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Note

Mapping the Baseline of Terrestrial Gamma Radiation in China

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Based on the previously constructed database on ^{226}Ra, ^{232}Th and ^{40}K contents in dry soils and the estimated distribution of soil moisture contents, the terrestrial gamma radiation was further estimated by using the recommended dose rate conversion factors (DRCFs). For obtaining more detailed information on the distribution of terrestrial gamma radiation, the spatial data were further interpolated, and the digital map of terrestrial gamma radiation in China was finally produced by using the techniques of Geographic Information System (GIS). The results show that the values of terrestrial gamma dose rate vary significantly over different regions of China. The area-weighted terrestrial gamma radiation in China was about 62.0 nGy/h, which was in well agreement with the surveyed result in the late 1980s.

Key words: database, radionuclides, soil moisture content, terrestrial gamma radiation, mapping

1. Introduction

Terrestrial gamma radiation originating from natural radionuclides in soils has always existed on earth and its exposure to all living organisms is continuing. It is also known as an important contributor for the public exposure to naturally occurred ionizing radiation[1]. On the other hand, the isodose map of terrestrial gamma radiation is indispensable for various purposes. It provides basic information in assessing the potential health effects of low-level radiations, and to serve as a base reference level in documenting changes to environmental radiation due to human activities, for decisions and actions in dealing with radiological accidents and emergencies, *etc*. Especially in China, with the rapid development of nuclear power plants, it is necessary to grasp the baseline of terrestrial gamma radiation as detailed as possible.

For acquiring the background of natural radiation, two nationwide surveys on both the terrestrial gamma radiation and radionuclides in soils had been conducted in 1980s. The first survey was initiated by the Ministry of Health, the terrestrial gamma radiation was surveyed at 38,611 sites, and the contents of uranium, ^{226}Ra, ^{232}Th and ^{40}K were analyzed in about 2,000 soil samples[2, 3]. The second survey was initiated by the Ministry of Environmental Protection, the terrestrial gamma radiation was surveyed at 8,805 sites, and the contents of uranium, ^{226}Ra, ^{232}Th and ^{40}K were analyzed in 7,777 soil samples[4]. However, as the lack of positioning system, advanced methods for data collection and processing, the two surveyed data were only published with the averages and ranges in a prefectural or a regional scale, it was difficult to draw the isodose maps. Moreover, the results of terrestrial gamma radiation from the two surveys were quite different, with the area-weighted averages of 80.3 nGy/h and 62.8 nGy/h, respectively. Even though the large variation has been explained as the different performances of the survey meters and quality controls

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of measurements[5], the true values are still not quite clear. However, it was found that both the distribution and provincial averages of ^{226}Ra, ^{232}Th and ^{40}K contents in dry soil in China were nearly the same, and the database had been successfully reconstructed in a grid of 25 km × 25 km and well reproduced both the amount and distribution of these radionuclides[6]. Therefore, the collected 1,099 sets of data on natural radionuclides in soil in China were utilized in this work.

In this study, for more accurate assessment of terrestrial gamma radiation, the distribution of soil water contents was estimated first in order to reconstruct the database on ^{226}Ra, ^{232}Th and ^{40}K contents in natural soils, and the terrestrial gamma radiation was further estimated by using the dose rate conversion factors (DRCFs) recommended in the UNSCEAR 2000 report[1]. For obtaining more detailed information on the distribution of terrestrial gamma radiation in China, the spatial data were further interpolated with the method of Ordinary Gaussian Kriging, and the digital map in a grid of 25 km × 25 km was finally created by using the techniques of Geographic Information System (GIS). It is hoped that the newly constructed baseline of terrestrial gamma radiation would be useful for further scientific studies and applications in related fields.

2. Material and methods

2.1. Estimation of moisture contents and modification of radionuclide contents in soil

For calculations of the absorbed dose rate in air from terrestrial gamma radiation based on the radionuclide contents of ^{226}Ra, ^{232}Th and ^{40}K in soils, several studies had addressed that the DRCFs recommended in the UNSCEAR report[1] were only applicable to the *in situ* soils, and it would be overestimated if the radionuclides contents in dry soils were used[7, 8].

In this work, for modifying the database on radionuclide contents we previously constructed for dry soils in China[6], the volumetric moisture content (θ_v) and the mass moisture content (θ_m) of soils were estimated by the following empirical formulas[9],

$$\theta_v = 25.033\ (0.7 \cdot E_t / P)^{0.3762} \quad (1)$$

$$\theta_m = \theta_v / (100\rho_b + \theta_v) \quad (2)$$

where E_t is the potential evapotranspiration, P is the precipitation, and ρ_b is the bulk density of soil. And based on the bulk density of soil and annual averages of the potential evapotranspiration and precipitation provided in the global ecosystems database (GED, Version II)[10], the distribution of annual averages of mass soil water content in China was estimated.

