

Radiological and toxicological implications of geophagic kaolin consumption during pregnancy in Ghana: A screening-level assessment of maternal and Foetal Exposure

Henry Lawluvi ^{1,2,*}, Cyril Cyrus Arwui ¹, Emmanuel Akrobortu ¹, Nelson Agbemava ¹, Etorname Ann Mensah ¹, Samuel Wotorchi-Gorden ¹ and Lilian Agyiman ³

¹ Nuclear Regulatory Authority, P.O. Box AE 50, Kwabenya, Accra, Ghana.

² School of Nuclear and Allied Sciences. University of Ghana, Legon

³ Ghana Atomic Energy Commission, Kwabenya, Accra, Ghana

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Abstract

Geophagic consumption of kaolin during pregnancy is widely reported in Ghana, yet its radiological implications remain poorly characterised within the broader environmental exposure framework. This study evaluates the potential contribution of naturally occurring radionuclides in commercially available kaolin to maternal and foetal radiation dose, situating radiological exposure within the wider context of geophagia-related health risks. Ten bulk kaolin samples obtained from major markets in southern Ghana were analysed using high-resolution gamma spectrometry. Activity concentrations of radionuclides from the uranium-238 and thorium-232 decay series, as well as potassium-40, were quantified. Maternal and foetal committed effective doses were estimated under two ingestion scenarios representing low and high habitual consumption. All samples contained measurable radionuclides, with potassium-40 exhibiting the highest activity concentrations, while radium and thorium series radionuclides contributed most strongly to dose. Estimated foetal doses ranged from 0.013 to 0.047 mSv, whereas maternal doses ranged from 0.431 to 1.509 mSv. Although these doses fall within the range of low-level natural exposures, sustained high intake resulted in maternal doses approaching commonly referenced public exposure benchmarks. The findings identify geophagic kaolin as a previously under-recognised ingestion pathway for naturally occurring radionuclides in Ghana. While radiological exposure is unlikely to represent the dominant health risk compared with toxicological and microbiological hazards, it contributes to cumulative exposure and warrants inclusion in integrated environmental health assessments.

Keywords: Geophagia; Kaolin; Pregnancy; Naturally Occurring Radionuclides; Internal Exposure; Maternal Dose; Foetal Dose; Ghana

1. Introduction

Geophagia, defined as the intentional consumption of earth materials such as clay or soil, is a widespread practice in many parts of sub-Saharan Africa, particularly among pregnant women [1-3]. In Ghana, reported prevalence rates of pica during pregnancy range from approximately 30% to 50%, with geophagic kaolin representing one of the most commonly consumed materials [1,3]. This practice is often associated with culturally embedded beliefs, management of pregnancy-related discomfort, and perceived nutritional or therapeutic benefits [1,4,5]. At the same time, geophagia has been linked to a range of environmental health concerns, including exposure to heavy metals, microbial contamination, and interference with nutrient absorption [3,4,6].

Most studies of geophagia in Ghana and comparable settings have focused on toxicological and microbiological risks, particularly the presence of lead, arsenic, cadmium, and pathogenic organisms in consumed materials [3,4,6]. However,

* Corresponding author: Henry Lawluvi

geophagic clays may also contain naturally occurring radionuclides derived from the uranium-238 and thorium-232 decay series, as well as potassium-40, reflecting their geological origin [6]. These radionuclides contribute to background radiation and may represent an additional ingestion exposure pathway when such materials are consumed regularly [6].

Despite this, the radiological dimension of geophagia has received limited attention in environmental health research [6-8]. Existing radioactivity studies on kaolin and related materials have primarily focused on activity concentrations, external hazard indices, and environmental radiation levels in mining or geological contexts [8-10]. Few studies have examined internal exposure resulting from direct ingestion, and even fewer have considered pregnancy-specific exposure scenarios in which both maternal and foetal doses may be relevant [6,7].

Understanding this exposure pathway is important because the embryo and foetus exhibit increased sensitivity to ionising radiation, with dose-response relationships that vary across gestational stages [11-13]. While the magnitude of exposure from geophagic materials is expected to be low relative to other environmental sources, repeated ingestion over the course of pregnancy may contribute to cumulative dose, particularly for the mother [6,9].

