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Research Article

Environmental Estimation of Radiation Equivalent Dose Rates in Soils and Waters of Northern Calabria (Italy)

Ilaria Guagliardi [iD],[1] **Tommaso Caloiero** [iD],[1] **Ernesto Infusino** [iD],[1,2] **Giovanni Callegari,**[1] **and Nicola Ricca** [iD][1]

[1]*National Research Council of Italy, Institute for Agricultural and Forest Systems in the Mediterranean (CNR-ISAFOM), 87036 Rende, Italy*
[2]*University of Calabria, Department of Environmental Engineering (DIAm), Rende, Italy*

Correspondence should be addressed to Tommaso Caloiero; tommaso.caloiero@isafom.cnr.it

In this study, the equivalent dose rate of natural radionuclides (H_T) in 99 spring water and surface soil samples was determined using an alpha, beta, and gamma high sensitivity detector up within a Geiger-Muller tube and with an external probe NaI (Tl). The samples were collected in the Crati basin (southern Italy), and during sample collection, water quality parameters were detected in situ and at the University of Calabria laboratories. A Pearson correlation coefficient analysis was applied to identify and clarify the relationships between water physical-chemical properties and soil and water radioactivity. Results show that the mean H_T for spring waters is 97.07 μSv/h. Furthermore, the mean H_T for surface soils is 97.92 μSv/h, thus evidencing higher mean H_T values than worldwide ones reported in a previous literature. Low correlation coefficients were detected between water H_T and conductivity and pH. On the contrary, a reasonable correlation was found between H_T in spring water and in soil. This relationship is associated with some rocks of the Sila Massif and of Coastal Chain, i.e., plutonic and metamorphic crystalline rocks. Finally, the estimation of the health risk was calculated: results did not evidence serious dangers for people living in the studied environment. The results from this survey for the H_T evaluation provide an extensive assessment of the background exposure levels in the investigated area.

1. Introduction

Knowledge of environmental natural radioactivity is essential to assess the current level of radiation exposure of the population and the degree of radioactive pollution in the environment in the future [1]. In fact, environmental radioactivity is the major source of radioactivity absorbed by people worldwide [2, 3] and cannot be avoided. Moreover, considering geochemical studies, it represents a significant source of information. Indeed, radiometric data can be used to coherently interpret correlations between radioelement distribution and other elements and to support the interpretation of petrogenetic or pedogenetic associations [4–6]. The evaluation of the environment natural radioactivity is also paramount to progressively monitor possible changes in natural background activity, as a result of radioactivity release [6].

Due to natural and man-made sources, a different level of radioactivity can be identified in the earth's crust [7, 8]. Naturally occurring radioactive materials include radioactive decay "chains" beginning with ^{238}U, ^{235}U and ^{232}Th, along with ^{40}K, ^{37}Rb, and other radioactive isotopes [9]. In particular, ^{238}U constitutes 99.3% of the isotopes of uranium found in nature, and thus, ^{235}U (0.7%), which provides a relatively insignificant radiation dose, is not surveyed further [10].

