Review of low-level background radioactivity studies conducted from 2000 to date in people Republic of China

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1. Introduction

Naturally occurring radioactive materials (NORMS) are an important constituent of the Earth’s crusts and soil. Terrestrial or cosmogenic are both regarded as continuous sources of radiation. Radiation emitted from multiple sources is ubiquitous in nature. A relatively small proportion of these is extraterrestrial; others originate from soil, air, and water (Namvaran & Negarestani, 2013). This natural radioactivity contains Uranium/Thorium decay species as well as Potassium-40 (Hosseini, 2007). When human beings are exposed to these radiations, chemical changes occur within the tissue and as a result this can produce harmful effects in it. Radioactive substances exist all over the world and are encountered during routine every-day activities. It is therefore important to assess radioactivity level in the environment for the protection of general public health, especially if the emitted radioactivity enters the food chain. In 1989 the member states of International Atomic Energy Agency (IAEA) demanded a radio-analysis of environmental samples following several nuclear accidents worldwide (IAEA, 1989). The identification of these radiation sources as well as their dose assessment through accurate measurement in soil, building materials, water, and dietary objects is essential in order to determine their potential impact on human health (Afshari et al., 2009). Different radiological surveys/studies on soil, rocks, water, and air have been conducted/reported in different parts of the globe in order to assess the radiation doses to living organisms (Jibiri & Biere, 2011; Korkmaz et al., 2017; Manigandan, 2009; M Rafique et al., 2011; Usikalu et al., 2015). Soil is one of the important environmental materials which is used for many purposes and it contains natural radionuclides that contribute to both indoor and outdoor exposure (Dabayneh et al., 2008). Therefore, for environmental protection the measurements of natural radioactivity in rock and soil are considered very important (Tufail et al., 2007). The strength and intensity of gamma (γ) radiation are strictly associated with the quantity of these radioactive nuclides in a particular territory (Saghatchi et al., 2010). The territorial, geographical, and geological circumstances are the main and vital measurable factors affecting the quantity of radioactive nuclides in the environment (UNSCEAR, 1988). Much recent research has focused on the assessment of radioactive nuclides, taking into account their significance (Abbasi & Bashiry, 2016; Ćujić et al., 2015; Jibiri & Biere, 2011; Mehra et al.,...
In the same way, various research groups in the People’s Republic of China have also carried out the measurement of natural as well as artificial radioactivity in the environment. The volume of the gathered data is vast and scattered, and it is required to compile all data regarding the natural as well as man-made radioactivity in China. The main goal of this paper is to establish a nationwide baseline data on natural radioactivity levels by reviewing and compiling the outcomes of the conducted studies from the entire People’s Republic of China. This paper assembles and organizes the scattered data in one article for the first time, which will help the researchers intended to conduct studies of this kind in future.

1.1. Methods adopted for the assessments of background radioactivity concentrations in People’s Republic of China

This section provides an overview of the different methods adopted by various researchers for the assessment of the background radioactivity in samples of different environmental media. All radionuclides were measured either by γ-spectrometry with HPGe or by Na(Tl) detectors. Tables 1 and 2 summarize the conclusions of the measurements of natural & artificially occurring radioactivity conducted by different researchers since 2000.

These tables include the radioactivity concentrations of primordial radionuclides (Uranium-238, Thorium-232, Radium-226, and Potassium-40) and anthropogenic (Cesium-137) obtained from samples collected country-wide. Normally, the specific radioactivity concentrations could be used for the assessment of radiological hazards linked with the environmental mineral samples. The samples contained a mixture of radioactive nuclides which were known to significantly contribute to the γ-doses. Therefore, a single quantity, i.e. Radium equivalent activity ($RA_{eq}$) in Bq/kg could be used to illustrate the γ-output from the mixture of these radionuclides present in the sample. $RA_{eq}$ can be calculated using equation 1 (Hamilton, 1971)

$$RA_{eq} = \left( \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810} \right) \times 370$$

The gamma activity index $I_{\gamma}$ is an alternative standard used for the analysis of gamma emissions associated with the natural occurring radionuclides inherent in substances used for construction throughout the world particularly in the European Union (EU). The world safe limit for $RA_{eq}$ of 370 Bq/kg corresponds to a maximum external γ-dose of 1.5mGy/yr. It can be estimated using equation 2 as follows (Alias et al., 2008)

$$I_{\gamma} = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_{K}}{3000}$$

Where $A_{Ra}$, $A_{Th}$ and $A_{K}$ in equation 1&2 are specific activity values of Ra-226, Th-232, and K-40. Values of gamma index, i.e. $2 \leq I_{\gamma} \leq 6$ are in consistent with a standard dose rate of 1 mSv/yr (Anjos et al., 2005; Righi & Bruzzi, 2006). Building materials with $I_{\gamma} > 6$ corresponds to γ-dose rates higher than the UNSCEAR recommended limit of 1 mSv/yr and use of such materials in infrastructure should be avoided (UNSCEAR, 1988).