This study, therefore, aims to characterise geophagic kaolin as a potential ingestion pathway for naturally occurring radionuclides in Ghana and to estimate associated maternal and foetal doses under plausible consumption scenarios. Rather than presenting a high-precision dosimetric analysis, the study adopts a screening-level approach to situate radiological exposure within the broader environmental and health context of geophagia. By integrating radiological assessment with existing knowledge on chemical and microbial risks, the study contributes to a more comprehensive understanding of the health implications of geophagic practices during pregnancy [1,3,4,6,7].

2. Materials and Methods

2.1. Study design and analytical approach

This study adopted a screening-level analytical design to characterise geophagic kaolin as a potential ingestion pathway for naturally occurring radionuclides and to estimate associated maternal and foetal exposure during pregnancy [14,15]. The approach combined laboratory-based measurement of radionuclide activity concentrations in commercially available kaolin with simplified intake and dose modelling under defined consumption scenarios, consistent with established environmental radioactivity and food-chain assessment approaches [14-16]. The objective was not to produce high-resolution dosimetric estimates, but to provide an initial quantitative indication of the potential contribution of geophagic materials to internal radiation exposure within a broader environmental health context [14,15].

2.2. Sample collection and preparation

Ten kaolin samples intended for human consumption were obtained from major open-air markets across the Greater Accra, Eastern, and Volta Regions of Ghana. Markets were purposively selected to reflect commonly patronised retail points and to capture variability in consumer-available products rather than geological source materials, following typical environmental sampling strategies for exposure assessment [15].

Approximately 1 kg of kaolin was collected from a primary vendor at each market. Samples were transported in sealed polyethylene bags to the laboratory, air-dried at ambient temperature, and mechanically homogenised [15]. Each sample was sieved to obtain a uniform particle size and transferred into 1 L Marinelli beakers, a geometry widely used in gamma spectrometric analysis of bulk materials [15,17]. The sealed samples were stored for a minimum of 30 days to allow secular equilibrium between parent radionuclides and their short-lived progeny prior to measurement, in line with standard practice for uranium- and thorium-series analyses [9,18].

2.3. Gamma spectrometric analysis

Radionuclide activity concentrations were determined using high-resolution gamma spectrometry with a p type extended range high purity germanium detector (Model GX4018). The detector had a relative efficiency of 40% and an energy resolution of 2.0 keV at 1332 keV, comparable to systems used for routine environmental monitoring [15,17]. To reduce background radiation, the detector was housed in a 5 cm thick lead shield lined internally with copper, cadmium, and Plexiglas [15,17].

Each sample was counted for 36,000 seconds to achieve low minimum detectable activities suitable for environmental samples [15,17]. Background spectra were acquired using distilled water-filled Marinelli beakers under identical

conditions and used for spectral correction, following established background-correction procedures [17,19]. Energy and efficiency calibration were performed using IAEA reference materials (IAEA RGU 1 and IAEA RGTh 1) and a certified multi gamma standard covering a wide energy range, consistent with recommended HPGe calibration methods [18,20].

Radionuclides were identified based on characteristic gamma emissions. Activity concentrations were determined for radionuclides representative of the uranium 238 and thorium 232 decay series, as well as potassium 40 [9,15]. Only peaks exceeding the minimum detectable activity at the 95% confidence level were used for quantification. For values below the minimum detectable activity, a substitution approach was applied for subsequent calculations, consistent with standard environmental radioactivity practice [14,17,21].

Activity concentrations were expressed in Bq kg^{-1} and calculated using standard gamma spectrometric equations incorporating net peak area, counting efficiency, gamma yield, counting time, and sample mass [15,17]. Measurement uncertainty was estimated using combined standard uncertainty and expressed as expanded uncertainty at the 95% confidence level, in line with typical uncertainty treatment in environmental gamma spectrometry [17].

2.4. Intake scenarios and exposure estimation

Daily ingestion of kaolin was modelled using two consumption scenarios representing lower and higher habitual intake levels reported in the literature: 20 g day^{-1} and 70 g day^{-1} [14]. These scenarios were used to provide bounded estimates of radionuclide intake under plausible behavioural conditions.

