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Research Article

Evaluation of Environmental Radioactivity and Estimation of Radiation Exposure in the Niankhene Agricultural Field in Senegal

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Abstract

The presence of radioactivity, originating from both natural and human-induced sources, is widespread in varying degrees throughout the Earth's crust. Soil, as a fundamental component of the Earth's crust, serves as an ongoing source of exposure to humans. The level of radioactivity in soil is influenced by factors such as soil composition and land usage. It is expected that barren soil exhibits distinct radioactivity levels compared to cultivated soil. To investigate the radioactivity levels within barren soil, a study was conducted on approximately 11 hectares of soil samples located in Niankhene. Utilizing gamma ray spectrometry methodology with a high purity germanium gamma-ray detector, activity concentration levels of radionuclides including ^{40}K, ^{137}Cs, ^{226}Ra, and ^{232}Th were evaluated. A total of 16 soil samples were collected at depths ranging from 0 to 40 cm with 20 cm intervals. The activity concentrations of the radionuclides were observed as follows: ^{40}K ranged from below the limit of detection to 34.7 Bq.kg^{-1}; ^{137}Cs varied from 0.06 to 0.80 Bq.kg^{-1}; ^{226}Ra measured was between 7.49 and 101.56 kg^{-1}; and ^{232}Th ranged 0.33 and 12.68 Bq.kg^{-1}. The total dose radiation exposure were 27 nGy/h in this study. Before conducting radiometric measurements, chemical analyses were performed to determine the concentrations of Na, Ca, and Mg, along with measurements of electrical conductivity and pH levels of the soil samples.

Keywords

Soil, Gamma Spectrometry, Environmental Radioactivity, ^{40}K, ^{226}Ra, ^{232}Th, ^{137}Cs

1. Introduction

Human reliance on soil and its quality is interdependent with human activities and their utilization. Defined as a composite of natural materials on the Earth's surface housing organic life and sustaining vegetation, soil is structured as a three-phase system comprising solids, liquids, and gases [1]. Soil is an assemblage of natural components on the Earth's surface, encompassing living organisms and serving as a foundation that nurtures or has the potential to nurture plant life [2]. It is a multifaceted substance owing to its considerable diversity in physical and chemical composition. Within it reside minute yet crucial amounts of both

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organic and inorganic compounds, pivotal for the flourishing of plant growth. Various soil types exist, contingent upon their physical and chemical makeup. Soil classification includes categories like saline, saline-sodic, alkali, and more [3]. Soil, for instance, experiences an elevation in salt concentration to a degree that detrimentally impacts crop growth. Soil comprises not only organic and inorganic compounds but also naturally occurring radionuclides such as uranium, thorium, radium, potassium-40, and others [4]. These elements exist naturally as a mixture of oxides, hydrated oxides, carbonates, phosphates, sulphates, vanadates, and silicates. Additionally, nuclear activities related to atomic weapons testing represent another source of soil contamination. The primary mode of contamination originated from direct fallout onto vegetation from the atmosphere [5]. The radioactive isotope, cesium-137 (137Cs), exhibits a strong affinity for absorption and retention by soil particles, akin to the behavior of natural radionuclides distributed at varying depths within soil [6, 7]. The issue of radioactive contamination gained significant public attention following the Chernobyl accident. Naturally occurring radionuclides, such as those from the uranium and thorium series, constitute the primary contributors to radiation doses received by humans. In response to heightened public concern and awareness regarding radioactive pollution, this study aims to quantify the level of radioactivity and evaluate radiation exposure from the soil in the Niankhene field in senegal.

2. Materials and Methods

2.1. Sampling and Preparation Samples

The surveyed sites were found to consist mainly of light sand, prompting an investigation into factors such as land use duration, climatic conditions, and the crops cultivated by local landowners. The study site is Niankhene which found in the Tivaoune department in senegal. The spacing between sampling points varied from 25 to 50 meters, depending on site accessibility [8-11]. For the investigation of Assessment of Environmental Radioactivity and deposition, field and laboratory equipment, including a COBRA percussion motor and a corer with 10 cm diameter PVC tubes, were utilized for sample collection [12, 13]. The next figure show the processus of collection, preparation of samples.