2. Summary of the results

A specific summary of the calculated radioactivity concentrations of Radium, Thorium, and Potassium is presented in this section of the article. Radium equivalent activity ($RA_{eq}$), and $I_{\gamma}$ were also calculated and presented in Table 1 for the mentioned three nuclides of interest. Xinwei in 2004 studied the natural radioactivity in building materials and the by-products (Fly ash & Slag) from coal fired power plants (L Xinwei, 2004a). The investigated building materials include cement, cement plaster, cement brick, red-clay brick, sand, gravel aggregate, lime/limestone, and roof asbestos. The results of Sand and gravel aggregate were obtained from the construction location and other building materials from various agencies supplying raw materials for building construction. Samples of fly ash and slag were collected from Baiji, western suburb of Xi’an and Baqiao power station situated in Shanxi. A report was published in July 2004 showing the radioactivity concentration of Radium, Thorium, and Potassium in samples of glaze and ceramic tiles using gamma ray techniques (L Xinwei, 2004b). The samples were obtained from Guangdong, Shaanxi, Shandong, and Zhejiang Provinces. In 2005 building materials (Cement, Cement brick, Cement plaster, Gravel aggregate, Red-clay brick, Sand, Lime/limestone, and Roof asbestos) were again investigated for the radioactivity concentration by Lu Xinwei and the samples were obtained from Xi’an (Xinwei, 2005a). Lu Xinwei used high purity gamma detector for the radioactive analysis of cements, cement brick, and cement plaster used in Xi’an (Xinwei, 2005b). Ya-xin Yang et al. in 2005 studied the low-level background radiation in soil samples from Xiazhuang granite massif of Southern China (Y. Y. Yang et al., 2005). During the year 2006, L. Xinwei, W. Lingqing, and J. Xiaodan assessed Chinese commercial granites using Na(Tl) gamma spectrometer along with a matrix inversion-based spectral technique for finding the radioactivity from radium, thorium, and potassium present in it (Xinwei, Lingqing, Xiaodan et al., 2006b). Lu Xinwei et al. in 2006 calculated the radioactivity concentration in Archeozoic-Cambrian rocks obtained from Weibei region in Shaanxi (L Xinwei, Lingqing, Xiaodan et al., 2006b). In 2006 Lu
### Table 1. Measured radioactivity of Ra-226, Th-232, K-40, Raeq and Gamma Index (Iγ) in samples from all over the People’s Republic of China.