For each radionuclide, daily intake (Bq day^{-1}) was calculated as the product of mean activity concentration and daily consumption rate, as commonly applied in dietary internal-dose assessments [14,16]. Intake was assumed to be constant over the duration of pregnancy (270 days), recognising that actual consumption patterns may vary temporally and individually but following standard practice in screening-type assessments [14,16,22].

2.5. Maternal and foetal dose estimation

Maternal and foetal committed effective doses were estimated using ingestion dose coefficients derived from the International Commission on Radiological Protection framework for internal dosimetry [23,24]. Adult dose coefficients were applied for maternal exposure, while pregnancy specific or age-dependent coefficients were used to approximate foetal dose resulting from maternal intake [22-24].

To reflect variation in foetal sensitivity over the course of pregnancy, gestation was divided into three representative stages (early, mid, and late pregnancy), and dose contributions were aggregated across these stages, consistent with age structured internal-dose and risk approaches [22]. Dose estimates were calculated as the product of radionuclide intake, corresponding dose coefficients, and duration of exposure [14,16,23].

Given the screening-level nature of the study, the dose modelling approach was intentionally simplified and based on reference biokinetic models rather than individual-specific physiological parameters [23,24]. The resulting estimates, therefore, represent indicative rather than individualised dose values.

2.6. Risk characterisation

Excess lifetime cancer risk was estimated for both maternal and foetal exposure using dose-based risk coefficients derived from standard radiological protection frameworks [14,16,22]. Risk was calculated as the product of committed effective dose and the corresponding risk coefficient and expressed as unitless probability, following approaches used in food and drinking-water radioactivity assessments [14,16,21]. For interpretative clarity, values were also presented as cases per 100,000 individuals [14,16].

2.7. Sensitivity analysis

To evaluate the influence of uncertainty in key input parameters, a deterministic sensitivity analysis was conducted. Daily consumption rates were varied by $\pm 25\%$ relative to baseline scenarios, and radionuclide activity concentrations were varied using the 10th and 90th percentiles of measured values, similar to percentile- or scenario-based analyses in environmental risk assessment [14,15,25]. Resulting changes in dose and risk estimates were examined to assess the robustness of model outputs and the stability of radionuclide contribution patterns [14,15].

2.8. Ethical considerations

The study involved analysis of commercially available materials and did not include human participants, biological samples, or identifiable personal data. Ethical approval and informed consent were therefore not required, consistent with prevailing norms for purely material-based environmental radioactivity studies [9,14,15].

3. Results

3.1. Radionuclide activity concentrations in geophagic kaolin

All analysed kaolin samples contained measurable levels of naturally occurring radionuclides, with variability observed across sampling locations and radionuclide types, consistent with findings from kaolin fields and deposits in Nigeria [9,26,27]. Detected radionuclides included members of the uranium-238 and thorium-232 decay series, as well as potassium-40 [9,10,28-30]. Uranium-238 activity concentrations were below the minimum detectable activity in several samples, indicating either low concentrations or analytical limitations at the detection threshold, a situation also reported in food and plant matrices where uranium-series radionuclides are near or below detection in some samples [29,31].

Across all samples, potassium-40 exhibited the highest activity concentrations, reflecting its common occurrence in clay minerals and soils [9,10,28,32]. In contrast, radium- and thorium-series radionuclides showed lower absolute activity levels but were consistently detected across samples [9,10,26]. Summary statistics for radionuclide activity concentrations are presented in Table 1.

The observed variability likely reflects differences in geological origin, processing, and market supply chains, in line with studies showing strong lithological control on natural radioactivity in kaolin terrains and soils [9,10,26,27]. However, as samples were obtained from retail markets rather than traced to specific deposits, the results are interpreted as representative of consumer exposure rather than source-specific geochemical characterisation.