Figure 1. *Collection and Preparation of samples.*

2.2. Gamma-ray Spectrometry

Analyses were conducted in the gamma spectrometer laboratory at the Institute. A CAMBERRA brand detector, a High Purity Germanium (HPGe) type N with 15% relative efficiency, equipped with a carbon window and covering an energy range from 10 keV to 10 MeV, was used to determine natural radionuclides (^{40}K, ^{232}Th, and ^{226}Ra decay products) as well as artificial radionuclides such as ^{137}Cs. Sample analysis was performed using the Genie 2000 software. Each sample underwent measurements for a minimum duration of 86,000 seconds [14-17]. Energy and relative efficiency calibrations for the detector were carried out using a multinuclide reference standard emitting gamma rays within the 60–1333 keV energy range. Geometry calibration and validation were conducted using the mathematical software Labsocs. The activity concentrations of the relevant radionuclides in each sample were determined based on their respective gamma lines or those emitted by their progenies. The equations used to calculate the activity concentration and its uncertainty followed the methodologies outlined by IAEA and Samat [18, 19]. Additionally, to account for minor photopeaks in each sample, the minimum detectable activity (MDA) was computed using the formula initially established by Currie [20]. Specific gamma lines used to identify and quantify radionu-

clides in the samples were 352 keV for ^{226}Ra, 911 keV for ^{232}Th, 662 keV for ^{137}Cs, and 1460 keV for ^{40}K [21]. These gamma lines were employed in gamma spectroscopy to determine the activity concentrations of radionuclides based on the characteristic gamma emissions associated with each radionuclide or its decay products. It appears that radioactive equilibrium within the ^{232}Th decay chain might not persist all the way to ^{232}Th itself but rather reach equilibrium at ^{228}Ra (^{228}Ac) or ^{208}Tl. However, for reporting consistency with current literature practices, the values will be presented as ^{232}Th, and the activity of ^{214}Pb will be considered as the values of ^{226}Ra. As for ^{40}K, its activity concentration was determined using its 1460 keV gamma line, and for ^{137}Cs, the 662 keV gamma line was utilized in determining its activity concentration [22]. Quality control tests were conducted using standard reference materials (IAEA-321 and IAEA-414, reference materials provided by the International Atomic Energy Agency). The obtained results aligned well with the values of the IAEA-321 and IAEA-414 samples, except for ^{232}Th due to its low activity. The activity concentrations of the radionuclides of interest were determined for each sample using specific gamma lines emitted by the respective radionuclides or their decay progenies. The gamma lines used were as follows: 911 keV for ^{232}Th (^{228}Ac) with an intensity of 26.2%, 352 keV for Ra (^{214}Pb) with an intensity of 35.6%, 662 keV for ^{137}Cs with an intensity of 84.9%, and 1461 keV for ^{40}K with an intensity of 10.5% [23]. These gamma lines were employed in gamma spectroscopy to identify and quantify the radionuclides present in the samples, enabling the determination of their activity concentrations based on the characteristic gamma emissions associated with each radionuclide or its decay products [24]. It appears that the radioactive equilibrium within the ^{232}Th decay chain might not persist all the way to ^{232}Th itself but rather reach equilibrium at ^{228}Ra (^{228}Ac or ^{208}Tl). However, for reporting consistency with current literature practices, the values will be presented as ^{232}Th, and the activity of ^{214}Pb will be considered as the values of ^{226}Ra. As for ^{40}K, its activity concentration was determined using its 1460 keV gamma line, and for ^{137}Cs, the 662 keV gamma line was utilized in determining its activity concentration. The quality control tests were conducted using standard reference materials (IAEA-321 and IAEA-414, reference materials provided by the International Atomic Energy Agency). The obtained results aligned well with the values of the IAEA-321 and IAEA-414 samples, except for ^{232}Th due to its low activity [25]. Gamma-ray spectrometry was utilized to measure the radioactivity of the samples under investigation. This system also included an inbuilt power supply and amplifier. The MCA card was installed within a personal computer (PC) for data acquisition and analysis purposes [26]. The International Atomic Energy Agency (IAEA) soil reference material was employed for calibrating the spectrometer. Spectra from each soil sample were collected for a duration of 65,000 seconds. The areas under the energy peaks, as provided in Table 1, were utilized to generate a peak efficiency curve by plotting the logarithm of efficiency against the logarithm of peak energy [27].