| S/No | Year | Location | Ra-226 | Th-232 | K-40 | Ra_{eq} | Gamma Index (Iγ) | Material studied | References |
|------|------|----------|--------|--------|------|---------|----------------|-----------------|------------|
| 1    | 2004 | Shaanxi  | 21.5–19.1 | 15.4–63.2 | 83.2–683.9 | <370 | 0.17–0.84 | Building material and by-products of CFPP | (Xinwei, 2004a) |
| 2    | 2004 | –        | 158–1087 | 917–1218 | 474–1031 | >370 | 1.14–10.06 | Glazed Tiles | (Xinwei, 2004b) |
| 3    | 2005 | Xi’an    | 65.3–131 | 15.4–106 | 386.7–866.8 | <370 | 0.61–1.25 | Ceramic Tiles | (Xinwei, 2005a) |
| 4    | 2005 | Shaanxi  | 19.5–68.3 | 13.4–51.7 | 63.2–714 | <370 | 0.15–0.72 | Building materials | (Xinwei, 2005a) |
| 5    | 2006 | WBBEI    | 46.2     | 28.4     | 137.4   | <370 | 0.34     | Cement bricks, cement plaster, | (Xinwei, 2005b) |
| 6    | 2006 | Baori    | 64.7     | 48.7     | 161.3   | <370 | 0.51     | Cementes | (Xinwei, 2005b) |
| 7    | 2006 | Baori CFPP | 34.7–68.3 | 18.5–51.7 | 127–225 | <370 | 0.25–0.56 | Building materials | (Xinwei, 2005b) |
| 8    | 2006 | Baori CFPP | 34.7–68.3 | 18.5–51.7 | 127–225 | <370 | 0.25–0.56 | Building materials | (Xinwei, 2005b) |
| 9    | 2007 | China    | 26.1     | 21.2     | 114.3   | <370 | 0.23     | Lime | (Lu et al., 2007) |
| 10   | 2007 | Baori    | 20.8     | 18.3     | 111.2   | <370 | 0.19     | Lime stone | (Lu et al., 2007) |
| 11   | 2007 | Baori    | 39.7     | 34.3     | 189.0   | <370 | 0.36     | Cement | (Lu et al., 2007) |
| 12   | 2007 | Cuihua Mountain National Geological Park | 27.2 ± 6.5 | 43.9 ± 62 | 653 ± 127.6 | <370 | 0.52–0.09 | Building materials | (X. Lu & Zhang, 2007) |
| 13   | 2008 | Rizhao bathing Beach | 7.6–17.2 | 7.8–25.1 | 883–1314 | <370 | 0.35–0.62 | Sand | (Lu & Zhang, 2008a) |
| 14   | 2008 | Xi’an    | 39.4–39.9 | 15.3–54.8 | 515–1,175 | <370 | 0.28–0.79 | River sand | (Lu & Zhang, 2008b) |
| 15   | 2009 | Xi’an    | 11.0–41.3 | 16.3–523 | 618–1,187 | <370 | 0.32–0.79 | River sand | (Lu & Zhang, 2009) |
| 16   | 2012 | Baori    | 40.3 ± 3.5 | 59.6 ± 3.1 | 751 ± 12.4 | 164–199 | 0.68     | Soil | (Lu, Li et al., 2012b) |
| 17   | 2012 | Eastern region of Sichuan | 26 | 49 | 440 | 130 < 370 | 0.47 | Soil | (Z. Wang et al., 2012) |
| 18   | 2012 | Xianyang | 13.4–69.9 | 13.1–99.1 | 125–915 | <370 | 0.15–1.03 | Building materials | (Lu, Li et al., 2012c) |
| 19   | 2012 | Baotou   | 39.5–53 | 48–66 | 745–961 | 110–230 | 0.61–0.82 | Building materials | (Zhao et al., 2012) |
| 20   | 2012 | Baqiao CFPP | 27.6–48.8 | 44.4–614 | 640–992 | <370 | 0.52–0.80 | Soil | (Lu et al., 2012d) |
| 21   | 2012 | Xi’an    | 67.6     | 74.3     | 22.5    | <370 | 0.67     | Fly and Bottom Ash | (Lu et al., 2012a) |
| 22   | 2013 | Yan’an   | 9.4–73.1 | 11.5–869 | 256–1,055 | 757–222 | 0.17–0.72 | Building materials | (Lu, Li et al., 2013a) |
| 23   | 2013 | Urumqi   | 19.8–87.4 | 273–981 | 11.6–47 | <370 | 1.43–5.21 | Building materials | (Ding et al., 2013) |
| 24   | 2013 | Changzhi | 146–131 | 9.9–138 | 96.1–819 | <370 | 0.13–4.0 | Building materials | (G. Y. Yang et al., 2013) |
| 25   | 2014 | Xiangyang | 130–1006 | 8.4–164 | 8.7–145 | <370 | 0.47–4.22 | Building materials | (Feng & Lu, 2014) |
| 26   | 2014 | Xining   | 11.6–120.6 | 10.2–107.1 | 228–1,035 | <370 | 0.16–1.28 | Building materials | (Chao et al., 2014) |
| 27   | 2014 | Weinan   | 15.6–266 | 11.8–642 | 181–835 | <370 | 0.17–1.48 | Building materials | (Lu et al., 2014) |
| 28   | 2015 | Huianan  | 22.8–73.5 | 25.2–754 | 310–493 | 296–335 | 0.30–0.78 | Soil | (You et al., 2015) |
| 29   | 2015 | Anhui    | 12.4–66.4 | 193–87 | 185–921 | <370 | 0.19–0.96 | Building materials | (Ge & Zhang, 2015) |
| 30   | 2015 | Xiamen Island | 7.9–25.7 | 6.3–41.4 | 197–847 | <370 | 0.12–0.45 | Beach sand | (Huang, Lu et al., 2015) |
| 31   | 2015 | Mawan CPP Shenzhen | 22–338 | 118–432 | 101–2168 | 346–878 | 0.86–0.76 | Soil | (Liu et al., 2015) |
| 32   | 2016 | Tongliao | 12.64 ± 4.27 | 13.5 ± 5.20 | 746.9 ± 38.2 | <370 | 0.37 | Soil | (Haribala et al., 2016) |
| 33   | 2016 | Industrial park of northwest | 30.2–37.5 | 56.5–79.8 | 785–940 (866.2) | 179–214 | 0.64–0.83 | Sediment | (Lu, Pan et al., 2016) |

(Continued)
Table 1. (Continued).

| S/No | Year | Location         | Ra-226 (Bq/kg)  | Th-232 (Bq/kg) | K-40 (Bq/kg) | Gamma Index ($I_\gamma$) | Material studied                      | References                  |
|------|------|------------------|-----------------|----------------|--------------|--------------------------|---------------------------------------|-----------------------------|
| 33   | 2016 | Xiangyang       | 90.3–1799       | 59.9–145.5     | 309–906.3    | >370                     | 0.70–7.023                            | Fly Ash                     | (Feng & Lu, 2016) |
| 34   | 2016 | Dingxi          | 13.2–64.7       | 15.4–46.7      | 166–3284     | <370                     | 0.17–0.87                             | Cement & sand               | (Li et al., 2016) |
| 35   | 2016 | Xining          | 15.8–65.3       | 24.3–86        | 433–702      | <370                     | 0.31–0.88                             | Sediment                    | (X. Lu et al., 2016) |
| 36   | 2016 | Bayanwula       | 24.8 ± 2.77     | 29.4 ± 3.14    | 923 ± 47.2   | <370                     | 1.53                                  | Soil                        | (Bai et al., 2017) |
| 37   | 2016 | Weifang         | 11.7–23         | 33.6–126       | 353–925      | 178                      | 0.32–1.01                             | Sand                        | (Yin et al., 2017) |
| 38   | 2018 | China            | 682 ± 0.5       | 174 ± 9.2      | 456 ± 15.1   | <370                     | 1.24                                  | Tiles                       | (Joel et al., 2018) |
| 39   | 2018 | East China      | 746 ± 495       | 488 ± 29.6     | 348 ± 19.1   | 178                      | 0.97                                  | Stones coal-bearing strata  | (Xu et al., 2018) |
| 40   | 2019 | Shangrao        | 9–145           | 15–102         | 417–1,263    | <370                     | 0.24–1.41                            | Top soil                    | (B. Yang et al., 2019) |
contamination (Xinwei Lu, Li et al., 2013). Xiang Ding et al. also analyzed the materials commonly used in Urumqi for the construction of buildings (Ding et al., 2013). Shiqiang Chao et al. (2014) determined the concentration of radioactivity in the building materials from Xining (Chao et al., 2014). In a separate study, these researchers also investigated the radioactivity in building materials from Weinan (Xinwei Lu et al., 2014). They also analyzed building material obtained from Xiangyang during this year (Feng & Lu, 2014). Mu You et al. in 2015 collected Coal, Ash (bottom and fly) and soil samples from the vicinity of coal fired power plant in Huaian and assessed for the radiological characterization by (You et al., 2015). Junyan Ge and Zhang Jianguo estimated the radiological hazards from the building materials mostly used in Anhui Province (Ge & Zhang, 2015). Vanadium mine situated in the central china was chosen for the collection of bone-calc samples to analyze for the gamma radioactivity by Yan-Jun Huang et al. (Huang, Chen et al., 2015).