Table 1 Activity concentrations of natural radionuclides in geophagic kaolin samples from selected markets in Ghana (Bq kg^{-1})

Market	^{238}U	^{226}Ra	^{228}Th	^{228}Ra	^{40}K
1	<MDA	32.5 ± 2.0	72.0 ± 6.0	85.0 ± 3.0	950 ± 100
2	40.0 ± 5.0	28.0 ± 1.5	68.0 ± 5.0	78.0 ± 2.0	720 ± 150
3	<MDA	35.0 ± 2.5	95.0 ± 8.0	100.0 ± 3.0	990 ± 90
4	55.0 ± 6.0	22.0 ± 1.0	50.0 ± 4.0	65.0 ± 2.5	310 ± 80
5	<MDA	30.0 ± 1.2	88.0 ± 7.0	95.0 ± 2.0	980 ± 100
6	45.0 ± 5.0	40.0 ± 1.8	120.0 ± 10.0	105.0 ± 2.5	930 ± 90
7	<MDA	27.0 ± 1.0	55.0 ± 5.0	70.0 ± 2.0	500 ± 120
8	60.0 ± 7.0	33.0 ± 1.7	78.0 ± 6.0	82.0 ± 2.0	910 ± 110
9	<MDA	25.0 ± 1.0	66.0 ± 5.0	77.0 ± 3.0	750 ± 100
10	50.0 ± 6.0	38.0 ± 2.0	100.0 ± 9.0	102.0 ± 2.5	980 ± 90
Mean \pm SD	26.3 ± 20.4	31.1 ± 6.3	79.2 ± 20.6	85.9 ± 13.6	802 ± 225

3.2. Estimated radionuclide intake from kaolin consumption

Estimated radionuclide intake increased proportionally with assumed daily kaolin consumption, as expected from standard intake formulation used in ingestion dose assessments [29,31,33]. Under the low-intake scenario (20 g day^{-1}), daily intake values remained low across all radionuclides. Under the high-intake scenario (70 g day^{-1}), intake increased substantially but retained the same relative pattern across radionuclides.

Potassium-40 contributed the largest share of total activity intake due to its higher concentration in the analysed samples, similar to observations in soil, herbs, and foodstuffs where potassium-40 dominates activity [10,28,32]. In

contrast, radionuclides from the uranium- and thorium-series contributed lower absolute intake values [29,31]. Estimated daily and weekly intake values for each radionuclide are summarised in Table 2.

Table 2 Estimated radionuclide intake from geophagic kaolin consumption

Radionuclide	Mean activity (Bq kg ⁻¹)	Daily intake (20 g day ⁻¹) (Bq day ⁻¹)	Daily intake (70 g day ⁻¹) (Bq day ⁻¹)	Weekly intake (70 g day ⁻¹) (Bq week ⁻¹)
²³⁸ U	26.3	0.53	1.84	12.9
²²⁶ Ra	31.1	0.62	2.17	15.2
²²⁸ Th	79.2	1.58	5.54	38.8
²²⁸ Ra	85.9	1.72	6.01	42.1
⁴⁰ K	802.0	16.0	56.1	392.0

3.3. Foetal committed effective dose

Estimated foetal committed effective doses over a full pregnancy period (270 days) were low under both intake scenarios. Total foetal doses ranged from 0.013 mSv for the low-intake scenario to 0.047 mSv for the high-intake scenario (Table 3), which is comparable in magnitude to ingestion-based doses reported for other environmental pathways and below typical global values for natural ingestion exposure [10,31,32].

Although potassium-40 contributed the largest proportion of radionuclide intake, it contributed minimally to foetal dose. Instead, thorium- and radium-series radionuclides dominated the overall dose contribution due to their higher ingestion dose coefficients for the embryo or foetus and adults [31,33,34]. This distinction highlights that dose contribution is not directly proportional to activity concentration.

Across both intake scenarios, estimated foetal doses remained well below commonly referenced radiological protection thresholds for prenatal exposure [33,34]. The magnitude of exposure is therefore consistent with low-level environmental background ingestion pathways [10,31,32].

Table 3 Estimated foetal committed effective dose from kaolin ingestion

Radionuclide	Dose coefficient range (mSv Bq ⁻¹)	Dose (20 g day ⁻¹) (mSv)	Dose (70 g day ⁻¹) (mSv)	Contribution (%) - high intake
²³⁸ U	1.6–3.7 × 10 ⁻⁶	0.0006	0.0022	5
²²⁶ Ra	2.6–6.0 × 10 ⁻⁷	0.0005	0.0016	3
²²⁸ Th	2.3–2.4 × 10 ⁻⁸	0.0090	0.0314	68
²²⁸ Ra	2.6–6.0 × 10 ⁻⁷	0.0032	0.0112	24
⁴⁰ K	5.7 × 10 ⁻⁹	0.00002	0.00009	<1
Total	—	0.013	0.047	100

