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Research article

Contribution of ^{40}K arising from agropastoral activities to the total effective dose by plant ingestion in the Far-North, Cameroon

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Abstract: This study assesses the level of radioactivity, its corresponding dose and risk in areas of intense agropastoral activities in the Mayo-Sava, Mayo-Tsanaga and Mayo-Kani Divisions of the Far North region of Cameroon. The ultimate aim is to show that beyond the geological structure and mineralogical composition of the soil, agricultural fertilizers and animal droppings from livestock farming can contribute significantly to the elevation of the ^{40}K-induced radioactivity level in an environment. Natural radionuclide analysis was carried out on 55 soil samples collected from the three aforementioned localities, using a laboratory NaI (Tl) gamma spectrometer. The mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K were 41, 59 and 529 Bq/kg respectively. The total effective dose to the public and the risk of cancer morbidity were generated by RESRAD-ONSITE code version 7.2. The 0.7 mSv/year maximum total effective dose was estimated at time $t = 38$ years, with contributions of 56%, 37.3%, 3.9%, 2.1%, 0.7% and 0.07% from plant ingestion, external exposure, meat ingestion, milk ingestion, soil ingestion and inhalation, respectively. Potassium-40 (^{40}K) from plant ingestion is the major contributor. The doses in the initial year of agropastoral activity and the total excess cancer risk were 0.3 mSv/year and 1.165×10^{-3} respectively. The ^{40}K contributions to effective dose from plant ingestion obtained in this work are high compared to areas where agropastoral activities are not intensive. This may be due to the various fertilizers and animal droppings distributed in nature which are very rich in potassium. Although potassium is essential to life, it is nevertheless necessary for radiation protection to take into account this type of radiological exposure which is not without harmful effects on the environment and health.

Keywords: effective dose; agropastoral activities; cancer morbidity risk; fertilizer; ^{40}K; RESRAD-ONSITE; plant ingestion

1. Introduction

Some activities such as agriculture and animal husbandry conducted in the countryside and agropastoral areas may present high risks of natural human exposure to radioactive sources such as ^{238}U, ^{232}Th and ^{40}K [1–3]. Agriculture is one of the foundations of the economy in most countries of the world. To become more profitable, agriculture needs fertilizers, which can be natural or industrial. The use of fertilizers in general takes into account the needs of the soil in mineral salts. The most commonly used chemical fertilizers are rich in potassium, nitrogen and phosphorus [4–6]. In plants, potassium is necessary for the strengthening of the cell walls, development of the leaf surfaces, and chlorophyll content of the leaves. This inorganic element is also associated with the flow of water in the plant. In general, potassium is the basis for photosynthesis of the plant canopy and the growth of the crop [3].

For humans and animals, potassium is one of the minerals that the body requires in large quantities. It is a chemical element that plays an important role in the regulation of physiological processes such as digestion and heart rate [7]. It is also involved in the reduction of blood sugar levels and the transfer of ions between the membranes of nerve cells. Potassium therefore has many benefits for human health and is essential for life [3]. An average adult has about 0.18% potassium, while a child has about 0.2% [1]. In nature, potassium occurs in three isotopes, two of which are very abundant: ^{39}K (93.26%), ^{41}K (6.73%), and an unstable ^{40}K (0.0117%), which is in trace amounts in natural potassium. Like uranium and thorium, potassium contributes to natural radioactivity of rocks and to the heat of the Earth [1]. In the environment, potassium is much more prevalent in algae, wood ash, guano, mulch, crushed rock, granite, crop wastes and some composts [3]. In addition, this environmental radioisotope is present in bauxite and red mud in small amounts, in some common foods including red meat, potatoes, white meat, carrots, bananas, lima beans and Brazilian nuts [3]. In addition to the various elements mentioned above, potassium also comes from chemical fertilizers manufactured in industries.

Several studies conducted around the world have shown radioactive elements in soil and food samples collected in different regions. In Cameroon, measurements of environmental radioactivity levels revealed the presence of certain radionuclides such as ^{238}U, ^{232}Th, ^{235}U, ^{234}U, ^{230}Th, ^{228}Th, ^{226}Ra and ^{210}Po in samples of crops and some plants collected in the localities of Poli in the north and, Ngombas, Awanda, Bikoué and Melondo located in the southwest of the Cameroon. The Transfer Factor values calculated for this purpose were found to be higher than those proposed by the IAEA [8–11]. In Iraq, similar work has shown the presence of ^{40}K in wheat and its derivatives (wheat flour, bran, yeast samples) from Wasit mills, as well as in wheat flour samples used in bakeries distributed in Wasit governorate [3].

In Madagascar, radioactivity levels in samples of cocoa beans and some foodstuffs were found to be significant [12,13]. All of these works focus on public exposure to natural radioactivity and possible causes. Unfortunately, they do not suggest other sources of exposure that are not directly related to soil characteristics or mining operations at a site. Literature shows that ^{40}K is an isotope that is 1/1000 of the natural potassium. In addition, it is found in trace amounts in natural potassium. Moreover, it is responsible for more than half of radioactivity in the human body. Apart from possible variations between individuals, the average dose of ^{40}K that each man receives is equivalent to 0.165 mSv/year for an adult and 0.185 mSv/year for a child [1]. Could this average effective dose that an individual receives increase and harm his health when he is in an area where the ^{40}K content in food is very high? If this is the case, beyond the geological structure of a site and the mineralogical composition of the soil, can man, through certain activities such as agriculture and animal husbandry, not contribute to the increase of this ^{40}K content in his environment? It is well known that potassium is an essential plant nutrient. Although ^{40}K appears in trace amounts in natural potassium, because of the importance of potassium in plant life in general, and their growth and production in particular, ^{40}K can be found in large proportions in plants. Unlike ^{232}Th and ^{238}U which are not useful to plants, ^{40}K is. However, man consumes plants considerably and some consumers are essentially vegans. In the same way, certain animals like the herbivores feed essentially on plants. Others like granivores feed on seeds from these plants and vegetables. By eating these animals and birds, humans indirectly consume ^{40}K present in their meat, milk and eggs. It is therefore necessary, even essential; to have knowledge of the proportions of radioactivity induced by ^{40}K in plants in general and in the plants eaten in particular, because beyond a certain threshold, this radioactivity can be very harmful for human health.