Beach sand samples were collected by Yingnan Huang et al. from Xiamen Island for activity concentration of natural radioactivity (Huang, Lu et al., 2015). In 2015 Guoqing Liu et al. studied samples of soil from the surrounding of Mawan CFPP situated in Shenzhen for the gamma radiation in this area (Liu et al., 2015). Radon exhalation and radioactivity concentration in fly ash used as construction materials in most parts of Xiangyang were studied by Tingting Feng and Xinwei Lu for gamma activity concentration (Feng & Lu, 2016). Hu B et al. made choice of Tongliao and collected some soil samples around the uranium mine of this region for the radiological analysis and heavy metals (Haribala et al., 2016). Xinwei Lu et al. collected sediment samples in the nearby ponds of the industrial park of northwest and analyzed for the gamma activity concentration in it (Lu, Pan et al., 2016). Yuxin Li, Xinwei Lu, and Xiaolan Zhang in 2016 determined the radioactivity concentration of naturally occurring radioactive nuclides in the samples of sand and cement used commonly in the region of Dingxi (Li et al., 2016). X. Lu, S. Chao, and X. Ding found radioactivity concentration in the sediment samples obtained from the Xining sector of the Huangshui River in the northwest of China (X X Lu et al., 2016). Jin Wang et al. in 2016 representative soil samples were collected from the surrounding of granitic uranium deposit situated in Guangdong to measure the radioactivity in the soil of this mine and hazards to the workers working in it (J. J. Wang et al., 2016). During 2017, Haribala Bai et al. studied the radiological health hazards of the heavy metals in collected surface soil samples from the vicinity of Bayanwula prospective uranium mining territory (Bai et al., 2017). High Purity Germanium (HPGe) spectrometry and inductively coupled plasma-mass spectrometry (ICP-MS) were used by them for the natural and anthropogenic radioactive nuclides and heavy metals in the obtained soil samples. Samples of geothermal water from the capital of PR China for comprehensive investigation of radiation concentrations of the radionuclides were collected by Shufang Wang et al. in 2017 (S. S. Wang et al., 2017). Yin et al. (2017) building material including sand samples from Weifang was gotten for the radio analysis (Yin et al., 2017). In 2018 tiles samples were obtained by E. S. Joel to determine the presence of radioisotopes in the collected samples. During the same year, i.e. 2018 stone coal-bearing strata in East China was evaluated by Naizheng Xu et al. for radioactivity concentration (Joel et al., 2018; Xu et al., 2018). Baolu Yang et al. in 2019 collected samples of topsoil from Shangrao Prefecture (eastern region) for the assessment of natural as well as artificial radioactivity concentration (B. B. Yang et al., 2019). Soon after that high concentration of Radon in the region of Shawan Cave in southwest of china were continuously monitored by Yanwei Wang et al. using the RAD7 radon detector (Y. Y. Wang et al., 2019).

Following is the outline of some other studies apart from the summary presented in Tables 1 and 2 regarding the assessment of background level radioactivity in samples of various materials from the human environment in China.

Weihai Zhuo et al. (2001) studied ground water samples for the assessment of natural radioactivity (Rn-222, Ra-226, Ra-228, and Uranium). Samples (total 552) were collected from various parts of Fujian province using a Radon (Rn) bubbler and α-scintillation cell method. These investigators also estimated the average lifetime risk of $1.3 \times 10^{-3}$ due to the ingestion of Rn-222 in the ground water of Fujian (Zhuo et al., 2001).
In 2009, Gang SONG et al. studied the Pearl River Delta Economic Zone, situated in Guangdong for the assessment of natural low-level background radioactivity in this area. They found outdoor absorbed dose rate in the range of 55.7 to 88.7 nGy/h from cosmic radiation with a mean value of 68.2 nGy/h and from terrestrial γ-radiation it was found in the range of 22.6 to 522 nGy/h with an average value of 137 nGy/h. A higher absorbed dose rate of 522 nGy/h in Conghua was found. They also estimated the level of radon content, i.e. indoor radon (30.5 Bq/m³) and outdoor (11.28 Bq/m³) in PRDEZ. The average values of U-238, Ra-226, Th-232 and K-40 in the soil samples from PRDEZ was found as 137.6, 136.7, 175.3, and 700.7 Bq/kg respectively. The reported result showed that natural radioactivity in Guangdong is higher than in other parts of China due to granite bedrocks (Song et al., 2009).