Table 4 Estimated foetal excess lifetime cancer risk

Scenario	Foetal dose (mSv)	Risk coefficient (Sv ⁻¹)	ELCR (unitless)	ELCR per 100,000
Low (20 g day ⁻¹)	0.013	0.055	7.15 × 10 ⁻⁷	0.0715
High (70 g day ⁻¹)	0.047	0.055	2.59 × 10 ⁻⁶	0.2585

3.4. Maternal committed effective dose

Maternal committed effective doses were higher than corresponding foetal doses under both intake scenarios, consistent with embryo or foetus modelling where a fraction of maternal dose is transferred to the conceptus [31,33,34].

Estimated maternal doses ranged from 0.431 mSv for the low-intake scenario to 1.509 mSv for the high-intake scenario (Table 5a).

As observed in the foetal assessment, radionuclide contributions to maternal dose were dominated by radium- and thorium-series radionuclides rather than potassium-40, reflecting their larger ingestion dose coefficients [31,33,34]. Under the high-intake scenario, cumulative maternal dose approached or exceeded the commonly referenced public exposure benchmark of 1 mSv per year within radiological protection frameworks [33,35].

Table 5a Estimated maternal committed effective dose

Radionuclide	Dose (20 g day ⁻¹) (mSv)	Dose (70 g day ⁻¹) (mSv)
²³⁸ U	0.00639	0.02237
²²⁶ Ra	0.04702	0.16458
²²⁸ Th	0.03079	0.10778
²²⁸ Ra	0.32006	1.12022
40K	0.02685	0.09398
Total	0.431	1.509

Table 5b Estimated maternal excess lifetime cancer risk

Scenario	Maternal dose (mSv)	Risk coefficient (Sv ⁻¹)	ELCR (unitless)	ELCR per 100,000
Low (20 g day ⁻¹)	0.431	0.041	1.77 × 10 ⁻⁵	1.77
High (70 g day ⁻¹)	1.509	0.041	6.19 × 10 ⁻⁵	6.19

3.5. Relative contribution of radionuclides to dose

The relative contribution of individual radionuclides to dose differed from their contribution to total activity intake. While potassium-40 dominated intake, its contribution to both maternal and foetal dose was comparatively small. In contrast, radionuclides from the uranium and thorium decay series accounted for the majority of dose due to their higher dose coefficients and more radiotoxic decay chains [31-34].

This pattern was consistent across both intake scenarios and indicates that radiological significance is driven more strongly by radionuclide-specific dose factors than by activity concentration alone, in agreement with dose apportionment reported for ingestion and inhalation of natural radionuclides in environmental media [29,31,32].

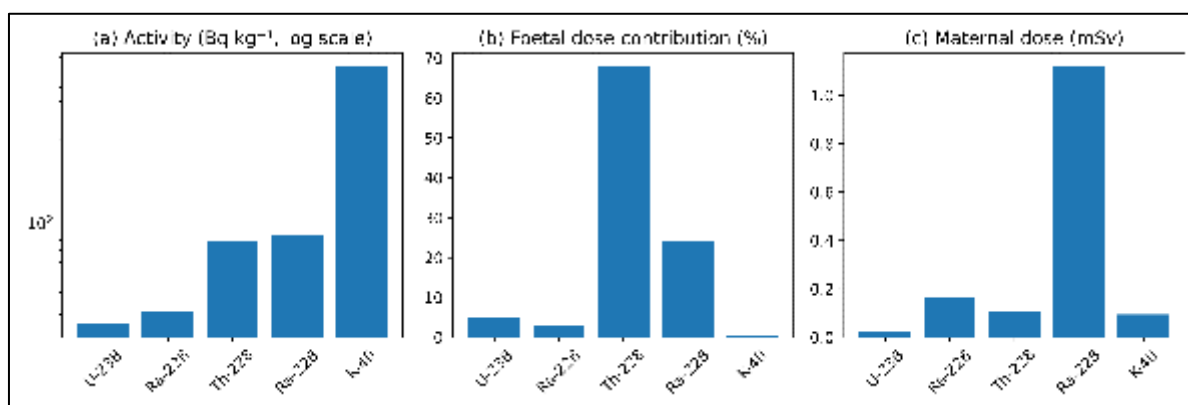


Figure 1 (a) Mean activity concentrations of radionuclides in geophagic kaolin samples from Ghana (log scale); (b) relative contribution of radionuclides to total foetal committed effective dose; and (c) radionuclide-specific contribution to maternal committed effective dose under high intake conditions (70 g day⁻¹).