Indeed, the soils of the Far North region are arid, poor and bare. Consequently, the use of fertilizers and animal manure, which are very rich in potassium, is necessary and even indispensable for any agricultural activity. Whether organic or inorganic, potassium is an abundant radioactive residue in nature, hence the use of the RESRAD code in this work to estimate the total effective dose received by the public and to assess the risk of exposure. Just like with ^{238}U and ^{232}Th, the risk of natural exposure to ^{40}K for humans can be very high under certain circumstances [3,5,6]. In the present study, the objective is to show that man, through the use of fertilizers in his multiple agricultural activities and animal droppings (fruits of his livestock activities), spread in nature, is a major contributor to the exposure of the public to environmental radioactivity induced by ^{40}K. To this end, soil samples collected in Mayo-Sava, Mayo-Tsanaga and Mayo-Kani, areas of intense agropastoral activities in the Far North region of Cameroon, were analyzed by gamma spectrometry. The concentrations of ^{238}U, ^{232}Th and ^{40}K were determined using a NaI (Tl) scintillation spectrometer. The total effective dose to the public and the risk of cancer morbidity were derived by deterministic and probabilistic analyses generated by RESRAD-ONSITE code version 7.2. As potassium is an essential element for the plant, the different contributions of ^{40}K to the total effective dose related to the ingestion of plants obtained in this work were compared with that of other areas where agropastoral activities are carried out in a relatively intense way.

2. Material and methods

2.1. Study area

The present work covers three Divisions in the Far North region (11º30'43,20"N, 14°33'03,60"E) of Cameroon: Mayo-Sava, Mayo-Tsanaga and Mayo-Kani having 2,736, 4,393 and 5,033 km^2 of surface area respectively [14].

Figure 1 presents the geological map of the study area. It distinguishes Mayo-Sava, Mayo-Tsanaga and Mayo-Kani Divisions, the localities in which this work was conducted. The climate is of the Sudano-Sahelian type, modified by orographic effects. Rainfall is mainly stormy and varies between 800 and 1,000 mm/year with an average value of 700 mm/year. The rainy season extends from June to October causing abundant runoff with a very high risk of erosion [15]. During the year, temperatures vary between 13 ºC (January) and 38 ºC (April) with an average value of 28 ºC. The annual potential evapotranspiration is about 1600 mm [16]. In the field, there are some valleys that are swept by floods, as well as river flood zones and muskeg along the main rivers of the region.

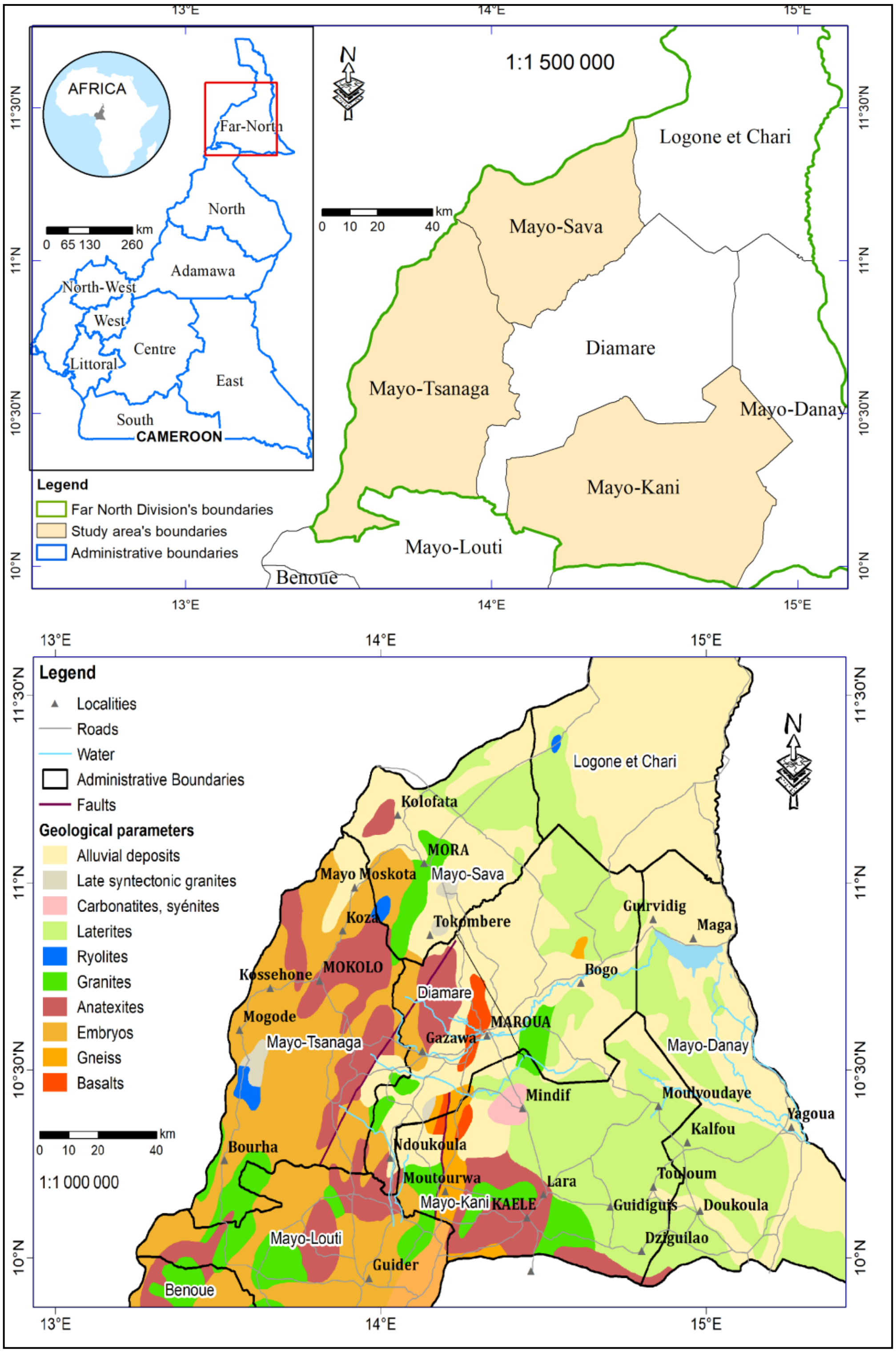

Figure 1. Geological map of the study area in Far-North Region, Cameroon.

The soil in the study area is made up of sand, clay, lacustrine, granites, gneisses and laterites. Figure 1 shows that syenite constitutes the partial bedrock of Mayo-Kani Division [15]. In literature, a strong relationship has been established between the radioactivity level of a locality and its bedrock.

It has also been proven that the contents of certain radioactive elements such as ^{238}U, ^{232}Th and ^{40}K are very high in granite and syenite. In clays, the contents of ^{238}U and ^{40}K are high [17–19]. The streams are seasonal. Indeed, it concerns the agricultural and animal husbandry production areas. The three Divisions investigated are known for their traditional sand and granite quarrying, cotton production and cereal production such as maize, millet, peanuts and rice. In 2004 in the Northern Regions of Cameroon, cotton cultivation covered approximately 250,000 hectares and was practiced by nearly 300,000 farmers whose surface area per producer was approximately 0.8 ha. This crop is one of the driving forces of the economy of the Far North region [4]. Livestock is also largely practiced there. Between 2015 and 2018, beyond other domestic animals and birds, 11581483 horses, camels and donkeys were bred there [20]. Most of these animals are raised in the yard. The agricultural fields surround family plots and entire villages. As a result, thousands of tons of animal manure and fertilizer, which are very rich in potassium, are spread in nature. The population is estimated at 313,413, 574,864 and 338,448 inhabitants respectively for Mayo-Sava, Mayo-Tsanaga and Mayo-Kani Divisions [14].