The distribution of naturally occurring radionuclides (principally ^{238}U, ^{232}Th, and their daughter products) and ^{40}K (among other radioactive elements) is strictly related to the distribution of rocks originating them and depends on the processes connected with their concentration [11]: it is caused by the decay of radionuclides derived from minerals. Consequently, the radioactivity amount in the soil depends on geology, soil type, soil moisture, organic matter, soil pH,
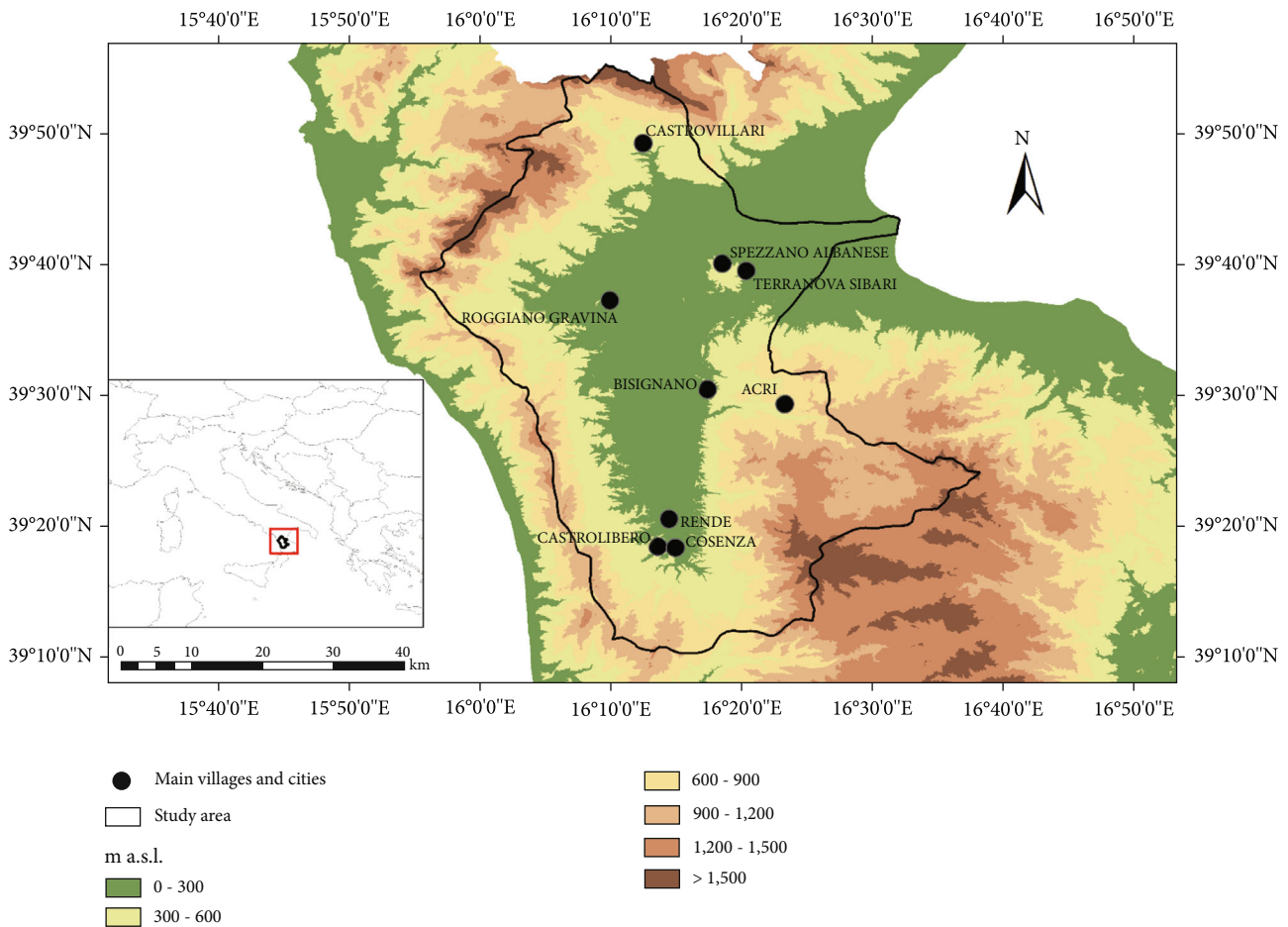
Figure 1: Crati river basin.

and climate with regard to the pluviometric and the thermometric regime of a region [12, 13]. Therefore, the concentrations of radionuclides vary widely depending on the location. Geologically, given the increasing uranium content of a rock with the silica content, high radiation levels can be generally found in igneous rocks, such as granite. In fact, some minerals which can be enriched in uranium and thorium (e.g., ilmenite, zircon, garnet, magnetite, rutile, and monazite) constitute the common mineral suites of these rocks. On the other hand, in some rock-forming, such as orthoclase, and accessory heavy minerals, the presence of potassium largely occurs. Lower levels are related to sedimentary rocks but with some peculiarity. In fact, in some shale and phosphate rocks a rather high content of radionuclides can be detected [14].

Environmentally, the soil on the earth's crust can be considered a radioactive threat because it is a source of continuous exposure for the population and because, considering agricultural soil, it allows radionuclides to enter the food chain and thus to contaminate humans through crops [15, 16]. Indeed, the soil-to-plant transfer can be considered a paramount process since; in the long run, radioelements enter the human food chains through the uptake of plant roots.

In addition, natural radioactive decay series can be dissolved in water and then move to surface water reservoirs, thus contributing to public radiation exposure [17]. This

occurs especially, when aquatic organisms and plants keep radioisotopes coming from river soil and sediment [3].