3.6. Sensitivity analysis

Sensitivity analysis demonstrated that variations in kaolin consumption rate and radionuclide activity concentration produced approximately proportional changes in estimated doses, as expected in linear screening models [26,29,36]. Increasing or decreasing consumption by 25% resulted in corresponding changes in both maternal and foetal dose estimates.

Similarly, using lower and higher activity concentration values altered absolute dose estimates but did not change the relative contribution pattern of radionuclides. Across all scenarios, maternal dose remained higher than foetal dose, and thorium- and radium-series radionuclides remained the dominant contributors, consistent with observations that uranium- and thorium-series nuclides usually dominate dose even where potassium-40 dominates activity [29,31-33].

These results indicate that, within the bounds of the assumptions applied, the qualitative interpretation of the findings is robust to plausible variation in key input parameters [26,29,31,36].

Table 6 Sensitivity analysis of foetal and maternal excess lifetime cancer risk

Consumption scenario	Condition	Foetal ELCR (per 100,000)	Maternal ELCR (per 100,000)
20 g day ⁻¹	Baseline	0.0715	1.77
	-25% consumption	0.0536	1.33
	+25% consumption	0.0894	2.21
	10th percentile activity	0.0501	1.24
	90th percentile activity	0.0915	2.26
70 g day ⁻¹	Baseline	0.2585	6.19
	-25% consumption	0.1939	4.64
	+25% consumption	0.3231	7.73
	10th percentile activity	0.1810	4.33
	90th percentile activity	0.3309	7.93

3.7. Excess lifetime cancer risk

Estimated excess lifetime cancer risk values were low under both intake scenarios. Foetal values ranged from approximately 7.15×10^{-7} to 2.59×10^{-6} , while maternal values ranged from approximately 1.77×10^{-5} to 6.19×10^{-5} . These magnitudes are within or below ranges reported for ingestion of natural radionuclides in food, water, and kaolin-related materials [9,10,26,32].

Risk values increased proportionally with estimated dose and remained consistent with low-level environmental exposure scenarios [10,31,32]. Maternal risk estimates were higher than foetal values, reflecting the higher maternal dose and the use of adult risk coefficients [31,33,34].

4. Discussion

4.1. Geophagic kaolin as an environmental exposure pathway

This study characterises geophagic kaolin as a previously under examined ingestion pathway for naturally occurring radionuclides within the broader environmental health context of geophagia in Ghana [6,7,37,38]. While the presence of radionuclides in soils and clays is well established, their contribution to internal exposure through intentional consumption has received limited attention relative to toxicological and microbiological hazards, which dominate existing geophagia research [1,39-42]. The findings indicate that commercially available kaolin contains measurable radionuclides and that habitual ingestion can result in quantifiable, albeit low level, internal radiation exposure [6,7,43].

Importantly, this pathway differs from conventional environmental exposure routes such as drinking water or dietary intake in that it involves the direct consumption of geogenic material, often in concentrated and repeated quantities [1,42]. As such, geophagia represents a behaviourally mediated exposure pathway in which individual practices strongly influence exposure magnitude [6,38,44].

4.2. Dose magnitude and radiological relevance

The estimated maternal and foetal doses fall within the range of low-level natural radiation exposure and do not indicate an acute radiological hazard [13,43,45]. Foetal doses remain well below commonly referenced thresholds for prenatal exposure, while maternal doses, although higher, only approached or exceeded benchmark values under the high intake scenario [13,45].

From a radiological protection perspective, these findings suggest that geophagic kaolin ingestion is unlikely to represent a dominant exposure pathway when compared with other natural or medical sources of radiation [13,43]. However, the results do not imply that the pathway is negligible. Rather, they indicate that geophagia contributes incrementally to cumulative internal exposure, particularly under conditions of sustained and frequent consumption [6,7,42].

