Title: PGNAA analysis of sediments from Garab hot spring in Behbahan, Iran, and assessment of radiation hazards of present radioactive elements

Author names: Mehdi Hassanpour , Mohammadreza Rezaie , Javad Tayebi Marzieh Hassanpour , Mohammad Rashed Iqbal Faruque , Mayeen Uddin Khandaker

Abastact: Radiation hazards in natural environments are closely associated with the activity concentrations of naturally occurring radionuclides such as ^{232}Th, ^{137}Cs, ^{40}K, and ^{238}U. The sediments of the Garab Hot Spring in Behbahan, Iran, widely utilized for recreational and therapeutic purposes, were investigated to assess potential radiological risks. Sediment samples were systematically collected from four different locations: the spring source, the downstream channel, the bathing pool, and the surrounding soil. Activity concentrations of the radionuclides were measured, and key radiological hazard indices were computed, including the Ra_{eq}, $Dr^{\cdot}$, $Dout^{\cdot}$, $Din^{\cdot}$, D_{tot}, H_{ex}, H_{in}, I_{γ}, and ELCR. Results indicated that, while the concentrations of ^{40}K and ^{238}U remained below the international safety limits recommended by UNSCEAR (2000), elevated levels of ^{232}Th and ^{137}Cs were observed. The Ra_{eq} values ranged from 38.8 to 312.65 Bq/kg, remaining below the critical threshold of 370 Bq/kg. However, the ELCR values ranged from 1.80E-3 to 6.12E-3, exceeding the accepted limit of 1.78E-3. Furthermore, all dose rate indices ($Dr^{\cdot}$, $Dout^{\cdot}$, $Din^{\cdot}$, D_{tot}), except for I_{γ}, H_{ex}, and H_{in}, surpassed their permissible levels, indicating a notable radiological hazard. In addition, the presence of heavy metals was analysed using the PGNAA method with a 5 Ci Am–Be neutron source. Sensitivity analysis identified gamma energies of 465.3 keV and 122.08 keV as the most reliable markers for detecting lead (Pb) and iron (Fe), respectively. Overall, the findings suggest that prolonged exposure to sediments from the Garab Hot Spring may pose significant radiological health risks, particularly due to elevated thorium and cesium activities and the associated excess lifetime cancer risk. Caution is therefore advised regarding long-term recreational or therapeutic use of the site.

Keywords: Specific activity Radiation hazards Soil Heavy radioactive elements PGNAA

10.1016/j.radphyschem.2025.113157