2.1.1. Sampling and conditioning

Fifty five (55) soil samples were collected randomly from the study areas. The collection of soil samples began with the identification of the sampling point. These were areas around dwellings and grazing fields, schoolyards and public services, markets and agricultural fields. In general, places where people spend a lot of time. An area of 1 m square was defined, ensuring that the sampling surface was free of vegetation cover in order to minimize the effects of contamination (migration, interference) from the coated soil. Using a planter, a core sample of soil 0–5 cm deep was taken at each vertex and in the middle of the square, where the diagonals meet. The 5 cores thus taken constituted a sample of about 1 kg in mass. The variability could be important from one point to another of the sampling site. Such a procedure made it possible to constitute an average sample from the elementary samples collected and to ensure an average and uniform distribution of the radionuclides at the sampling point represented by the square of dimension 1 m. Coarse material larger than 2 cm and plant roots were removed. The cores were then packaged in a plastic bag, sealed and labeled to avoid contamination and confusion between different samples. After collection, the samples were transported to the Research Centre for Nuclear Science and Technology (CRSTN), Institute of Geological and Mining Research (IRGM) for analysis by γ-spectrometry. Once in the laboratory, the wet samples were dried for 48 hours at 105 ºC in an oven. To ensure homogeneity, the samples were crushed and then sieved. Once this step was completed, the samples were placed in 500 mL cylindrical polyethylene Marinelli beakers, partially filled to allow space for outgassing. To prevent heterogeneity, the samples were mechanically shaken. To ensure tightness, a six-micron thick plastic was placed on top of the vial before sealing with its lid. Such a precaution is necessary to prevent the emanation of radon gas. The set was labeled and then placed in a dry place for a period of 30 days to ensure the secular equilibrium between ^{226}Ra and its daughters.

2.1.2. ^{238}U, ^{232}Th and ^{40}K activity concentrations

Radioactivity measurements in the soil samples were made using a NaI (Tl) detector at CRSTN-IRGM. It is a Canberra type, Model 802, with a Crystal of dimensions 7.6 cm×7.6 cm. Its relative efficiency is 7.5% for a resolution of 667 keV. The associated electronics consists of a Canberra preamplifier and an Accuspec acquisition card. The data processing is done by the GENIE 2000 software [21]. These steps allowed obtaining spectra that were stripped and then analyzed. The energy calibration was carried out with reference sources ^{155}Eu, ^{113}Sn, ^{57}Co, ^{137}Cs, ^{58}Mn and ^{85}Zn from the

International Atomic Energy Agency [22]. Since direct determination was not obvious for the activities of ^{238}U and ^{232}Th by γ-spectrometry, the 609.3 and 1120 keV energy lines of ^{214}Bi, 338.3 and 911.2 keV of ^{228}Ac, γ-emitting daughters, and the 1460 keV lines were used to determine ^{238}U, ^{232}Th and ^{40}K activity concentrations, respectively. The radionuclide concentration was determined using the following equation [1]:

$$A(Bq/kg) = \frac{C_n}{\varepsilon(E_\gamma) \times P_\gamma \times m \times t}$$

Where A is the concentration of the radionuclide in the sample, C_n is the count under the corresponding peak, $\varepsilon(E_\gamma)$ is the detector efficiency for the specific gamma ray, P_γ is the absolute transition probability of the specific gamma, t is the counting time in seconds, and m is the sample mass expressed in kg.

The minimum detectable activities of NaI (Tl) detector system for ^{40}K, ^{238}U and ^{232}Th are 1.10, 0.74 and 0.43 Bq/kg respectively for a counting time of 100, 000 s.

2.2. Approach to modeling the RESRAD-ONSITE code

Table 1. Site-specific parameters and default values using the RESRAD-ONSITE.

Parameters	Default values	Site-specific values
Area of contaminated zone	-	4500 km^2
Thickness of contaminated zone	-	0.05 m
Cover depth	0	-
Length parallel to aquifer flow	100	-
Density of contaminated zone	1.5 g/cm^3	-
Contaminated erosion rate	0.001 m/year	-
Contaminated zone total porosity	0.4	-
Contaminated zone b-parameter	5.3	-
Evapotranspiration coefficient	0.5	-
Wind speed	-	4 m/s
Precipitation rate	-	0.7 m/year
Irrigation rate	0.2 m/year	-
Density of saturated zone	1.5 g/cm^3	-
Saturated zone total porosity	0.4	-
Saturated zone effective porosity	0.2	-
Saturated hydraulic gradient	0.02	-
Saturated zone b-parameter	5.3	-
Water table drop rate	0.001 m/year	-
Well pump intake depth	10	-
Exposure duration	30 years	-
Indoor time factor	-	0.6
Outdoor time factor	-	0.4
Fruits and grains consumption rate	-	148 kg/year
Leafy vegetable consumption rate	-	17 kg/year
Soil ingestion rate	36.5 g/year	-
Drinking water intake	-	689.85 L/year

The enhanced version 7.2 of the RESRAD-ONSITE code was used in this study. This code was developed by Argonne National Laboratory of the US Department of Energy (DOE) and the US Nuclear Regulatory Commission (NRC). It was used to estimate radiation doses and cancer risks to the public in a radioactively contaminated environment. In addition, it also allows for the monitoring, cleanup and derivation of radionuclide levels from the following human exposure pathways: external gamma, plant ingestion, meat ingestion, milk ingestion, fish ingestion, drinking water ingestion, soil ingestion, and inhalation of radon emitted from contaminated soil over a 1000-year period. In this work, the total effective dose and cancer morbidity risks were derived by probabilistic and deterministic analyses of the RESRAD-ONSITE code using two types of parameters: parameters specific to the different study areas and some default parameters defined by the RESRAD-ONSITE code version 7.2. These different parameters relate to the characteristics of the contamination, meteorological, hydraulic and hydrogeological data specific to the contaminated study site [23,24]. Table 1 shows the different specific and default parameters used in this study.

3. Results and discussion

3.1. Activity concentrations of ^{238}U, ^{232}Th and ^{40}K

Table 2. ^{40}K, ^{232}Th and ^{238}U activity concentrations in soil samples collected in Mayo-Sava, Mayo-Tsanaga and Mayo-Kani.