Having estimated the annual averages of soil moisture content in different regions of China, the previously constructed database on radionuclide contents in dry soils was modified in their normal status by using the following equation[11],

$$C = C_{dry} / (1 + \theta_m) \quad (3)$$

where C and C_{dry} are the activity concentrations of radionuclides in normal and dry conditions, respectively.

2.2. Calculation of the terrestrial gamma radiation

Based on the modified database on radionuclide contents in natural soils, the terrestrial gamma dose rate at the height of 1 m above the ground surface was calculated according to the following equation,

$$D = \mathrm{DRCF}_{Ra} \cdot C_{Ra} + \mathrm{DRCF}_{Th} \cdot C_{Th} + \mathrm{DRCF}_{K} \cdot C_{K} \quad (4)$$

where C_{Ra}, C_{Th} and C_K are activity concentrations (in Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K in natural soils, respectively; and the DRCFs for ^{238}U-, ^{232}Th-series and ^{40}K radionuclides were set to be 0.462, 0.604 and 0.0417 $nGy{\cdot}h^{-1}/(Bq{\cdot}kg^{-1})$, respectively[1].

2.3. Interpolation and digital mapping

In order to obtain more detailed information on the distribution of terrestrial gamma radiation in China, the spatial data interpolation was performed with the method of Ordinary Gaussian Kriging[12]. It is a method of interpolation embodied in geostatistics, which is generally considered to be an optimal technique of estimation in the sense that the estimates are unbiased and the estimation variances are known and are minimized[12]. According to the comparative study of geostatistical methods, the Gaussian Kriging was also validated to be suitable for estimation of gamma dose rate[13].

Having interpolated and converted the data into the mapping software of ArcView®, the isodose map of the baseline of terrestrial gamma radiation in China was produced and the statistical analyses were further conducted by using the techniques of GIS.

3. Results and discussion

3.1. Geographical distribution of the soil moisture content

Figure 1 shows the distribution of annual averages of soil moisture content in China estimated in this study. Both the absolute values and the distribution pattern are in well agreement with the results reported by other researchers[14]. As shown in Figure 1, the soil moisture content obviously differs with the geographic position, the value in southern China is generally much higher than that in northern China. The area-weighted average of mass moisture content is estimated to be 0.16 in whole

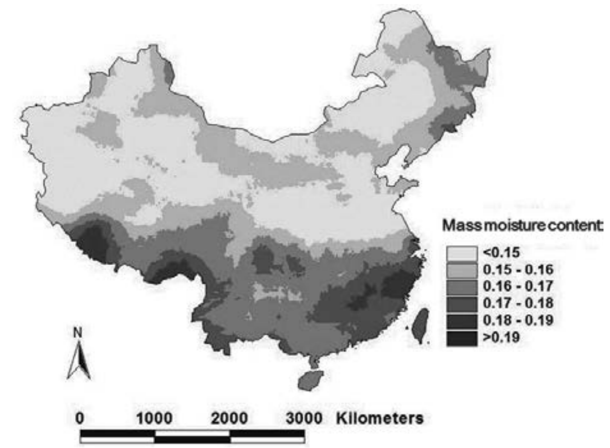

Fig. 1. Distribution of mass moisture content in soils in China.

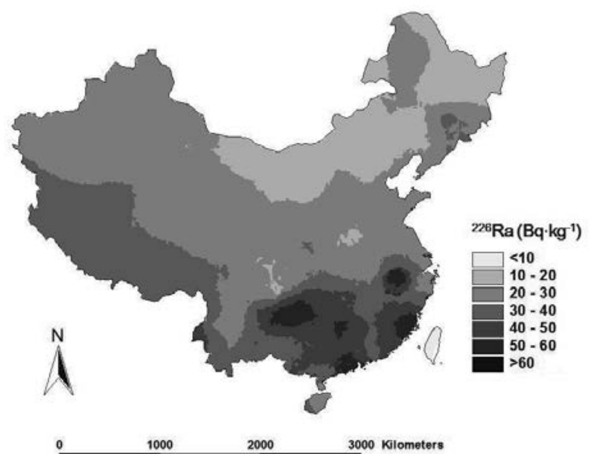

Fig. 2. Distribution of soil ^{226}Ra contents in China.