Table 1. *Gamma-ray energies used for the calibration of spectrometer and for the measurement of activity of the radionuclides of interest.*

Parent nuclide	Daughter nuclide	γ-ray energy (keV)	Abundace (%)
^{226}Ra	^{214}Pb	241.98	7.12
	^{214}Pb	395.21	19.20
	^{214}Pb	351.92	35.10
	^{214}Bi	609.32	44.60
	^{214}Bi	768.30	4.76
	^{214}Bi	1120.28	14.70
	^{214}Bi	1238.11	5.78
	^{214}Bi	1764.52	15.10
^{232}Th	^{228}Ac	202.39	3.81
	^{212}Pb	238.63	43.50
	^{228}Ac	338.42	11.26
	^{228}Ac	463.10	4.50
	^{208}Tl	583.19	30.58
	^{208}Bi	727.33	6.64
	^{208}Tl	860.56	4.50
	^{228}Ac	911.16	26.60
	^{228}Ac	964.64	5.05
	^{228}Ac	968.97	16.23
	^{208}Te	2641.60	35.80
^{40}K		1460.60	10.67

The lowest limits of detection (LLD) for the isotopes 40K, 137Cs, 232Th, and 226Ra were determined and are presented in Table 2. Spectra for each sample were collected over a duration of 86,000 seconds.

Table 2. *The lowest limit of detection (LLD) for the radionuclides for ^{40}K; ^{137}Cs; ^{232}Th and ^{226}Ra.*

Nuclides	Lowest detection limit (Bq.kg^{-1})
^{40}K	-
^{137}Cs	0.01
^{226}Ra	1.20
^{232}Th	0.10

3. Results and Discussion

Gamma-ray spectrometry was employed to investigate the activity concentrations of natural radionuclides from the uranium and thorium series, as well as ^{40}K and the fission product ^{137}Cs, in soil samples from Niankhene, located in the department of Tivaoune in the Thies region of Senegal. The primary radionuclides of interest in the area were identified as ^{40}K, ^{226}Ra, and ^{232}Th [28]. Table 3 provides the average values of specific gamma-ray activities attributed to ^{40}K, ^{137}Cs, ^{232}Th, and ^{226}Ra in the soil samples.

Table 3. *Activity of naturally occurring radioisotopes in the soil samples in Niankhene.*

Sample name	Activity concentrations in (Bq.kg^{-1})			
	^{40}K	^{232}Th	^{226}Ra	^{137}Cs
S1	0.33 ±0.26	3.42 ±0.39	7.49 ±0.05	Below LDL
S2	1.32 ±0.01	6.45 ±0.50	69.89 ±12.18	0.57 ±0.03
S3	0.69 ±0.01	0.33 ±0.02	19.35 ±1.01	0.80±0.01
S4	34.7 ±1.70	3.54 ±0.22	9.39 ±0.59	0.09 ±0.02
S5	Below LDL	12.68 ±1.31	16.45 ±1.67	0.11 ±0.02
S6	Below LDL	3.12 ±0.19	86.66±12.82	0.06 ±0.02
S7	Below LDL	3.13 ±0.19	101.56±15.09	0.15 ±0.02
S8	1.35±0.01	3.11 ±1.01	101.55 ±1.30	0.15 ±0.03

Notably, the activity levels were observed to conform to a normal distribution. Regarding the distribution of activity concerning depth, no discernible correlation was noted between these two parameters. This suggests that the activity concentrations of the investigated radionuclides do not exhibit a systematic variation with depth in the soil profile. Natural potassium consists of three isotopes: ^{39}K, ^{40}K, and ^{41}K. Only the isotope ^{40}K exhibits natural gamma radioactivity, with a half-life of approximately 1.3×10^{9} years. In nature, ^{40}K accounts for about 0.012% of all potassium. During its decay, ^{40}K undergoes beta decay to produce two daughter isotopes: ^{40}Ca and ^{40}Ar. This decay process involves the emission of beta particles and gamma radiation. The extensive use of fertilizers, particularly those containing potassium, has significantly impacted the concentration of radionuclides in the environment. Potassium-containing fertilizers are one of the primary contributors to the elevated levels of ^{40}K activity observed in soil [29]. The concentration range of ^{40}K in the soil ranged from below the limit of detection to 34.7 Bq.kg^{-1}, with an average value of 4.80 Bq.kg^{-1}. The low amount of ^{40}K is explained by the fact that the Niankhene site is very poor in fertilizers. As previously mentioned, in addition to ^{40}K, the other naturally occurring radionuclides measured were ^{226}Ra and ^{232}Th. ^{226}Ra (a member of the ^{238}U series) is considered the most highly radiotoxic natural radionuclide [30]. The activity range of ^{226}Ra measured was between 7.49 and 101.56 kg^{-1}, with an average of 52.42 Bq.kg^{-1}. The specific activity range of ^{232}Th (with a half-life of 1.4×10^{10} years) was between 0.33 and 12.68 Bq.kg^{-1}, averaging at 4.47 Bq.kg^{-1}. The average activity of ^{226}Ra was found to be 11 time that of ^{232}Th [31]. Additionally, the activity concentration of ^{226}Ra in soil is an order of magnitude higher than that of ^{40}K and ^{232}Th. Since the turn of the century, it has been recognized that phosphate rocks harbor significant concentrations of uranium, thorium, radium, and the decay products of radium [32]. Phosphate rock serves as a crucial raw material in the production of various types of phosphatic fertilizers. Consequently, during the processing of this rock into fertilizers, a significant portion of the uranium and some of the radium are carried along with the fertilizers [33]. Previous estimations have indicated that the application of phosphatic fertilizers to fields in recommended quantities could lead to an increase in the radioactivity levels in soils. The activity of ^{137}Cs in all the samples was found to be very low and ranged from 0.06 to 0.80 Bq.kg^{-1}. Several reasons may account for the low activity of ^{137}Cs in the soil of Niankhene. Firstly, the presence of trees and grass in the area could have acted as a shield, resulting in a reduction of ^{137}Cs within the soil. Additionally, since the land remained barren, it's plausible that cattle consumed contaminated grass containing ^{137}Cs. Moreover, any remaining ^{137}Cs might have been eroded by environmental factors such as rain and wind over time. The observed variations in activity levels have been noted to fall within the range of activity values measured worldwide [34]. A comparison of activity levels with global standards can be seen in Table 4.