Globally, an average radioactive dose from natural sources equal to about 2.4 mSv/y has been estimated. The exposure can be external, deriving from direct radiation, both cosmic and terrestrial, or internal, originating from the possible inhalation or ingestion of terrestrial and cosmogenic radionuclides which can be found in air, water, food, and soil. In particular, considering the world population, results of the assessments of the whole radiation dose evidenced that this is due to natural and artificial sources in fractions of about 96% and 4%, respectively [18].

The absorbed dose rates can be evaluated directly, thus allowing an even more extensive estimation of the background exposure levels in the study areas. Results of the spectrometric measurements show that, in both outdoors and indoors, the three items of the external radiation field, ^{238}U, ^{232}Th, and ^{40}K contributed equally to the externally incident gamma radiation dose to individual [19].

The dose received by each single members of the population can significantly vary considering the different sources. In fact, while all the population can be affected by some sources of radiation, in other cases, only few individuals can be exposed. For example, considering natural radioactivity, this can be found in all the soils, thus exposing all the
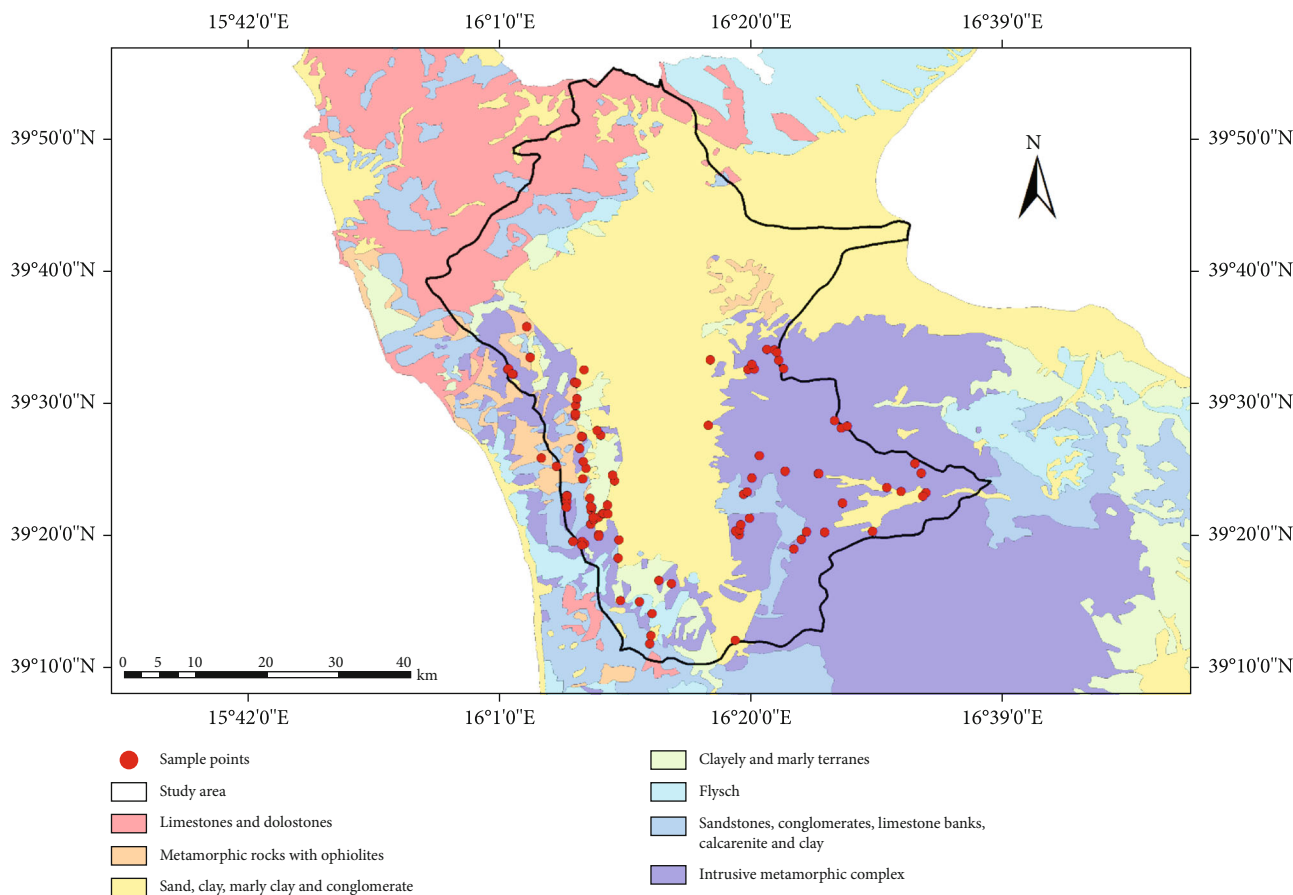
FIGURE 2: Lithological map of the study area and sample points.

population to some radiation dose. Conversely, considering the case of medical exposures, only people directly involved in medical treatment with radiation can receive a radiation dose [10].