Study area	Radionuclide	Mean (Bq/kg)	Median (Bq/kg)	Min - Max (Bq/kg)
Mayo-Sava	^{40}K	684 ± 62	704	343–1204
	^{232}Th	64 ± 7	54	34–129
	^{238}U	47 ± 5	42	33–83
Mayo-Tsanaga	^{40}K	706 ± 69	749	217–1207
	^{232}Th	64 ± 8	56	18–90
	^{238}U	47 ± 6	45	7–87
Mayo-Kani	^{40}K	326 ± 47	223	144–943
	^{232}Th	53 ± 10	37	18–249
	^{238}U	34 ± 5	23	15–103
All study area	^{40}K	529 ± 60	500	144–1207
	^{232}Th	59 ± 8	47	17–248
	^{238}U	41 ± 5	34	7–104

Table 2 presents ^{238}U, ^{232}Th and ^{40}K activity concentrations in soil samples collected in Mayo-Sava, Mayo-Tsanaga and Mayo-Kani Divisions. They ranged from 7 ± 1 to 104 ± 17 Bq/kg with an average value of 41 ± 5 Bq/kg for ^{238}U, from 17 ± 1 to 248 ± 20 Bq/kg with an average value of 59 ± 8 Bq/kg for ^{232}Th and, from 144 ± 21 to 1207 ± 152 Bq/kg with an average value of 529 ± 60 Bq/kg for ^{40}K. More than half of the soil samples collected and analyzed in this study had ^{238}U and ^{232}Th concentrations greater than 34 Bq/kg and 47 Bq/kg respectively. All these values are higher than the corresponding world average values given by UNSCEAR [1]. In addition, 18% of the samples had ^{238}U concentrations at least twice as high as 33 Bq/kg, the world average value; 13% of these samples had ^{232}Th concentrations at least twice as high as 45 Bq/kg, the world average value [1]. As for ^{40}K, 51% of the concentrations were above 500 Bq/kg, the median value; this value is higher than the world average value of 420 Bq/kg. In general, the different localities in this study had high ^{238}U, ^{232}Th and ^{40}K concentration values at several points.

These high values of activity concentrations of primordial radionuclides can be justified by the fact that part of the present study areas are underlain by syenite (Mayo-Kani). As for the rest of the study areas, sands, clay, granite, gneiss and laterite are abundant [15,16]. Specifically, the study areas are sahelian; hence the abundant presence of sand. This sand certainly comes from the degradation of granite and gneiss which are the essential constituents of the bedrock of the region. In the literature, it is proven that there is a strong correlation between radioactivity level and rock [25–33]. Some rocks such as syenite, granite, and clays sometimes have very high uranium and thorium contents [17,19]. Work carried out in the localities of Akongo, Ngombas, Bikoué, Awanda and Lolodorf, in southwestern Cameroon, revealed the presence of ^{238}U, ^{232}Th and ^{40}K at relatively high levels in certain soil and rock samples [2,34–37]. Indeed, the localities of Ngombas, Akongo, Awanda and Lolodorf are in the same area. Syenite, granite and gneiss are the basic rocks from which their different soils were formed [2]. A study of the vertical distribution of uranium and thorium in the Akongo lateritic profile in southwestern Cameroon over a depth ranging from the superficial layer to the syenite revealed the presence of uranium and thorium at varying levels depending on the different layers of the profile. The average grades in the source rock were 5 ppm (or 20 Bq/kg) for uranium and 3 ppm (or 37 Bq/kg) for thorium. In the matrix of the surface layer, the concentration of uranium decreased until it reached 3ppm (12.18 Bq/kg), while that of thorium increased to values 5 times higher than the initial value (185 Bq/kg) [17]. Similarly, the analysis of several soil and rock samples also showed a high concentration of uranium and thorium in granites and syenites, while they were found to be lower in basalts and very low in peridotites [38]. All these show that there is a strong link between the rock and radioactivity on the one hand, and the syenite, granite, clay and the variations of the concentrations of ^{238}U, ^{232}Th and ^{40}K on the other hand. In view of the above data, it follows that the high concentrations of the primordial radionuclides in the soil samples obtained in this work are the direct consequences of the mineralogical and geological structure of the soil and subsoil of Mayo-Tsanaga, Mayo-Sava and Mayo-Kani localities.

3.2. Dose assessment

Figure 2 shows the contributions of ^{40}K, ^{232}Th and ^{238}U from all exposure pathways summed over 100 years in the study areas. For the entire study area, the maximum total effective dose of 0.7 mSv/year is obtained at time $t = 38$ years. At $t = 1$ year, the dose is minimal. Then, it increases and reaches a maximum value before starting to decrease to 0.5 mSv/year at $t = 100$ years. For ^{40}K, the highest dose, estimated at 0.23 mSv/year, is obtained in the first year. Thereafter, it decreases slightly. For ^{232}Th, the lowest dose is obtained in the initial year and the highest dose occurs at time $t = 38$ years. At $t = 100$ years, this value is estimated to be 0.46 mSv/year. During the whole period from 1 to 100 years, ^{232}Th dose has the same behavior as the total effective dose. The ^{238}U dose appears as a trace in the different localities from the initial year to time $t = 100$ years. Initially ($t = 1$ year), the total effective doses due to the sum of all radionuclides were 0.32 mSv/year, 0.33 mSv/year, 0.16 mSv/year in Mayo-Sava, Mayo-Tsanaga and Mayo-Kani, respectively. Initially, it was found that among the three radionuclides investigated in the current work, ^{40}K contributes 91%, 92%, 86% and 91% to the total effective dose respectively in Mayo-Sava, Mayo-Tsanaga, Mayo-Kani and the whole study area. In general, this contribution remains maximum during the first 6 years.