In 2010 an inter-comparison exercise was conducted for the assessment of radioactivity contents in soil and building materials was organized by the National Institute for Radiological Protection (NIRP), CDC China. They used a γ-ray detector for the analysis of soil samples obtained from farms in Jiuquan and bricks from suppliers and factories situated in Beijing (Tuo et al., 2010).

In 2013 Xinwei Lu et al. observed the presence of heavy metals and natural radioactivity in samples of soil around the major coal power plants operated in Xin’an using XRF and γ ray spectrometry (Xinwei Lu, Liu et al., 2013).

Heavy metals (Cu, Pb, Zn, Co, and Cr) were found in higher concentration in the studied soil samples compared to the corresponding values for background in Shaanxi soil showed contamination of soil with heavy metals. Measured values for activity concentration of Ra-226, Th-232, and K-40 were also found higher than the mean of Shaanxi soil. The contamination of soil with heavy metals and higher concentration of primordial radionuclides were mainly due to the combustion of coal for the energy generation. During the same year (G. Yang et al., 2013) Guang Yang, Xinwei Lu, Caifeng Zhao, and Nan Li studied building materials for γ activity using gamma spectrometry techniques and found the radioactivity concentration of K-40, Th-232, and Ra-226 in the range of 96.1–819.0, 9.9–138.8, and 14.6–131.2, respectively, in the studied building materials. Results of this study were compared with available data for other countries as well as world’s average values and found that $H_{ext} < 1$ for all studied samples, while $H_{ext}$ and $I_{p}$ for gravel aggregate and hollow brick exceeded the world permissible limit, indicated to avoid these as building materials (G. Yang et al., 2013). In 2013 Xiao-Xiang Miao et al. collected water samples from the vicinity of the nuclear facility of seven provinces of PR. China for the assessment of radiation content in it (Miao et al., 2013). They found gross alpha and Beta ($\alpha$ & $\beta$) values in various water samples less than the World Health Organization (WHO) permissible limits of 0.58 Bq/L and 1.08 Bq/L respectively.

In 2015 Jerzy Falandysz et al. conducted a study for the comparison of radiocesium and the activity concentration of naturally γ-emitting radionuclide K-40 Boletus mushrooms grown in various regions of Yunnan and Europe in China. This study revealed that samples of mushroom obtained from the European region were found 2 to 4 times more contaminated with Cs-137 compared to mushroom collected from Yunnan province (Falandysz et al., 2015).

3. Discussion

This section includes a summary of the measurement of radioactivity concentration in the environmental samples conducted by various research groups in People’s Republic of China from 2000 to 2019. The results summarized in Tables 1 and 2 show a broad fluctuation in the concentration level of radioactivity of the desired radioactive nuclides in the analyzed minerals environmental samples collected from some parts of the country.

These samples included water, sediment, soil, rocks, ash, bricks, cement, etc. This variation in the concentration of radioactivity of the natural radionuclides is mainly due to the difference in soil, geological positioning, or geographical distinctiveness of the region. The data reported to date has confirmed the level of background radiation of NORMS within the internationally permissible limits. The radioactivity concentration of Radium, Thorium, and Potassium ranges from the lower limits of detection to 1800 Bq/kg, 1220 Bq/kg and 2168 Bq/kg, respectively. Radium equivalent activity ($Ra_{eq}$) in most case is less than 370 Bq/kg but it was found to be higher than 370 Bq/kg in soil samples collected from the surrounding areas of Baoji CFPP, building materials commonly used in Weinan and Xining, fly ash from the Xiangyang and stone coal-bearing strata from east china. The gamma activity index ($I_{p}$) was also found less than 6 corresponding to a gamma dose rate less than 1 mSv/yr. But radium equivalent activity of glazed tiles from Guandong, Xhaanxi, Shandong, and Zhejiang was found to be greater than 370 Bq/kg with gamma index ranges from 1.14 to 10.6 corresponding to γ-dose rate higher than the permissible limit of 1 mSv/yr.

The reported values of activity concentration of Cs-137 and U-238 were also found in the range of 4.23 ± 4.76 to 6 Bq/kg and 3.3 to 442 Bq/kg, respectively.

All the literature reported to date revealed the hazards from NORM in environmental samples including dietary items and building materials. In soil, the concentration level of natural radioactivity was assessed taking into account the soil type and its surface specification. Many studies comprising measurements of the
concentration of radioactivity in building materials as well as soil from agriculture land collected from across China are available, but none of the studies reported the measurement of NORMS and other radionuclides in dairy items (milk, butter, cheese, and yogurt), air and drinkable bottled water. Also, there is no availability of data for condensed milk. In addition, insufficient data exists for underground Uranium and some other mineral deposits existing in rocks and soil. The investigation of natural radioactivity in bones & teeth of animals and humans is also needed at the current time.