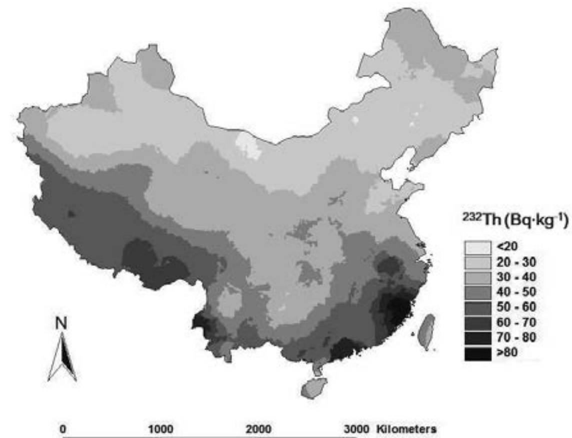

Fig. 3. Distribution of soil ^{232}Th contents in China.

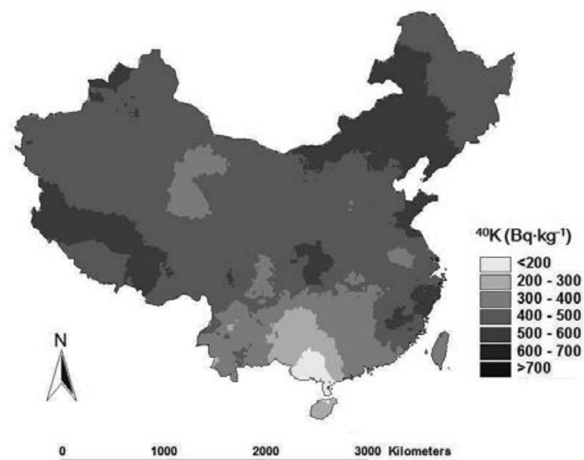

Fig. 4. Distribution of soil ^{40}K contents in China.

China, which is much higher than the constant of 0.1 assumed in the previous study on the terrestrial gamma radiation in China by other researchers[5]. The above results indicate that the distribution of moisture content in soil should be carefully considered in studying the baseline of terrestrial gamma radiation in China.

3.2. Geographical distributions of radionuclide contents in natural soils

Having been modified by the moisture effect, the digital maps of ^{226}Ra, ^{232}Th and ^{40}K contents in natural soils in China were created. As shown in Figures 2, 3 and 4, wide ranges of regional distributions of ^{226}Ra, ^{232}Th and ^{40}K contents in soils exist in China. For ^{226}Ra and ^{232}Th, their contents in southern China are generally higher than those in northern China, while the distribution of ^{40}K contents seems more complicated than those of ^{226}Ra and ^{232}Th. The phenomena can be explained as the complicated geological structures and the diversity of soil-forming rocks in China[6, 15].

The area-weighted averages of soil ^{226}Ra, ^{232}Th and ^{40}K contents in China were estimated to be 32.0, 43.5 and 502 Bq/kg, respectively. Compared with the values (36.6, 49.8 and 585 Bq/kg for ^{226}Ra, ^{232}Th and ^{40}K, respectively) in dry soils[6], they are about 13.1% lower in average, and the ratio varies from 12.6% to 16.4% in a scale of 25 km $\times$ 25 km as the different soil moisture contents.

3.3. Geographical distribution of the terrestrial gamma radiation

Having generated the database of terrestrial gamma radiation in China based on the new soil database on radionuclide contents and their corresponding DRCFs, the geographical distribution of terrestrial gamma dose rate was mapped and is illustrated in Figure 5. As shown in Figure 5, the regional variation of terrestrial gamma radiation is also obvious in China. The gamma dose rate is generally higher in the southern and southwest of China than that in the north. The distribution pattern is much more similar to that of soil ^{226}Ra or

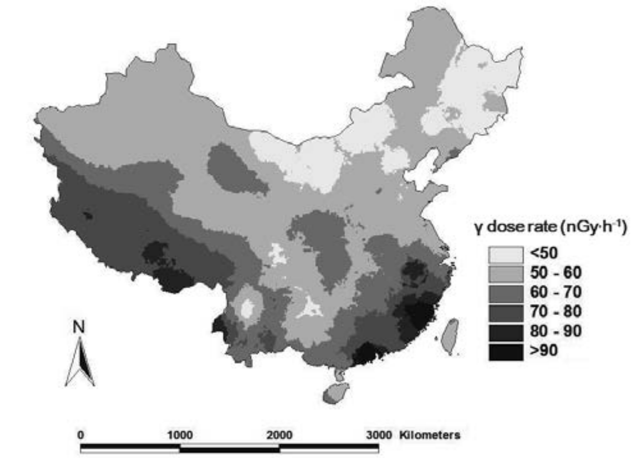

Fig. 5. Distribution of terrestrial gamma dose rate at 1 m height above ground surface in China.