Since the present study represents the first examination of a more detailed environmental survey, it offers an interesting and informative source to delineate the natural radiation equivalent dose rates in soils and waters of the Calabria region, located in southern Italy. Its preliminary findings illustrate a global overview of the study area setting and show that there are many future investigations needed. In particular, exploring and mapping the activity of the naturally occurring radionuclides are necessary and required in order to have information about the environment radiation level to assess the interaction between ionizing radiation and the human body. Thus, the survey performed in this study is aimed at quantifying the dose of radiation exposure, obtained from environmental radiation, in order to detect the possible risks for the public health caused by radiations from natural sources. Moreover, data obtained in this survey can contribute to the global data bank on radioactivity, thus allowing a more detailed evaluation of the mean values of the dosimetric quantities at global scale. The contribution to this data bank is especially important since these data allow a better understanding of the effects of low-level radiation in human health.

2. Site Characterization

The Crati basin is the largest and most important basin in the Calabria region [20]. It has an area of $2447.7 \, \text{km}^2$ and a perimeter of about 320 km, with an elevation ranging from sea level to 2258 m a.s.l. and an average altitude of 597 m a.s.l. (Figure 1). Due to its dimension, the hydrographical system flowing in the basin includes waters deriving from several geological formations. The climate of the basin is largely influenced by its orography and its position in the middle of the Mediterranean basin [21–23]. Indeed, a hot summer Mediterranean climate, with very warm dry summers and mild rainy winters, characterizes the basin following the Köppen-Geiger classification [24].

The Crati basin is a depressed block of the crust bordered by parallel faults and circumscribed by the Sila Massif to the east, the Coastal Chain to the west and south, and the Pollino group to the north which represent the three morphostructural highs of the northern Calabria. The first one is composed by plutonic and metamorphic crystalline rocks, the second one by crystalline and sedimentary rocks, and the last one by carbonate and siliciclastic sedimentary rocks.

Geologically, it is branded by a succession of pliocenic sediments overlaying on Paleozoic intrusive-metamorphic complex (Figure 2). The lithological composition of this last one is characterized by paragneiss, biotite schists, and gray

phyllitic schists with quartz, chlorite, and muscovite, frequently affected by a weathering process [25].

The Coastal Chain shows, along its margins, the Miocene deposits characterized by the presence of basal conglomerate passing to sand, sandstone, calcarenite, and clay; the Messinian evaporite deposits is composed of conglomerate, marl, limestone, and clay with intercalated gypsum. Basal microconglomerate and sandstone evolving to clay characterize the Early Pliocene deposits. Polygenic conglomerate passing to marly clay, sand, and sandstone followed by marly clay, regressive sand, and conglomerate distinguishes the Upper Pliocene-Pleistocene sequences. Over these last ones, terraced marine deposits of Middle Pleistocene occur. Lastly, Holocene alluvial deposits crop out along the main river plains [26].

As evidenced in the regional soil map at 1 : 250,000 scale [27] the leading soil types of the study area vary from poorly to moderately differentiated soils, such as Fluvisols, Leptosols, Arenosols, Cambisols, Calcisols, Umbrisols, and Phaeozems to more developed Vertisols and Luvisols [28] and Entisols, Inceptisols, Mollisols, Vertisols, and Alfisols [29]. Intermediate soil properties between the ones typical of cold and subtropical climates characterize the Calabria region [30]. These features yield a manifest seasonality in radionuclides given the marked contrasts in temperature and relative humidity [31].

Concerning the spring waters in the study area and according to Gaglioti et al. [32], they are bicarbonate alkaline-earth and chloride-sulphate alkaline-earth waters. These findings reflect the global lithological environment of the study area. In fact, in the Coastal Chain, it mainly constituted calcareous and carbonatic rocks (providing high Ca^{2+}, Mg^{2+}, and HCO^{3-} ion concentration in water), while in the Sila Massif it is constituted by intrusive magmatic or metamorphic rocks (providing high SO_4^{2-} and Cl^- ion concentration in water).