4. Conclusion & Future work

The reviewed literature demonstrated the high level of current research activity in the assessment and measurement of natural as well as artificial radioactivity concentrations in soil, water, building materials (sand, cement, and cement plaster, bricks, tiles glazed & ceramic), air, and dietary items in various parts of the country. Most researchers used high purity Germanium detectors along with NA(Tl) for these investigations. A large-scale fluctuation in radioactivity concentration has been observed in the investigated materials. Furthermore, soil around the Baoji CFPP, fly ash from Xiangyang coal fired power plants, some building materials from Weinan, Xining, and stone coal-bearing strata from east China showed radioactivity levels higher than all of the studied materials with $R_{eq} > 370$ Bq/kg and $I_a < 6$, while the radioactivity concentration in the rest of the studied samples was observed to be well below the internationally permissible limits and poses no health hazards to the public. A higher gamma activity index $(1.14–10.06)$ with $R_{eq} > 370$ Bq/kg was noticed in glazed tiles from Guandong, Xhaanxi, Shandong, and Zhejiang corresponding to gamma dose rate higher than the permissible limit of 1 mSv/yr, which may pose possible health risks for its users and it is therefore suggested to avoid their use as building materials. None of the studies reported the measurement of NORMS and other radionuclides in dairy items (milk, butter cheese, yogurt), air, and drinkable bottled water. Also, there is no availability of data for condensed milk. In addition, insufficient data exists for underground Uranium and some other mineral deposits existing in rocks and soil. The investigation of natural radioactivity in bones & teeth of animals and humans is also needed at the current time. Further investigation is proposed to explore natural radioactivity and radon concentration in unexplored regions (Central and Northeast China) of China.

Disclosure statement

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References

Abbasi, A., & Bashiry, V. (2016). Measurement of radium-226 concentration and dose calculation of drinking water samples in Guilan province of Iran. International Journal of Radiation Research, 14(4), 361–366. https://doi.org/10.18869/acadpub.jrr.14.4.361
Afshari, N. S., Abbasisiar, F., Abdolmaleki, P., & Nejad, M. G. (2009). Determination of 40K concentration in milk samples consumed in Tehran-Iran and estimation of its annual effective dose. Iranian Journal of Radiation Research, 7(3), 159–164. http://ijrr.com/article-1-568-en.html
Alias, M., Hamzah, Z., Saat, A., Omar, M., & Wood, A. K. (2008). An assessment of absorbed dose and radiation hazard index from natural radioactivity. The Malaysian Journal of Analytical Sciences, 12(1), 1–3. http://www.ukm.my/mjas/v12_n1/27.pdf
Anjos, R. M., Veiga, R., Soares, T., Santos, A. M. A., Aguilar, J. G., Frascá, M. H. B. O., Brage, J. A. P., Uzeda, D., Mangia, L., Facure, A., Mosquera, B., Carvalho, C., & Gomes, P. R. S. (2005). Natural radionuclide distribution in Brazilian commercial granites. Radiation Measurements, 39(3), 245–253. https://doi.org/10.1016/j.radmeas.2004.05.002
Bai, H., Hu, B., Wang, C., Bao, S., Sai, G., Xu, X., Zhang, S., & Li, Y. (2017). Assessment of radioactive materials and heavy metals in the surface soil around the bayanwula prospective uranium mining area in China. International Journal of Environmental Research and Public Health, 14(3), 300. https://doi.org/10.3390/ijerph14030300
Chao, S., Lu, X., Zhang, M., & Pang, L. (2014). Natural radioactivity level and radiological hazard assessment of commonly used building material in Xining, China. Journal of Radioanalytical and Nuclear Chemistry, 300(2), 879–885. https://doi.org/10.1007/s10967-014-3065-6
Čujić, M., Dragović, S., Dördević, M., Dragović, R., Gajić, B., & Miljanic, Š. (2015). Radionuclides in the soil around the largest coal-fired power plant in Serbia: Radiological hazard, relationship with soil characteristics and spatial distribution. Environmental Science and Pollution Research, 22(13), 10317–10330. https://doi.org/10.1007/s11356-014-3888-2
Dabayneh, K. M., Mashal, L. A., & Hasan, F. I. (2008). Radioactivity concentration in soil samples in the southern part of the West Bank, Palestine. Radiation Protection Dosimetry, 131(2), 265–271. https://doi.org/10.1093/rpd/ncn161
Dai, L., Wei, H., & Wang, L. (2007). Spatial distribution and risk assessment of radionuclides in soils around a coal-fired power plant: A case study from the city of Baoo, China. Environmental Research, 104(2), 201–208. https://doi.org/10.1016/j.envres.2006.11.005
Ding, X., Lu, X., Zhao, C., Yang, G., & Li, N. (2013). Measurement of natural radioactivity in building materials used in Urumqi, China. Radiation Protection Dosimetry, 155(3), 374–379. https://doi.org/10.1093/rpd/nct002
spectrometry. Environmental Monitoring and Assessment, 134(1-3), 333–342. https://doi.org/10.1007/s10661-007-9624-3

Miao, X. X., Ji, Y. Q., Shao, X. Z., Wang, H., Sun, Q. F., & Su, X. (2013). Radioactivity of drinking-water in the vicinity of nuclear power plants in China based on a large-scale monitoring study. International Journal of Environmental Research and Public Health, 10, 6863–6872. https://doi.org/10.3390/ijerph10126863