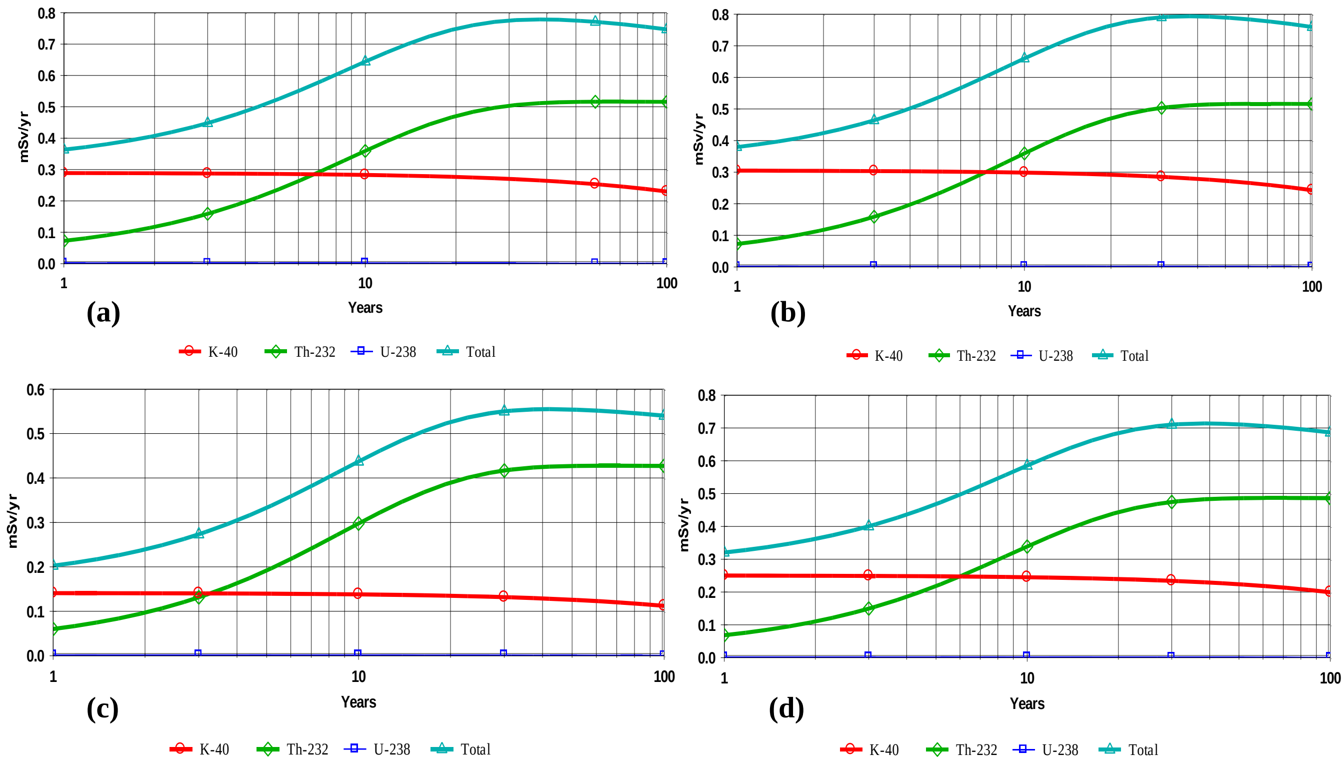

Figure 2. Dose contributions of ^{40}K, ^{232}Th and ^{238}U from all exposure pathways summed over 100 years in Mayo-Sava (a), Mayo-Tsanaga (b), Mayo-Kani(c) and All study area (d).

Maximum effective doses were estimated at time $t = 37$ years for Mayo-Sava and Mayo-Tsanaga, and at $t = 42$ years for Mayo-Kani. Their values were 0.55 mSv/year in Mayo-Sava and 0.8 mSv/year in Mayo-Tsanaga, and Mayo-Kani. The contributions of ^{232}Th to the estimated maximum total effective dose from all pathways were the highest, followed by those of ^{40}K. The aforementioned maximum total effective dose values are all lower than1 mSv/year, the limit value set by UNSCEAR [1]. The results show that the effective doses of the different radionuclides vary between locations. This is related to possible variations in the geological and mineralogical structure of the soils. On the other hand, this dose variation can also be justified by the intensive agricultural and livestock activities carried out in these localities [5,20].

Figure 3 illustrates the effective doses from the different exposure pathways over 100 years. In fact, there are thirteen (13) exposure pathways divided into two major groups: water-dependent and water-independent. The maximum total effective dose 0.7 mSv/year in the present study was estimated at time $t = 38$ years, with contributions of 56%, 37.3%, 3.9%, 2.1%, 0.7% and 0.07% from plant ingestion, external exposure, meat ingestion, milk ingestion, soil ingestion and inhalation respectively. It can be seen that the pathway that contributed most to the total dose was plant ingestion (water independent), followed by the external gamma radiation pathway. The pathways characterized by the ingestion of meat, milk, water, soil and inhalation contributed small proportions to the total effective dose compared to the other two pathways. Potassium, an essential element for life, is believed to be abundant in plants and meat. The contribution of the various radionuclides in plant ingestion, which is the most dominant exposure pathway, was 0.17%, 0.55%, and 38.4% for ^{238}U, ^{232}Th, and ^{40}K respectively. In the present study areas, ^{40}K is the major contributor in this pathway in the initial year. In addition, this high contribution of ^{40}K can be justified by the intensive practice of agropastoral activities in these different localities. In terms of proportions of fertilizers used, in 2010 for example, 24.5% of organic fertilizers against 75.5% of mineral fertilizer were used to increase agricultural production [4]. As organic manures are produced from animal manure, composts and plants, as a fertilizer used at 24.5% to boost agricultural production, it is inevitable that the soil will be rich in potassium and subsequently crops cultivated in these areas.

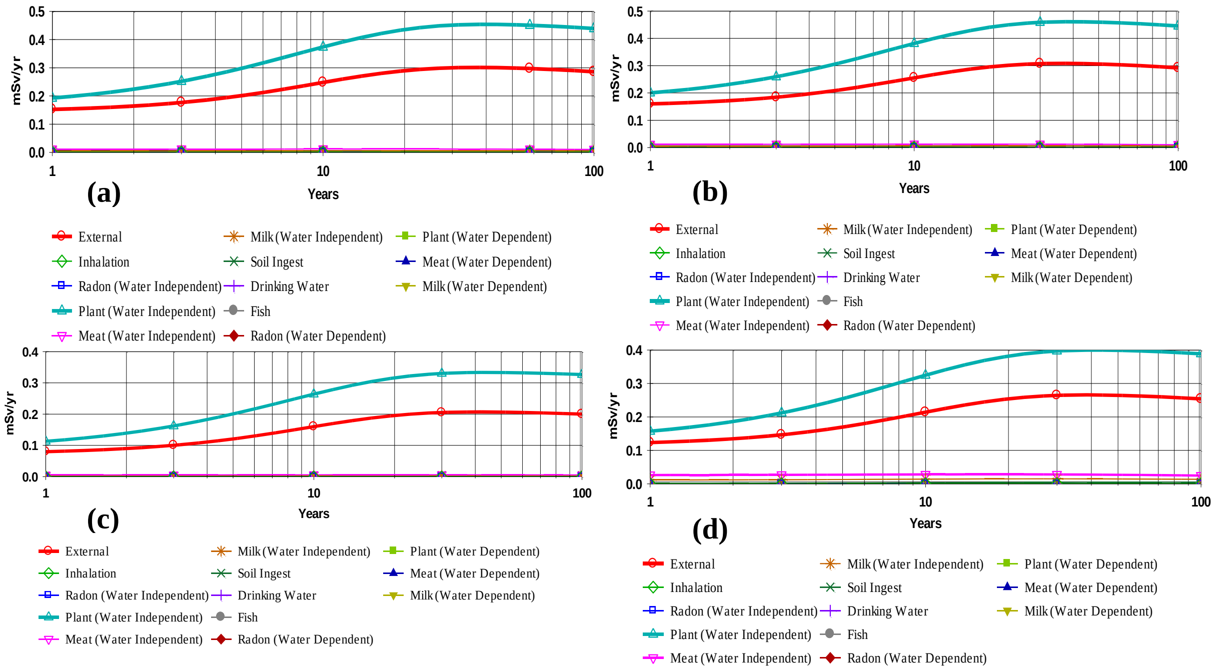

Figure 3. Dose contributions from ^{40}K, ^{232}Th and ^{238}U summed in all exposure pathways over 100 years in Mayo-Sava (a), Mayo-Tsanaga (b), Mayo-Kani (c) and All study area (d).