The distinction between low individual dose and cumulative exposure is important in environmental health assessment, especially for vulnerable populations such as pregnant women, for whom even small additional doses may be relevant when aggregated with other sources [13,45].

While the estimated doses fall within low-level environmental exposure ranges, their interpretation requires caution. Screening-level assessments, by design, prioritise conservatism and simplicity over individual variability, and therefore may either under- or over-estimate true exposure depending on consumption behaviour and radionuclide bioavailability. In the present context, uncertainties related to intake variability, physicochemical form of ingested material, and gastrointestinal absorption are likely to be more influential than analytical uncertainty in activity concentration. As such, the reported dose values should be interpreted as order-of-magnitude indicators rather than precise estimates of individual risk. This distinction is important when situating geophagia within broader environmental exposure pathways, where cumulative and behaviour-driven exposures may be more relevant than single-pathway dose comparisons.

4.3. Discrepancy between activity concentration and dose contribution

A key finding of this study is the divergence between radionuclide activity concentration and dose contribution. Although potassium 40 dominated total radionuclide intake, it contributed minimally to both maternal and foetal dose. In contrast, radionuclides from the uranium and thorium series, present at lower activity concentrations, accounted for the majority of dose due to their higher ingestion dose coefficients [13,43].

This finding reinforces the importance of dose based assessment in evaluating environmental exposures. Reliance on activity concentration alone may lead to misinterpretation of radiological significance, particularly in materials where radionuclide composition varies [7,46]. The results highlight the need to consider both concentration and radiological weighting when assessing ingestion related exposure pathways [13,43].

This divergence also has methodological implications for environmental exposure assessment. It underscores the limitation of using activity concentration as a standalone indicator of radiological risk, particularly in heterogeneous natural materials such as clays. Dose-based metrics inherently integrate radionuclide-specific radiotoxicity and biokinetic behaviour, and therefore provide a more meaningful basis for risk characterisation. In this regard, the findings reinforce the need for integrated assessment approaches that move beyond concentration-driven screening towards dose-informed evaluation frameworks, particularly in studies of non-conventional exposure pathways such as geophagia.

4.4. Integration with toxicological and microbiological risks

The radiological findings should be interpreted within the broader context of geophagia related health risks. Previous studies in Ghana and other African settings have consistently identified heavy metal contamination, microbial pathogens, and nutritional interference as primary concerns associated with geophagic clay consumption [1,38-41]. Compared with these hazards, the radiological component is likely to represent a secondary or complementary risk rather than the dominant health concern.

Nevertheless, the presence of radionuclides adds an additional dimension to the exposure profile of geophagic materials [6,7,42]. A narrow focus on toxicological risks alone may therefore underestimate the full spectrum of potential health impacts. Integrating radiological considerations into geophagia research supports a more comprehensive environmental health assessment and aligns with multidisciplinary approaches to exposure science [1,7,42].

4.5. Behavioural and cultural dimensions of exposure

Geophagic practices are influenced by cultural norms, perceived health benefits, and individual coping mechanisms during pregnancy [1,37,38,44]. These behavioural factors play a central role in determining exposure magnitude, as intake frequency and quantity directly affect radionuclide ingestion and resulting dose [6,44].

This behaviour dependent variability introduces an additional layer of complexity into exposure assessment. Unlike environmental contamination scenarios where exposure is externally imposed, geophagia reflects voluntary and culturally mediated behaviour [1,6,44]. As a result, risk mitigation strategies must consider not only the presence of contaminants but also the social and cultural context in which consumption occurs [1,7,44].

4.6. Implications for environmental health and risk communication

The findings have implications for environmental health policy and risk communication. Although radiological risks associated with geophagic kaolin are low, the absence of any corresponding benefit from radionuclide ingestion supports the application of exposure minimisation principles, consistent with ALARA type approaches in pregnancy [13,47]. In practical terms, this does not necessarily require prohibition of geophagic practices but rather informed awareness of potential risks [6,7,42].

Risk communication strategies should therefore be integrated with existing public health messaging on geophagia, which typically emphasises toxicological and microbiological hazards [1,6,38]. Incorporating radiological considerations may enhance the overall effectiveness of interventions by providing a more complete picture of exposure [7,42].

