In a situation where $RQ > 1$, there is $>5\%$ probability that the benchmark has been exceeded and further assessment is recommended (Tier 2).

The basic equations for Tier 2 assessment are presented in Equations (2) and (3).

$$\dot{D}_{int}^{j} = \sum_i C_i^j \cdot DCC_{int,i}^{j} \tag{2}$$

where C_i^j is the average concentration radionuclide i in the reference organism j (Bq·Kg^{-1} fresh weight); $DCC_{int,i}^{j}$ is the radionuclide specific dose conversion coefficient for internal exposure (µG·h^{-1} per Bq·Kg^{-1} fresh weight).

$$\dot{D}_{ext}^{j} = \sum_z v_z \sum_i C_{zi}^{ref} \cdot DCC_{ext,zi}^{j} \tag{3}$$

where v is the occupancy factor of the organism j at location z; C_{zi}^{ref} is the average concentration of radionuclide i in the reference media in a given location z, and $DCC_{ext,zi}^{j}$ is dose conversion coefficient for external exposure. The total dose rate $\dot{D}_{Tot}^{j}$ is assessed by summing the two Equations (1) and (2). Two RQ_s (Expected $\left[RQ_{exp}\right]$ and Conservative $\left[RQ_{cons}\right]$) are obtained at the end of this assessment.

Tier 2: This allows the modeler to be more interactive, to change the default parameters (screening dose rate and radionuclides) and to select specific reference organisms. The evaluation is performed directly against the screening dose rate, with the dose rate and RQ_s generated for each reference organism selected for assessment. A "traffic light" system is used to indicate whether the situation can be considered:

1) Green: of negligible concern (with a high degree of confidence);
2) Yellow: of potential concern, where more qualified judgments may need to be made and/or a refined assessment at Tier 2 or an in-depth assessment in Tier 3 performed; and
3) Red: of concern, where the user is recommended to continue the assessment, either at Tier 2 if refined input data can be obtained, or at Tier 3.

Decisions to exit an assessment given outcomes 2) and 3) should be justified, for example by using information from FREDERICA provided in the Tool as "look-up effects tables" for different wildlife groups.

In Tier 2, the total risk quotient is calculated as

$$\sum RQ = \frac{D_{Tot}}{D_{lim}} \tag{4}$$

where D_{Tot} is the total dose rate and D_{lim} is the screening dose rate.

Tier 3 is a probabilistic risk assessment in which uncertainties within the results may be determined using sensitivity analysis. The assessor can also access up-to-date scientific literature (which may not be available at Tier 2) on the biological effects of exposure to ionizing radiation in a number of different species.

Detailed descriptions of the ERICA tool and the integrated approach for ecological impact assessment have previously been presented in the literature [20] [21] [32] [34]-[36].

3. Results and Conclusions

The results of the Tier 2 ERICA Tool run based on the data reported by Ibeanu [5] are presented in **Figure 1**. The models show very large variation among different groups in the predicted dose rates. The graph (**Figure 1**) indicates two threshold dose rate levels of interest. The first is the 10 µGy·h^{-1} level that is considered of interest by those promoting the ERICA tool (e.g. Beresford, etc.); the ERICA universal dose rate is assumed for all ecosys-
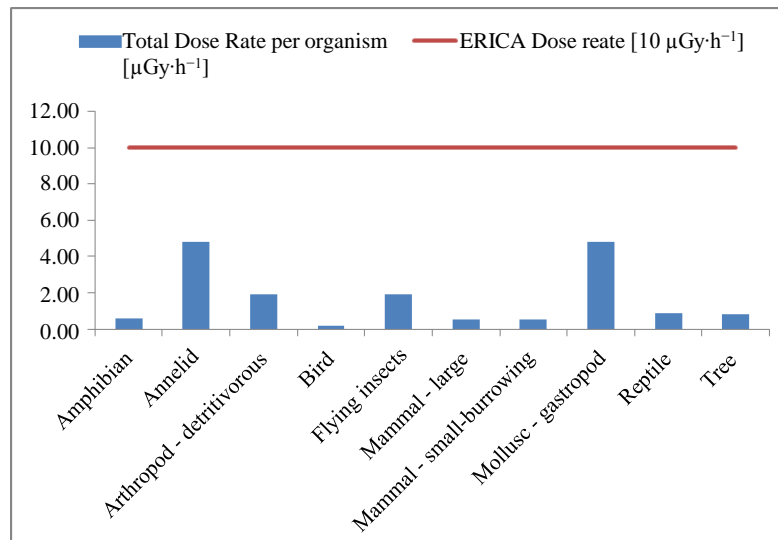
Figure 1. Total dose rate to reference terrestrial organisms due to tin mining.

tems. The second is 40 μGy·h⁻¹ which is felt by IAEA [37], UNSCEAR [38], and USDoE [39] to be of significance for terrestrial animals. It has been previously suggested that below this value of chronic exposure to radiation, measurable population effects will occur. It is worth noting that there is ongoing discussion on this threshold value, given controversial studies of organisms living in the forests of Chernobyl [40] [41].

The expected and conservative risk quotients for large mammals due to internal and external exposure to enhanced level of radioactivity are 0.05 and 0.16, respectively. Since all risk quotients are less than unity, this indicates that there is less than 5% probability that the screen dose rate of 10 μGy·h⁻¹ is exceeded. The organisms that receive the maximum total dose are mollusc-gastropod and annelid (earth worm). There is need to further investigate the impacts of chronic exposure to low-dose rate ionizing radiation using field data by directly observing any physiological or morphological aberrations in the specific organism and comparing the data with that of controls. The dose rate to our animal of interest, large mammal is relatively low (0.52 μGy·h⁻¹) and the risk quotients are less than unity indicating that large mammals (cattle) are not at risk.

This paper assessed the potential radioecological impacts of tin mining in Jos, Nigeria, with the aim of investigating if large mammals are affected by the enhanced levels of radioactivity in the soil, which is due to tin mining and milling. The results of this study have shown that terrestrial organisms like mollusc-gastropod and annelid (earth worm) receive the maximum estimated dose rate of 4.7 μGy·h⁻¹. While the estimated dose rate for large mammal is far less than the universal screening dose rate of 10 μGy·h⁻¹, which suggests that the animals are not likely at risk.

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