3.3. Contribution of ^{40}K to the effective dose from plant ingestion

This part of the study focuses on ^{40}K and its contribution to the effective dose from plant ingestion. Potassium is an essential plant nutrient. Tables 3 and 4 compare the contributions of ^{40}K to the effective dose from plant ingestion in locations in Cameroon where agropastoral activities are also conducted, but relatively intense. The locations in Tables 3 and 4 are divided into two main groups: the Grand-North and the Grand-South of Cameroon, which differ in climate and vegetation. The Grand-North has a Sudano-Sahelian climate with temperatures ranging from 13 °C to 38 °C [21]. It is made up of the localities of Mayo-Sava, Mayo-Tsanaga, and Mayo-Kani in the Far North and Poli in the North. The Grand-South has an equatorial climate with temperatures ranging from 25°C to 26°C [2]. It is made up of Betaré-Oya in the East, Akongo, Awanda, Eséka, Lolodorf and Ngombas in the Southwest of Cameroon.

Figure 2 shows that the effective dose of ^{40}K is maximum at the initial time point. That is, at the first year when this study was done. During the rest of the time up to year 100, the value of ^{40}K effective dose decreases slightly; but does not cancel out. Table 3 presents the estimated effective doses of ^{40}K at the times when the maximum values were obtained. The total effective dose values related to plant ingestion obtained in the localities of Mayo-Sava, Mayo-Tsanaga, Mayo-Kani, and Poli ranged from 8.37×10^{-2} to 1.65×10^{-1} mSv/year.

Table 3. Comparative contributions of ^{40}K to total effective doses from plant ingestion at selected locations in Cameroon in the initial year. Data from Akongo, Awanda, Eséka, Ngombas, Lolodorf, Poli and Betaré-Oya are used for comparison.

Localities	Effective dose from ^{40}K in plant ingestion (mSv/year)	Total effective dose from plant ingestion (mSv/year)	Contribution of ^{40}K to the effective dose from plant ingestion	Total effective dose (mSv/year)	Contribution of ^{40}K to the total effective dose (%)
Mayo-Sava	1.373×10^{-1}	1.575×10^{-1}	43.33	3.164×10^{-1}	91.29
Mayo-Tsanaga	1.450×10^{-1}	1.652×10^{-1}	43.53	3.330×10^{-1}	91.70
Mayo-Kani	6.705×10^{-2}	8.374×10^{-2}	40.90	1.639×10^{-1}	86.17
Poli	1.016×10^{-1}	1.104×10^{-1}	44.48	2.263×10^{-1}	94.55
Lolodorf	3.653×10^{-2}	5.320×10^{-2}	36.70	9.955×10^{-2}	77.30
Betaré-Oya	3.955×10^{-2}	5.129×10^{-2}	39.67	9.968×10^{-2}	83.58
Akongo	2.188×10^{-2}	3.624×10^{-2}	33.51	6.530×10^{-2}	70.58
Awanda	1.786×10^{-2}	2.449×10^{-2}	38.27	4.667×10^{-2}	80.63
Eséka	1.766×10^{-2}	2.859×10^{-2}	34.09	5.102×10^{-2}	71.81
Ngombas	3.645×10^{-2}	5.310×10^{-2}	36.69	9.935×10^{-2}	77.29

Table 4. Contribution of ^{40}K to total effective doses from plant ingestion in selected localities in Cameroon at maximum time. Data from Akongo, Awanda, Eséka, Ngombas, Lolodorf, Poli and Betaré-Oya are used for comparison.

Localities	Effective dose from ^{40}K in plant ingestion (mSv/year)	Total effective dose from plant ingestion (mSv/year)	Contribution of ^{40}K to the effective dose from plant ingestion	Total effective dose (mSv/year)	Contribution of ^{40}K to the total effective dose (%)	Maximum time (year)
Mayo-Sava	1.259×10^{-1}	4.539×10^{-1}	16.17	7.785×10^{-1}	34.06	37
Mayo-Tsanaga	1.337×10^{-1}	4.609×10^{-1}	16.77	7.993×10^{-1}	35.32	37
Mayo-Kani	6.089×10^{-2}	3.335×10^{-1}	10.97	5.548×10^{-1}	23.12	42
Poli	9.261×10^{-2}	2.342×10^{-1}	22.23	4.166×10^{-1}	46.84	76
Lolodorf	3.223×10^{-2}	3.043×10^{-1}	6.53	4.936×10^{-1}	13.76	45
Betaré-Oya	3.551×10^{-2}	2.256×10^{-1}	9.53	3.727×10^{-1}	20.08	42
Akongo	1.916×10^{-2}	2.554×10^{-1}	4.67	4.100×10^{-1}	9.84	47
Awanda	1.593×10^{-2}	1.236×10^{-1}	7.84	2.020×10^{-1}	16.51	43
Eséka	1.549×10^{-2}	1.952×10^{-1}	4.93	3.138×10^{-1}	10.40	47
Ngombas	2.162×10^{-2}	2.851×10^{-1}	4.52	4.787×10^{-1}	9.52	70

These values are generally higher than those obtained in Lolodorf, Betaré-Oya, Akongo, Awanda, Eséka, and Ngombas; the latter ranging from 2.45×10^{-2} to 5.32×10^{-2} mSv/year. Table 3 also shows that plants contribute nearly 50% to the total effective dose. This large contribution of plants to the total effective dose finds its reason in the proportions ^{40}K occupies in dose related to plant ingestion. Compared to the other locations, the ^{40}K dose from plant ingestion in Mayo-Sava, Mayo-Tsanaga, Mayo-Kani and Poli in the Grand-North are higher. The smallest and largest ^{40}K dose values are 1.83 and 8.14 times higher, respectively, than their counterparts in the Grand-South. These ^{40}K effective dose values are mostly 3 times higher.

Table 4 shows the contributions of ^{40}K to the effective dose from plant ingestion at maximum times; a time that is specific to each locality. Here, the effective dose of ^{40}K in the different study locations no longer contributes predominantly to the effective dose from plant ingestion. This can be justified by the fact that after a relatively long time, the ^{40}K content starts to decrease. Table 4 shows that effective doses from plant ingestion in the Grand-North localities still remain higher than those in other localities. They ranged from 6.089×10^{-2} to 1.337×10^{-1} mSv/year. In this part of the country, the ^{40}K contributions are between 1.5 and 3.7 times are higher than in other localities. The highest value of ^{40}K dose was measured in Mayo-Tsanaga locality. The lowest ^{40}K dose estimated at 6.089×10^{-2} mSv/year in Mayo-Kani. In the other localities, the effective doses of ^{40}K due to plant ingestion ranged from 1.549×10^{-2} to 3.551×10^{-2} mSv/year. The highest value was measured at Betaré-Oya, a gold mining locality located in the East of Cameroon. Gold is mined both in an artisanal and industrial manner. The localities of Mayo-Sava, Mayo-Tsanaga, and Mayo-Kani are not recognized as mining nor potential mining areas. On the other hand, Poli, Ngombas, Lolodorf, Akongo, Awanda and Eséka are potential mining areas; but are not yet operational. Previous work in these areas has revealed relatively high concentrations of ^{40}K in soil samples. A study conducted by Saïdou et al. [8] in the uranium bearing region of Poli in Northern Cameroon, revealed the occurrence of potassium anomalies with activity concentrations of ^{40}K reaching 1124 Bq/kg with the average value of 506 Bq/kg.