From a regulatory perspective, the findings highlight a gap in current exposure assessment frameworks, which rarely consider intentional ingestion of geogenic materials as a distinct pathway. Existing radiological protection systems, including those based on annual dose limits for the public, are not explicitly designed to account for culturally mediated behaviours such as geophagia. While the estimated doses do not suggest a need for regulatory intervention, they do support the inclusion of such pathways in broader environmental health surveillance and risk communication strategies. Integrating geophagia into public health discourse may therefore enhance the contextual relevance of exposure guidance, particularly in settings where the practice is prevalent.

4.7. Limitations

Several limitations should be considered. First, the number of analysed samples was limited and may not fully capture the variability of kaolin products available across Ghana, a challenge also noted in regional geochemical surveys [37,38,40]. The use of market sourced samples reflects consumer exposure but does not allow direct linkage to geological sources or processing conditions [37,40].

Second, intake scenarios were based on literature derived estimates and may not fully represent individual consumption patterns, which can vary widely in frequency, quantity, and duration [6,37,41,48]. Third, the dose assessment relied on standardised biokinetic models and reference dose coefficients, which do not account for individual variability in absorption, metabolism, or physiological conditions during pregnancy [13,43,47].

Finally, the study adopts a screening-level approach, and the results should therefore be interpreted as indicative rather than definitive estimates of exposure. The primary value of the analysis lies in identifying the presence, direction, and relative magnitude of radiological contributions within a multi-risk exposure context, rather than providing precise individual dose quantification.

4.8. Future research directions

Future research should expand sampling to include a larger number of products across diverse geographic regions and, where possible, link retail samples to source deposits [37,38,40]. Detailed characterisation of consumption behaviour, including frequency and quantity of intake during pregnancy, would improve exposure assessment [6,37,44,48].

In addition, the application of probabilistic modelling approaches could better capture variability and uncertainty in both activity concentrations and intake patterns [7,43,46]. Integrating radiological, toxicological, and microbiological analyses within a unified framework would further strengthen understanding of the health implications of geophagia [1,7,38-40,42].

Overall, the findings position geophagic kaolin consumption as a low-magnitude but non-negligible contributor to internal radiation exposure, operating within a broader multi-risk framework that includes toxicological and microbiological hazards. The radiological component does not dominate the risk profile but adds to cumulative exposure in a manner that is both behaviourally mediated and context-dependent. As such, the significance of this pathway lies less in absolute dose magnitude and more in its integration into holistic environmental health assessment. Recognising geophagia as a composite exposure pathway, rather than a purely cultural or nutritional practice, provides a more complete basis for future research and public health engagement.

5. Conclusion

This study demonstrates that commercially available geophagic kaolin consumed in Ghana contains measurable concentrations of naturally occurring radionuclides and therefore constitutes a plausible, though low-level, ingestion pathway for internal radiation exposure during pregnancy. Using a screening-level analytical approach, the results show that foetal committed effective doses remain low under plausible consumption scenarios, while maternal doses are consistently higher and may approach commonly referenced public exposure benchmarks under sustained high intake.

The findings indicate that the primary radiological relevance of geophagic kaolin lies in cumulative maternal exposure rather than direct foetal dose. Although the magnitude of exposure does not suggest an acute radiological hazard, the absence of any corresponding benefit from radionuclide ingestion supports the application of exposure minimisation principles, particularly in the context of repeated consumption.

Importantly, radiological exposure should be interpreted within the broader environmental health framework of geophagia. Compared with established toxicological and microbiological risks, the radiological contribution is likely to be secondary but not negligible. Its inclusion in risk assessments provides a more complete characterisation of geophagic materials and supports a multidisciplinary approach to evaluating health implications.

Overall, this study extends the current understanding of geophagia by incorporating a radiological dimension that has been largely overlooked in prior research. It demonstrates that even low-magnitude exposure pathways can be relevant when considered within cumulative and behaviour-driven risk frameworks. Future research should build on this foundation by expanding sample coverage, refining consumption data, and integrating radiological, toxicological, and microbiological assessments within unified exposure models. Such approaches will be essential for advancing evidence-based environmental health evaluation in settings where geophagia remains a prevalent practice.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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