Namvaran, M., & Negarestani, A. (2013). Measuring the radon concentration and investigating the mechanism of decline prior an earthquake (Jooshan, SE of Iran). Journal of Radioanalytical and Nuclear Chemistry, 298(1), 1–8. https://doi.org/10.1007/s10967-012-2162-7

Parial, K., Guin, R., Agrahari, S., & Sengupta, D. (2016). Monitoring of radionuclide migration around Kolaghat thermal power plant, West Bengal, India. Journal of Radioanalytical and Nuclear Chemistry, 307(1), 533–539. https://doi.org/10.1007/s10967-015-4152-z

Qu, L., Yao, D., Cong, P., & Xia, N. (2008). Radioactivity Concentrations in Soils in the Qingdao Area, China. Annals of the New York Academy of Sciences, 1140(1), 308–314. https://doi.org/10.1196/annals.1454.038

Rafique, M., Jabbar, A., Khan, A. R., Rahman, S. U., Basharat, M., Mehmood, A., & Matiullah. (2013). Radiometric analysis of rock and soil samples of Leepa Valley; Azad Kashmir, Pakistan. Journal of Radioanalytical and Nuclear Chemistry, 298(3), 2049–2056. https://doi.org/10.1007/s10967-013-2681-x

Rafique, M., Rehman, H., Matiullah, Malik, F., Rajput, M. U., Rahman, S. U., & Rathore, M. H. (2011). Assessment of radiological hazards due to soil and building materials used in Mirpur Azad Kashmir, Pakistan. International Journal of Radiation Protection, 9(2), 77–87. http://ijrp.com/article-1-739-en.html

Rahman, S., Faheem, M., & Matiullah, (2008). Natural radioactivity measurements in Pakistan—an overview. Journal of Radiological Protection, 28(4), 443–452. https://doi.org/10.1088/0952-4746/28/4/R01

Righi, S., & Bruzzi, L. (2006). Natural radioactivity and radon exhalation in building materials used in Italian dwellings. Journal of Environmental Radioactivity, 88, 158–170. https://doi.org/10.1016/j.jenvrad.2006.01.009

Saghatchi, F., Salouti, M., Esmai, A., & Sharafi, A. (2010). Natural radioactivity levels of 226Ra and 40K in soil of Zanjan province, Iran. Radiation Protection Dosimetry, 141 (1), 86–89. https://doi.org/10.1093/rpd/ncq151

Song, G., Tang, Z., Yue, Y., & Chen, D. (2009). Natural radioactivity levels in the pearl river delta economic zone of Guangdong, China. 2009 3rd International Conference on Bioinformatics and Biomedical Engineering, (230), 1–3. Beijing, China. https://doi.org/10.1109/ICBEE.2009.5163098

Taqi, A. H., & Battawy, A. A. (2018). Natural radioactivity assessment in soil samples from Kirkuk city of Iraq using HPGe detector. Iranian Journal of Radiation Research, 16(4), 455–463. https://doi.org/10.18869/acapub.ir.16.4.455

Tufail, M., Nasim-Akhtar, Sabihah-Javid, & Hamid, T. (2007). Natural radioactivity hazards of building bricks fabricated from saline soil of two districts of Pakistan. Journal of Radiological Protection, 27(4), 481–492. https://doi.org/10.1088/0952-4746/27/4/009

Tuo, F., Zhang, Q., Zhang, J., Zhou, Q., Zhao, L., Li, W., Zhang, J., & Xu, C. (2010). Inter-comparison exercise for determination of 226Ra, 232Th and 40K in soil and building material. Applied Radiation and Isotopes, 68(12), 2335–2338. https://doi.org/10.1016/j.apradiso.2010.04.023

Turhan, Ş., Gören, E., Garad, A. M. K., Altkülaç, A., Kurnaz, A., Duran, C., Hançerlioğullan, A., Altıental, V., Güçkan, V., & Özdemir, A. (2018). Radiometric measurement of lignite coal and its by-products and assessment of the usability of fly ash as raw materials in Turkey. Radiochimica Acta, 106 (7), 611–621. https://doi.org/10.1515/ract-2017-2863

UNSCAR. (1988). Report to the General Assembly scientific annexes. United Nations.

Usikalu, M. R., Maleka, P. P., Malik, M., Oyeyemi, K. D., & Adewoyin, O. O. (2015). Assessment of geogenic natural radionuclide contents of soil samples collected from Ogun State, South western, Nigeria. International Journal of Radiation Research, 13(4), 1–9. https://doi.org/10.7508/ijrr.2015.04.009

Veiga, R., Sanches, N., Anjos, R. M., Macario, K., Bastos, J., Iguatemy, M., Aguier, J. G., Santos, A. M. A., Mosquera, B., Carvalho, C., Baptista Filho, M., & Umisedo, N. K. (2006). Measurement of natural radioactivity in Brazilian beach sands. Radiation Measurements, 41(2), 189–196. https://doi.org/10.1016/j.radmeas.2005.05.001

Wang, J., Liu, J., Chen, Y., Song, G., Chen, D., Xiao, T., Wu, S., Chen, F., & Yin, M. (2016). Technologically elevated natural radioactivity and assessment of dose to workers around a granitic uranium deposit area, China. Journal of Radioanalytical and Nuclear Chemistry, 310(2), 733–741. https://doi.org/10.1007/s10967-016-4809-2