3. Methodology

3.1. Sample Collection and Measurement Set-Up. In this study, 99 spring water and surface soil samples were analysed. Given the dimension of the basin (about 2400 km^2), the number of sampled points reflects the several outcropping geological formations in the study area.

In these sample locations, the equivalent dose rate of natural radionuclides (H_T) was determined at 1 m above the ground using an α, β, and γ high sensitivity detector up within a Geiger-Muller tube and with an external probe NaI (Tl).

During the sample collection, water quality parameters (temperature, pH, and conductivity) were detected in situ and at the University of Calabria laboratories. Air temperature was also measured. The technical specifications of the measurement apparatus are indicated in Table 1.

3.2. Equivalent Dose and Health Risk. The radiation dose, when reaching body tissues and organs, chains itself with the part of the body affected, the exposure pathway; therefore, no adsorbed Becquerel of radioactivity vehicles the same

TABLE 1: Technical specifications of the radiation detector.

Inside Geiger-Muller detector	
Energy range	0.06–3 MeV
Accrual of environmental equivalent dose	10 μSv/h–100 mSv/h
Environmental equivalent dose	10 μSv–1 Sv
Sensitivity with ^{137}Cs source	0.3 cps/μSv.h-1
Weight	0.5 kg
Dimensions	92 × 62 × 52 mm
Detector NaI (TI) diam. 40 × 40 mm. External probe	
Energy range	0.04–3 MeV
Accrual of environmental equivalent dose	0.03 to 100 μSv/h
Environmental equivalent dose	0.03 μSv–0.3 Sv
Sensitivity with ^{137}Cs source	900 cps/μSv.h-1
Weight	1.2 kg
Dimensions	diam. 60 × 320 mm
General characteristics	
Intrinsic measurement error	±20%
Protection class	IP64
Autonomy	24 h
Operating temperature	-30° to +50°
Relative moisture at 35° and below the compensation limit	Up to 95%
Beam	Extensible
Power source	Internal batteries MI-MH 6 V AC, 50 Hz 220 V DC 12 V
Radio interference	CEI/IEC CISPR 22 : 1997
Electromagnetic compatibility	CEI/IEC 61000-4-2 : 1995 - IEC 61000-4-3 : 1995

equal radiation dose as another. In order to assess the differences of the various radiations, which have dissimilar biological impacts, the unit "equivalent dose" (symbol H_T), whose measuring unit is the Sieverts (Sv), has been conventionally adopted. Quantitatively, the equivalent dose has a higher biological significance than the absorbed dose.

To calculate the H_T, a multiplication of the absorbed dose to the organ or tissue (DT) with the radiation weighting factor, wR, is required. wR is strictly associated to the type and energy of the incident radiation. Its value is 1 for X-rays, gamma rays, and beta particles and higher for protons (wR = 5), neutrons (wR is between 5 and 20 depending on energy), alpha particles, and heavy fragments (wR = 20) [33].

The estimation of fatal cancer risk for an individual, $\widehat{R}_i$, is defined by equation (1) [34]:

$$\widehat{R}_i = aH_T, \tag{1}$$

where a is the risk factor equal to 0.05 Sievert for terrestrial gamma radiation dose [35] and H_T is the equivalent dose rate.

TABLE 2: Main descriptive statistics of the measured parameters.