Compared to the Far North areas, ^{40}K contributions to the effective dose from plant ingestion are lower in Akongo, Eséka and Ngombas localities in the Centre Region, Awanda and Bétaré-Oya in the southern and eastern regions of Cameroon respectively.

This difference can be explained by the many agropastoral activities that are intensively carried out in the far north of the country. In practice, majority of the population of Poli, as well as those of Mayo-Kani, Mayo-Tsanaga and Mayo-Sava live from agriculture and animal husbandry [4,5,20]. In these areas, the soils are very arid. To enrich the soil and increase production, farmers continuously use large amounts of agricultural fertilizers and livestock droppings [4,5]. These products are very rich in potassium. As a result, every year thousands of tons of animal manure, mineral and organic fertilizers, which are very rich in potassium, are released into the environment as radioactive waste. Since potassium is an essential element for plants, the high contributions of ^{40}K in plant ingestion doses are strongly related to the potassium content of the soil. Thus, if the soil is permanently enriched with potassium from any source, the plants in the soil consume it and inevitably become rich in potassium, and ^{40}K.

3.4. Excess cancer risk due to ^{238}U, ^{232}Th and ^{40}K in the different summed exposure pathways

Figure 4 shows the excess risk of cancer morbidity due to ^{238}U, ^{232}Th and ^{40}K in the different summed exposure pathways. The results generated by the RESRAD code revealed a total excess cancer morbidity risk of 1.165×10^{-3} across the study area. The cancer morbidity risk was estimated to be 3.585×10^{-6} for ^{238}U, 4.447×10^{-4} for ^{232}Th, and 7.168×10^{-4} for ^{40}K. These different values of excess cancer risk are all higher than 3.00×10^{-4}, the global cut-off value set by World Health Organization [39]. Compared to the work conducted by Shima Ziajahromi et al., the risk of cancer morbidity in Iran due to ^{238}U (4.73×10^{-2}) is higher. In contrast, this risk is lower for ^{232}Th (1.41×10^{-4}) and ^{40}K (1.3×10^{-4}) [39]. In addition, the above results show that the risk of morbidity from prolonged exposure to ^{40}K is higher than all others in this study. In Mayo-Sava, Mayo-Tsanaga and Mayo-Kani localities, the contribution of ^{40}K to the excess cancer risk was 63.21%, 64.45% and 50.35% respectively. For the pathways related to ingestion of meat, milk, water, soil, and inhalation, their different contributions to the total excess cancer risk were low for the entire period. The contributions of 3.9% and 2.1% to the intake of meat and milk respectively, which are not zero, can be explained by the fact that the study areas host activities that spread waste rich in potassium, an element that feeds the plants and is consumed by the animals through these plants. Consequently, it is found in the meat and milk of these animals.

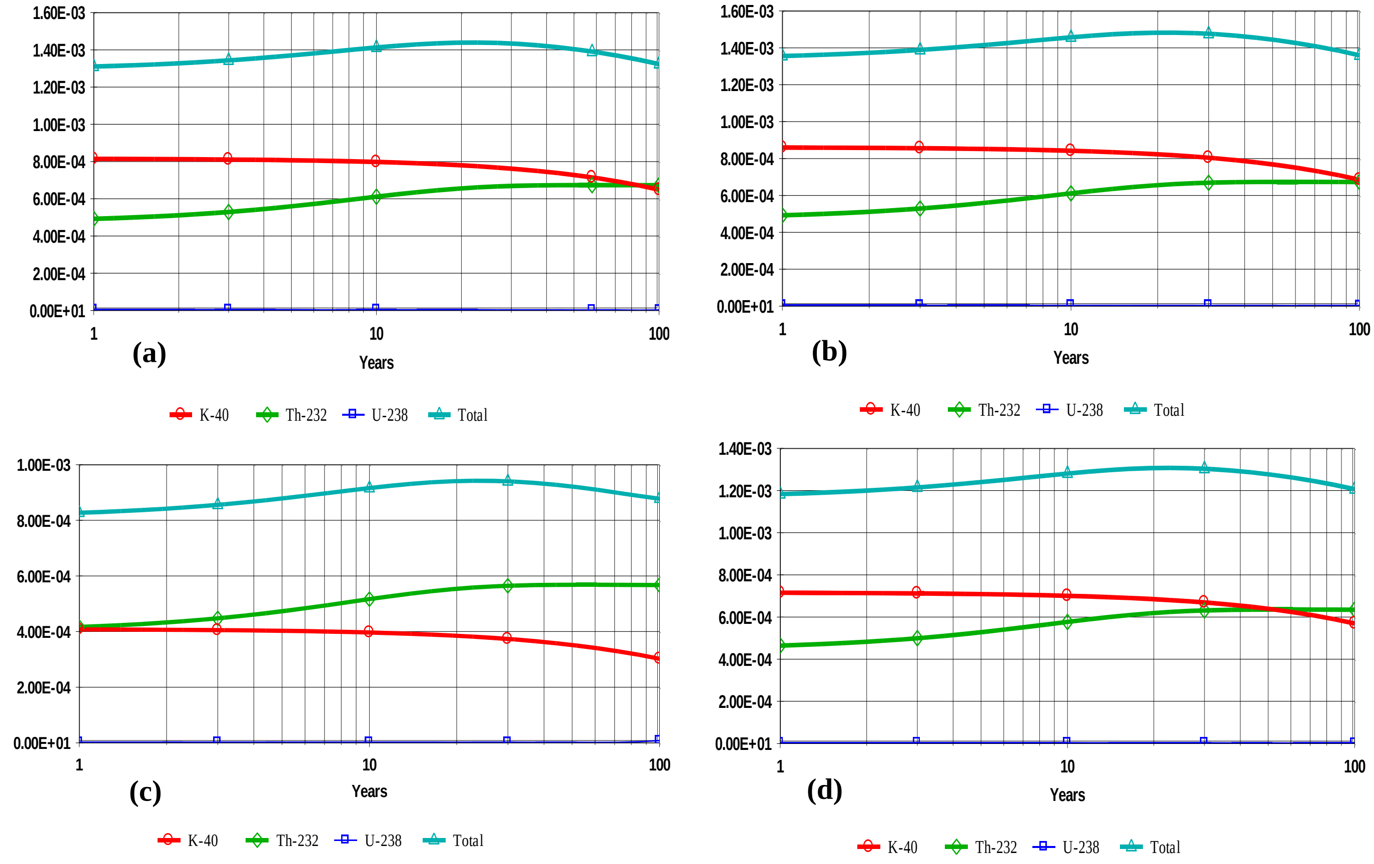

Figure 4. Excess cancer morbidity risk due to ^{40}K, ^{232}Th and ^{238}U in the different exposure pathways summed over 100 years in Mayo-Sava (a), Mayo-Tsanaga (b), Mayo-Kani (c) and All study area (d).