Wang, S., Ye, C., Liu, J., Lin, P., Liu, K., Dong, P., Wang, S., Sun, Y., Liu, Y., Wang, L., & Wang, G. (2017). Natural radioactivity of geothermal water in Beijing, China. Journal of Radioanalytical and Nuclear Chemistry, 313(3), 1547–1555. https://doi.org/10.1007/s10967-017-5541-2

Wang, Y., Luo, W., Zeng, G., Wang, Y., Yang, H., Wang, M., Wang, Y., Wang, Y., Wang, M., Zhang, L., Cai, X., Chen, J., Cheng, A., & Wang, S. (2019). High 222Rn concentrations and dynamics in Shawan Cave, southwest China. Journal of Environmental Radioactivity, 199–200, 16–24. https://doi.org/10.1016/j.jenvrad.2018.12.029

Wang, Z., He, J., Du, Y., He, Y., Li, Z., Chen, Z., & Yang, C. (2012). Natural and artificial radionuclide measurements and radioactivity assessment of soil samples in eastern Sichuan province (China). Radiation Protection Dosimetry, 150(3), 391–397. https://doi.org/10.1093/rpd/ncr413

Xinwei, L. (2004a). Natural radioactivity in some building materials and by-products of Shaxian, China. Journal of Radioanalytical and Nuclear Chemistry, 262, 775–777. https://link.springer.com/article/10.1007/s10967-004-0509-4

Xinwei, L. (2004b). Radioactivity level in Chinese building ceramic tile. Radiation Protection Dosimetry, 112(2), 323–327. https://doi.org/10.1093/rpd/ncn396

Xinwei, L. (2005a). Natural radioactivity in some building materials of Xi’an, China. Radiation Measurements, 40(1), 94–97. https://doi.org/10.1016/j.radmeas.2005.01.003

Xinwei, L. (2005b). Radioactive analysis of cement and its products collected from Shaxian, China. Health Physics, 88(1), 84–86. https://doi.org/10.1093/HP.000014298.08451.c8

Xinwei, L., Lingqing, W., & Xiaoan, J. (2006a). Radiometric analysis of Chinese commercial granites. Journal of Radioanalytical and Nuclear Chemistry, 267(3), 669–673. Retrieved from https://link.springer.com/article/10.1007/s10967-006-0101-1

Xinwei, L., Lingqing, W., Xiaoan, J., Leipeng, Y., & Gelian, D. (2006b). Specific activity and hazards of Archeozoic-Cambrian rock samples collected from the Weibei area of Shaanxi, China. Radiation Protection Dosimetry, 118(3), 352–359. https://doi.org/10.1093/rpd/ncl339
Xinwei, L., & Xiaolan, Z. (2006b). Measurement of natural radioactivity in sand samples collected from the Baoji Weihe Sands Park, China. Environmental Geology, 50(7), 977–982. https://doi.org/10.1007/s00254-006-0266-5

Xu, N., Wei, X., Kuang, F., Zhang, L., & Liu, H. (2018). Study on the natural radioactivity level of stone coal-bearing strata in East China. Environmental Earth Sciences, 77(21), 726. https://doi.org/10.1007/s12665-018-7916-2

Yang, B., Zhou, Q., Zhang, J., Li, Z., Li, W., & Tuo, F. (2019). Assessment of radioactivity level and associated radiation exposure in topsoil from eastern region of Shangrao Prefecture, China. Journal of Radioanalytical and Nuclear Chemistry, 319(1), 297–302. https://doi.org/10.1007/s10967-018-6298-y

Yang, G., Lu, X., Zhao, C., & Li, N. (2013). Natural radioactivity in building materials used in Changzhi, China. Radiation Protection Dosimetry, 155(4), 512–516. https://doi.org/10.1093/rpd/nct018

Yang, Y., Wu, X., Jiang, Z., Wang, W., Lu, J., Lin, J., Wang, L.-M., & Hsia, Y. (2005). Radioactivity concentrations in soils of the Xiazhuang granite area, China. Applied Radiation and Isotopes, 63(2), 255–259. https://doi.org/10.1016/j.apradiso.2005.02.011

Yin, N., Lu, X., & Li, Y. (2017). Radioactive analysis and radiological hazards of sand in Weifang, China. International Journal of Radiation Research, 15(2), 225–228. https://doi.org/10.18869/acadpub.ijrr.15.2.225

You, M., Hu, Y., Lu, J., & Li, C. (2015). Evaluation of the radiological characterization in a coal-fired power plant, China. Environmental Progress & Sustainable Energy, 34(4), 1080–1084. https://doi.org/10.1002/ep.12105

Zhao, C., Lu, X., Li, N., & Yang, G. (2012). Natural radioactivity measurements of building materials in Baotou, China. Radiation Protection Dosimetry, 152(4), 434–437. https://doi.org/10.1093/rpd/ncs054

Zhuo, W., Iida, T., & Yang, X. (2001). Occurrence of 222Rn, 226Ra, 228Ra and U in groundwater in Fujian Province, China. Journal of Environmental Radioactivity, 53(1), 111–120. https://doi.org/10.1016/S0265-931X(00)00108-9