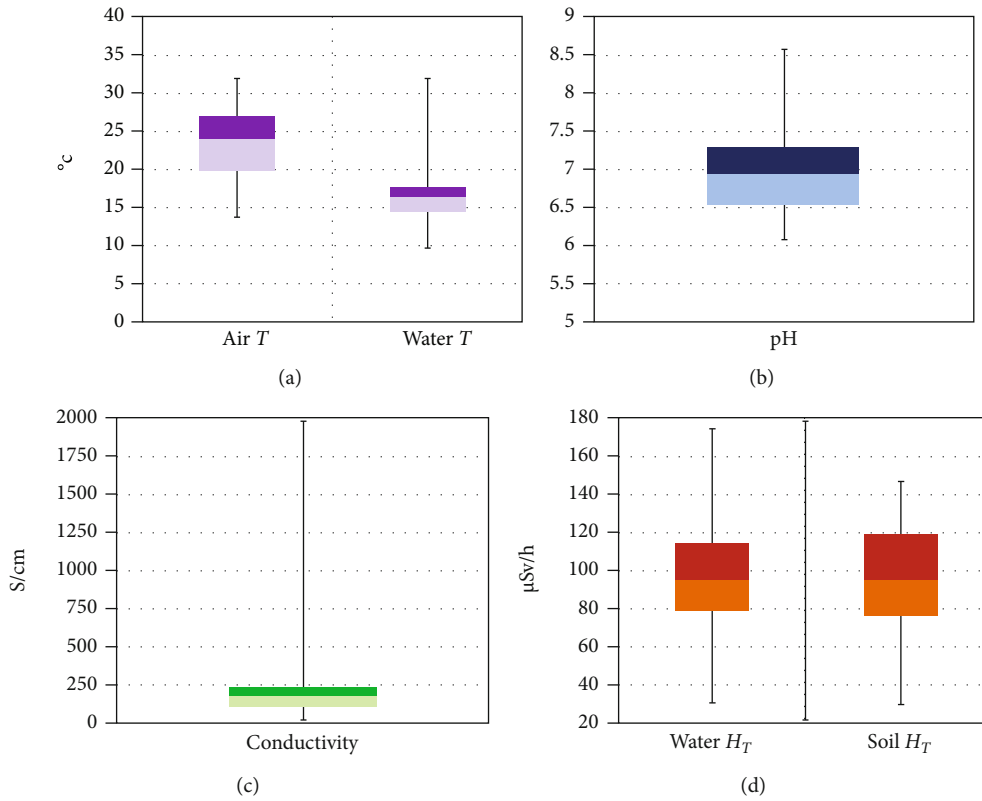| Statistics	Air T (°C)	Water T (°C)	pH	Conductivity (S/cm)	Water H_T (μSv/h)	Soil H_T (μSv/h)
Minimum	14.00	9.90	6.09	23.10	31.00	31.00
Maximum	32.00	32.00	8.59	1984.00	175.00	147.00
Mean	23.94	16.70	7.01	227.42	97.07	97.92
Median	24.00	16.20	6.96	170.30	95.00	95.00
St. Dev.	4.75	4.00	0.54	242.47	27.19	25.31
Skewness	-0.01	1.41	0.68	4.54	0.25	-0.01
Kurtosis	-0.87	3.01	0.02	28.41	0.17	-0.74

(a)

(b)

(c)

(d)

FIGURE 3: Boxplots of measured parameters.

4. Results and Discussion

Results show that the mean H_T for spring waters is 97.07 μSv/h, with a maximum value of 175 μSv/h and a minimum of 31 μSv/h (Table 2). Furthermore, the mean H_T for surface soils is 97.92 μSv/h, with a maximum value of 147 μSv/h and a minimum of 31 μSv/h (Table 2).

The main descriptive statistics of measured parameters are shown in Figure 3.

The Pearson correlation coefficient analysis was applied to identify the relationships between water physical-chemical properties, soil, and water radioactivity.

Low correlation coefficients were detected between the water H_T and conductivity and pH, with R^2 values equal to 0.057 and 0.1, respectively. On the contrary, a reasonable correlation was found between H_T in water and soil. This

relationship is associated with some rocks (plutonic and metamorphic crystalline) of the Sila Massif and of the Coastal Chain, upon which the Crati basin soils are imposed.

According to Guagliardi et al. [13], a strong control on radioactivity can be assessed by considering the foremost pedogenetic features showed in the soil map of the Calabria region [27]. The soil sampling locations involved several soil types and geological background. The highest H_T values have been detected in locations characterized by soil type that originates mainly from igneous-metamorphic rocks (Figure 4) or in fairly young soils such as Fluvisols, Leptosols, and Cambisols. On the contrary, in older soils constituted on conglomerates and sands (Luvisols and Arenosols), lower values were mainly recorded.