Figure 5 presents the cancer risk induced by ^{238}U, ^{232}Th and ^{40}K in the different exposure routes for 100 years. During the first 30 years, there is a slight increase in the risk values for the external gamma exposure pathway and plant ingestion. These values decrease considerably between 30 and 100 years. The excess cancer risk at the initial year is strongly influenced by plant ingestion and external gamma respectively.

Although it appears in trace amounts in natural potassium, due to the high requirement of potassium for plant life in general and their growth in particular, in the present study ^{40}K is found in large proportions in plants. On the other hand, humans consume plants considerably and some are essentially vegan. Similarly, some animals, such as herbivores, eat mainly plants. Others, such as granivores, live on seeds from these plants and vegetables. Thus, humans, by feeding on these animals and birds, indirectly consume ^{40}K present in their meat, milk and eggs. Beyond a certain threshold, this radioactivity can be very dangerous for our health. It is therefore necessary and even essential to have knowledge on the proportions of radioactivity induced by ^{40}K in plants in general and in the plants we consume in particular.

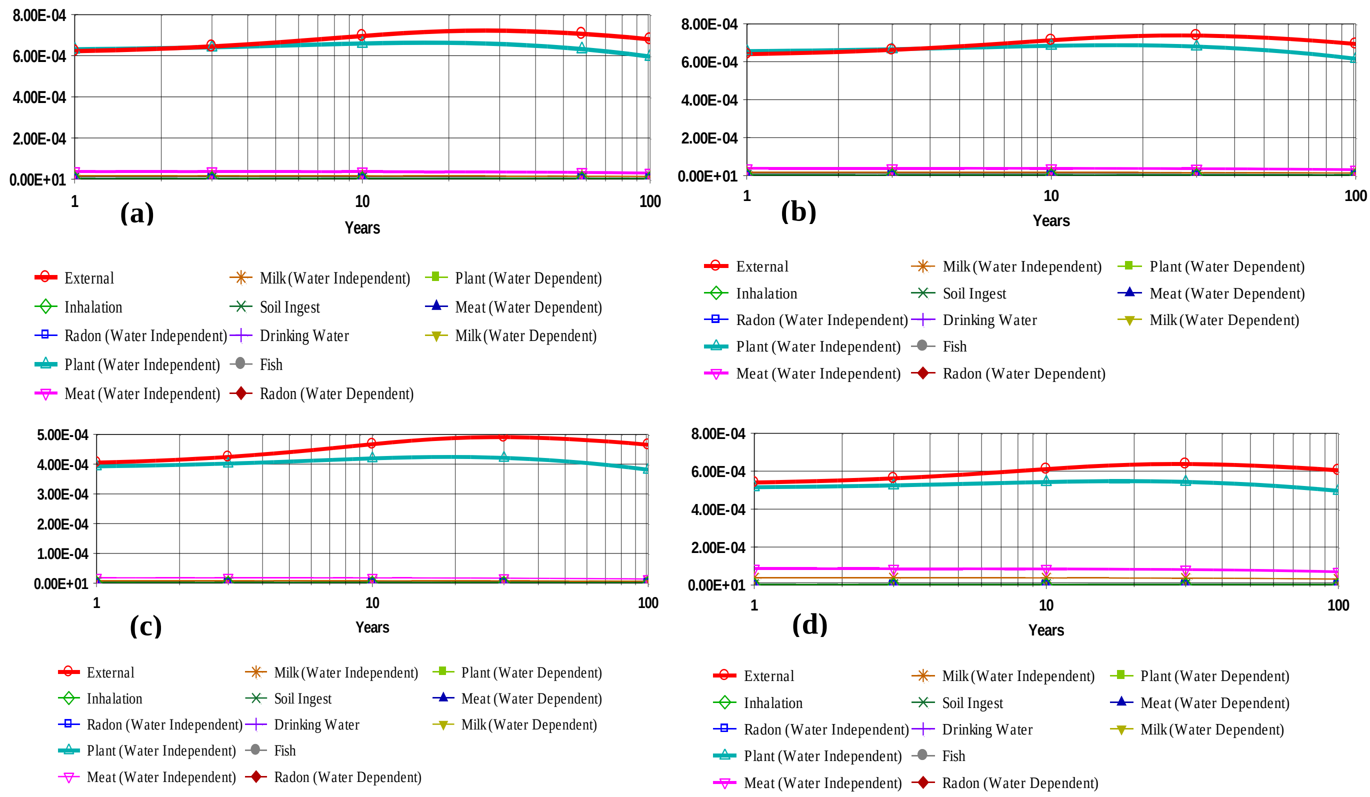

Figure 5. Cancer risk from different exposure pathways due to ^{40}K, ^{232}Th and ^{238}U over 100 years in Mayo-Sava (a), Mayo-Tsanaga (b), Mayo-Kani (c) and All study area (d).

4. Conclusion

The levels of natural radioactivity, radiation dose and risk were assessed in Mayo-Sava, Mayo-Tsanaga and Mayo-Kani, three areas of intense agropastoral activities in the Far North region of Cameroon, using a NaI (Tl) scintillation spectrometer and the RESRAD code, respectively. The mean values of ^{238}U, ^{232}Th and ^{40}K activity concentrations obtained were all above their global correspondents set by UNSCEAR. The maximum total effective dose of 0.7 mSv/year for the entire study was estimated at time $t =$ 38 years, with contributions of 56%, 37.3%, 3.9%, 2.1%, 0.7% and 0.07% from plant ingestion, external exposure, meat ingestion, milk ingestion, soil ingestion and inhalation, respectively. ^{40}K through plant ingestion was the major contributor. Compared to areas where agropastoral activities were not intensively conducted, the contributions of ^{40}K to the effective dose from plant ingestion were higher. Besides the geological structure and mineralogical composition of the soil, the present state of affairs may be due to the various fertilizers and animal droppings that are very rich in potassium and are distributed in the environment. Although potassium is essential to life, it is necessary, even indispensable, to have knowledge of the proportions of radioactivity induced by ^{40}K in plants in general and in plants that humans consume in particular. This is because beyond a threshold, radioactivity induced by ^{40}K can be very dangerous for health.

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Conflict of interest

All authors declare no conflict of interest in this paper.

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