Table 4. *Comparison of activity levels in the Niankhene soil and the world average.*

Location	Activity concentration (Bq.kg^{-1})		
	^{40}K	^{226}Ra	^{232}Th
Niankhene soil	Below LDL - 35	7-102	0-13
World average	140-850	17-60	11-64

The decay of naturally occurring radionuclides in soil generates gamma and beta radiation fields within the soil, which can extend beyond the soil-air interface, resulting in human exposure [35]. Outdoor external exposures stem from terrestrial radionuclides present in trace amounts in all soils. The external gamma dose rate in the air is determined by measuring the concentration of the relevant radionuclide in the soil. In the UNSCEAR 2000 report, coefficients for converting activity concentration to absorbed dose rate in air are provided and presented in Table 5.

Table 5. *Activity to dose rate conversion factors [36].*

Radionuclides	Dose coefficient (nGy.h^{-1} per Bq.kg^{-1})
^{40}K	0.0417
^{238}U	0.462
^{232}Th	0.604

The application of these dose coefficients, which relate soil concentration to absorbed dose rate in air, to the measured values yields results as shown in Table 6.

Table 6. *Radiation dose in air due to natural radioactivity in the Nainkhene soil sample.*

Radionuclides	Average activity (Bq.kg^{-1})	Absorbed dose in the (nGy.h^{-1})
K	4.80	0.2
U	24.23	24.23
Th	2.70	2.70
	Total	
	World range	27.13
	[36]	18-93

The Total absorbed dose rates in at radionuclides (^{238}U, ^{232}Th, and ^{40}K) could ba calculated by using Equation (1) on the guidelines provided by: [37]

$$D(nGyh-1) = 0.462A_U + 0.604A_{Th} + 0.0417A_K$$

Where are the average activity concentration of ^{238}U, ^{232}Th and ^{40}K respectively?

The calculated value is 27 nGy/h, which falls within the dose rate range of 18–93 nGy/h given for the world in the UNSCEAR 2000 report.

4. Conclusion

In this study, an evaluation of environmental radioactivity and estimated radiation exposure in the Niankhene agricultural field in Senegal. Through systematic measurements and analysis, we determined the level of radioactivity present in the soil and surrounding environment. The calculated radiation exposure level, represented by the value of 27 nGy/h, was found to fall within the dose rate range of 18 to 93 nGy/h as outlined in the UNSCEAR 2000 report. These findings provide valuable insights into the radiological safety of the agricultural field and its potential impact on public health. The results of this evaluation underscore the importance of ongoing monitoring and assessment of environmental radioactivity in agricultural areas. Such efforts are crucial for ensuring the safety of agricultural workers, nearby residents, and consumers of agricultural products. Furthermore, this study highlights the need for continued research and mitigation strategies to address any potential risks associated with radiation exposure in agricultural settings. In conclusion, the evaluation of environmental radioactivity and radiation exposure in the Niankhene agricultural field contributes to our understanding of radiological safety in Senegal and emphasizes the importance of proactive measures to safeguard public health and the environment.

Abbreviations

IAEA: International Atomic Energy Agency
MDA: Minimum Detectable Activity
MCA: Multi Channel Analyser
HPGe: High Purity of Germanium
PVC: Poly Vinyl Chloride
LDD: Low Detection Limit

Conflicts of Interest

The authors declare no conflicts of interest.

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