In the Sila Massif, primary minerals constituting rocks contain K, U, and Th. Monazite, zircon, and K-feldspar are
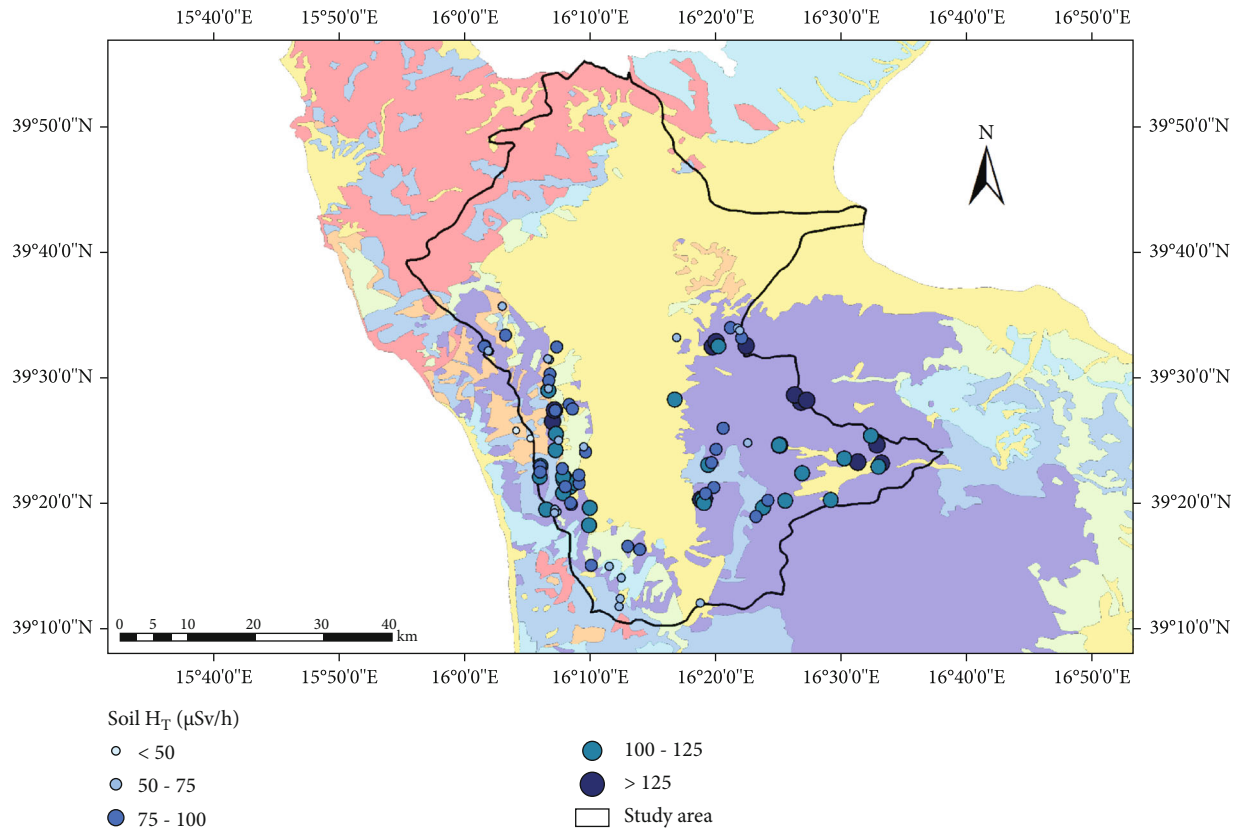
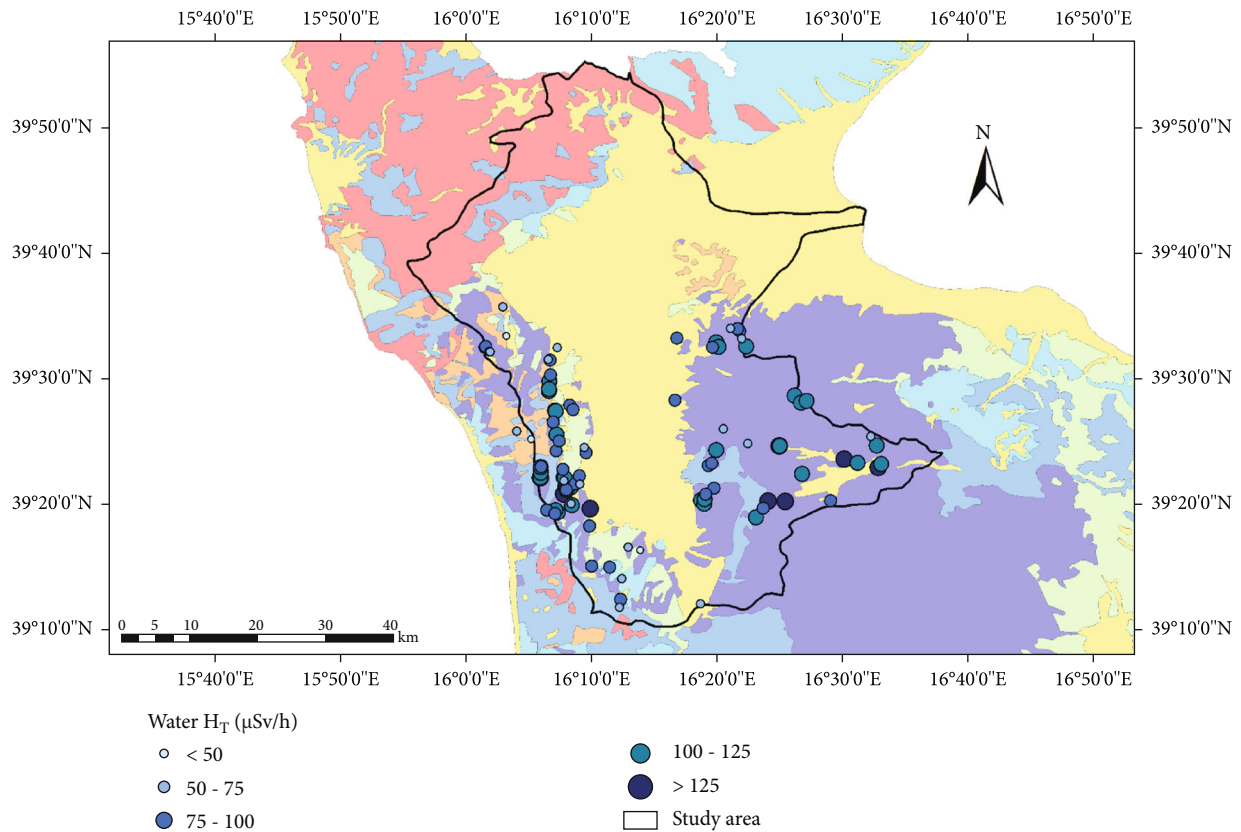FIGURE 4: Dot map of equivalent dose rate in soils.