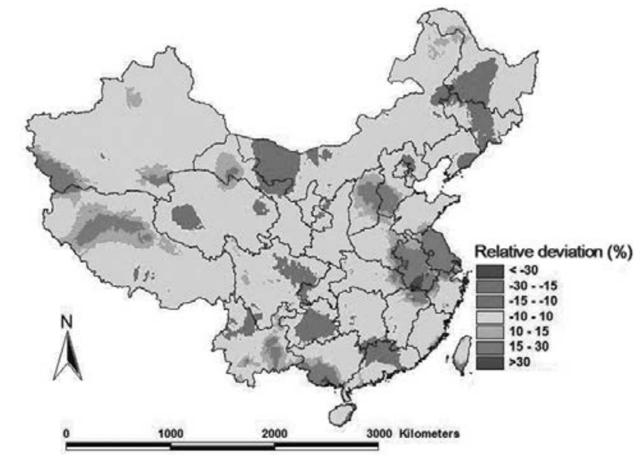

Fig. 7. Relative deviation of terrestrial gamma radiation between the constructed database and the second survey.

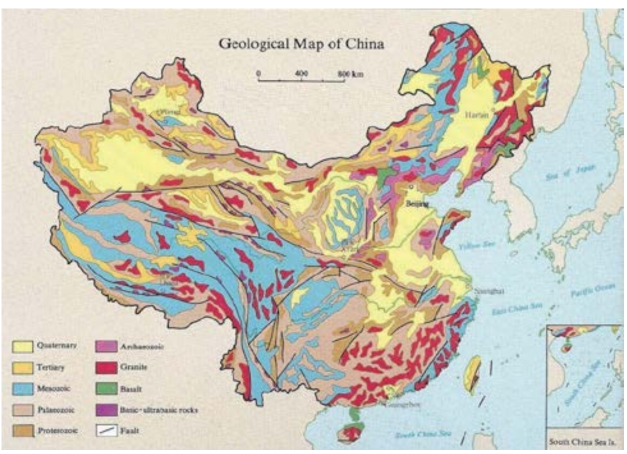

Fig. 6. Geological map of China.

^{232}Th activity concentrations rather than that of soil ^{40}K activity concentrations. It can be explained as the major contributions to the total dose rate in air are attributed by the ^{238}U- and ^{232}Th-series which are usually abound in magmatic rocks especially for granite, and the magmatic rocks are widely distributed in south China.

According to the statistical analysis done by the ArcView®, the area-weighted terrestrial gamma radiation in China was 62.0 nGy/h, which well agrees with the published result (62.8 nGy/h) in the second survey. Furthermore, based on the population data[16)], the population-weighted terrestrial gamma radiation in China was estimated to be 61.7 nGy/h. It is slightly higher than the worldwide population-weighted average of 60 nGy/h reported by UNSCEAR 2000.

3.4. Comparisons of the terrestrial gamma radiation

As the second field survey on terrestrial gamma radiation was systematically carried out in a certain sizing grid (25 km × 25 km or 50 km × 50 km), the results of the second survey were taken as the reference values for comparisons of the estimated area-weighted values in this work.

As shown in Figure 6, the relative deviations of terrestrial gamma radiation estimated in this study in most areas of China are less than ± 10%. In the provincial scale, among the 34 provinces, municipalities, autonomous or special administrative regions, the deviations in 32 of them are less than ± 15%. Even though the uncertainty for the dose rate estimated in this study may come from the measured activities of radionuclides, the used DRCFs and the spatial data interpolation, and it is still hard to quantify, it still indicated that the database on terrestrial gamma radiation in China was well constructed in a grid of 25 km × 25 km. It is considered that the baseline of terrestrial gamma radiation in China is generally reliable.

4. Conclusion

In this study, based on the previously constructed database on ^{226}Ra, ^{232}Th and ^{40}K contents in dry soils in China, the database in natural soils was reconstructed and used for estimating the terrestrial gamma radiation. The results show that the regional distributions on both the radionuclide contents in soils and terrestrial gamma radiation in China are quite obvious. They are generally higher in southern China than those in northern China. The area-weighted average of terrestrial gamma radiation in China estimated in this study was 62.0 nGy/h, which well agrees with the field monitoring result (62.8 nGy/h) in the second national survey. The provincial averages of terrestrial gamma radiation are generally consistent with their monitoring results with ± 15%. It is expected that the newly constructed baseline of terrestrial gamma radiation in China would be useful for further scientific studies and applications in related fields.

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Conflict of Interest Disclosure

The authors declare that they have no conflict of interest.

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