FIGURE 5: Dot map of equivalent dose rate in waters.

responsible of the apparent activity of the radionuclides. Specifically, in monazite, primarily radionuclides from the ^{232}Th series and from the ^{238}U series occur. Plagioclase and total feldspar content are related to U activities. Likewise, the primary minerals (such as K-feldspars, muscovite, and biotite) and the neo-formed phyllosilicate clays such as illite, which is a common weathering product of primary micas [36], contains potassium.

Similar outcomes can be assessed for the equivalent dose rates in waters (Figure 5). According to Gaglioti et al. [32], the sampled waters have origin in the calcareous and carbonatic rocks of the Coastal Chain and intrusive magmatic or metamorphic rocks of the Sila Massif, and consequently, their equivalent dose rates well fit the elemental distribution of the undergoing lithologies.

In order to assess the health effects, the soil radiation dose rate in the studied locations was calculated considering the UNSCEAR [19] recommendation using a factor of 0.007 to obtain units of radiation dose (in μSv/h) from an absorbed dose rate in air (in μGy/h). The soil radiation dose rate in the study area ranged from 4429 μGy/h to 21000 μGy/h with the mean value of 13989 μGy/h. The range of this value falls within the average world value of 5700 μGy/h [19], but the mean one is 2 times higher than it.

The mean effective dose in the soil area is 97.92 μSv/h. Using equation (1), this value will cause fatal cancer risk of about 43×10^6 per year to each individual in the area.

Nowadays, as a result of several studies performed worldwide, it has been generally recognized that, for radiation exposure doses lower than 100 mSv, statistically significant cancer excess has not been detected [37–43]. The health hazard evaluation shows that no significant radiological impact of the population occurs in the study area. This does not exempt the scientific community from paying attention to these issues because even if there is a dosage of low-level radiation below which no damage occurs, a long-term exposure can cause health damage.

5. Conclusions

Ionizing radiation from natural and anthropogenic sources concurs to human exposure and therefore constitutes a potential risk to human health.

The results from this survey for the H_T assessment provide a preliminary evaluation of the background exposure levels in the Crati basin in the Calabria region. For both soil and water, the highest H_T values were found at locations with soil types that originate mainly from igneous-metamorphic rocks and/or in relatively young soils. Conversely, the lowest values occur in older soils imposed on conglomerates and sands.

These equivalent dose rates do not pose a serious radioactive health hazard to the population living in the environment. However, exposure to the dose level over a long period can constitute a serious health risk. The results can reliably serve as reference values for the assessment of the equivalent dose due to natural radioactivity in the environment.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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