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Radioactivity level and toxic elemental concentration in groundwater at Dei-Dei and Kubwa areas of Abuja, north-central Nigeria

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HIGHLIGHTS

- The estimation of human radiological risk over lifetime consumption.
- Determination of radiological risks.
- The annual effective dose of ^{238}U in drinking water.
- Carcinogenic and non-carcinogenic pollutants.

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ABSTRACT

The activity concentrations of uranium and toxic elements in Dei-Dei borehole, Kubwa borehole, Water Board and hand-dug well water samples in Abuja area were measured using inductively coupled plasma mass spectrometry (ICP-MS) system. The results obtained were used to calculate human radiological risk over lifetime consumption by the inhabitants in the area. The activity concentrations of ^{238}U in all the water supplies for drinking ranges from 0.849 mBq L^{-1} to 2.699 mBq L^{-1} with the highest value of 2.699 mBq L^{-1} noted at Dei-Dei borehole whereas the lowest value of 0.849 mBq L^{-1} was noted in Kubwa borehole. The highest annual effective dose from natural ^{238}U in all the water samples was found in Dei-Dei borehole with a value of 8.9×10^{-5} mSv y^{-1} whereas the lowest value was noted in Kubwa borehole with a value of 2.8×10^{-5} mSv y^{-1}. The radiological risks for cancer mortality were found distinctly low, with the highest value of 1.01×10^{-7} reported at Dei-Dei borehole compared to Kubwa borehole with a value of 3.01×10^{-8}. The cancer morbidity risk was noted higher in Dei-Dei borehole with a value of 1.55×10^{-7} whereas lower value of 4.88×10^{-9} was reported in Kubwa borehole. The chemical toxicity risk of ^{238}U in drinking water over a lifetime consumption has a value of 0.006 μg kg^{-1} day^{-1} in Dei-Dei borehole whereas lower value of 0.002 μg kg^{-1} day^{-1} was found in Kubwa borehole. Measured lead (Pb) and chromium (Cr) concentrations reported higher in Water Board compared to Dei-Dei and Kubwa borehole samples. Significantly, this study inferred that the ^{238}U concentrations originate from granitic strata of the tectonic events in the area; thus, there was a trend of diffusion towards north to south and re-deposition towards Dei-Dei area.

1. Introduction

The uranium concentration in groundwater depends on lithology, geomorphology and other geological factors of the region. In groundwater, both uranium and toxic elements are present in particulate and dissolved form due to certain minerals such as uranitie, pitchblende and cornalite or as secondary mineral in form of complex oxide of silicate, phosphate, validates, lignite and monazite sands (Mahesh et al., 2001). To guide the groundwater quality in an environment, some areas that have been contaminated by high concentration of uranium and toxic elements need to be identified, the degree of damage assessed and the causes resulting to imbalances determined. Some toxic metals potentially resulting from anthropogenic activities cause severe disturbances of ecosystems (Abdallah and Morsy, 2013). However, it is essential to protect the quality of the environment all over, such that the human activities of negative effect will be drastically reduced.

The toxic effect of some radioactive elements like uranium compounds have been extensively studied in kidney (Kundt et al.,

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2009; Kurttio et al., 2002; Leggett, 1989) and bone of laboratory animals (Larivière et al., 2007). The toxicity of the human kidney by chronic ingestion of the uranium through drinking water in the range of 0.004 to 9 $\mu g\ L^{-1}$ per body weight per day may produce interference with kidney functions (Zamora et al., 1998). In more recent studies on humans by Kurttio et al. (2005), nephrotoxic effects of uranium in drinking water were found even for low concentrations without clear threshold. Most results from uranium studies in drinking water suggest that the safe concentration of uranium in drinking water may be within the range guideline values of 2–30 $\mu g\ L^{-1}$ (Kurttio et al., 2002; WHO, 2006). Because uranium is predominantly alpha-emitting radionuclide, there is a concern about the potential DNA damage if the emitted alpha-particles reach the cell nuclei of the body, for instance through water ingestion. Attempt by cells to repair this damage if occurs, may result in repair errors, producing gene mutations or chromosomal aberrations. These effects, when sufficiently severe, may be manifested as cancer and possibly as developmental malformations in children and developing fetus.

Metals, such as cadmium (Cd) and zinc (Zn) that do not form highly stable complexes with organic matter are not as greatly affected by the presence of dissolved organic matter in the soil solution as copper (Cu), lead (Pb), or mercury (Hg) metals that do form stable complexes. Dunnivant et al. (1992), however, demonstrated that dissolved organic matter does reduce Cd sorption due to complication formation under their experimental conditions; Zn is readily adsorbed by clay minerals, carbonates, or hydrous oxides. Hickey and Kittrick (1984), Kuo et al. (1983), and Tessier et al. (1980) found that the greatest percent of the total Zn in polluted soil is and sediments was associated with Fe and Mn oxides. Precipitation is not a major mechanism of retention of Zn in soils because of the relatively high solubility of Zn compounds. Cadmium may be adsorbed by clay minerals, carbonates or hydrous oxides of iron and manganese or may be precipitated as cadmium carbonate, hydroxide, and phosphate. Evidence suggests that adsorption mechanisms may be the primary source of Cd removal from soils (Dudley et al., 1988). In the soil environment, arsenic (As) exists as either arsenate, or as arsenite which is the more toxic form of arsenic element found as a contaminant in groundwater system.

This study is proposed to investigate the quality of groundwater (borehole) used for human consumption without treatments on extended areas of Abuja satellite towns and suburbs. The groundwater samples for this study will be compared with the public water supply (Abuja Water Board collected at Area 10, Garki tap water) and world standard to ascertain the quality level for groundwater-based drinking water. There are lack of data on the radiological and chemical effect of radionuclides and other heavy metals in borehole drinking water supply at Dei-Dei and Kubwa in Abuja in the north-central part of Nigeria. Samples were taken from the boreholes of varying depths, 70 m at Dei-Dei, 40 m at Kubwa and 14 m hand dug well at the same location in Dei-Dei for this work. The study areas are bounded by 8° 53′N–9° 13′N latitudes and 7° 00′E–7° 30′E longitudes. The towns are in the coordinates 9° 6′52″N latitudes and 7° 15′39″E longitudes (Dei-Dei) and 9° 6′ 16.7″N latitudes and 7° 16′ 26.0″E longitudes (Kubwa). Thus, the need for evaluating the radionuclides and toxic elements on groundwater in Dei-Dei and Kubwa were highlighted by Maxwell et al. (2013) as follows:

1) The World Health Organization (WHO) and UNICEF reports for 2012 ranked Nigeria as one of the most populous country without adequate water and proper sanitation (Godknows, 2012).
2) The Abuja Water Board has a designed capacity which is in anti-phase with the city growth in the recent time. The increase in demand for water has led to compulsory alternative source of borehole (groundwater) to augment the inadequate public water supply (Maxwell et al., 2013).
3) Borehole is the only source of water in densely populated area of about 0.3 to 1 million inhabitants.
4) The risk associated with naturally occurring radioactive materials (NORM) in water–rock interactions needs urgent attention to restrict the inhabitants to the exposure of the water that comes from unsafe and radionuclide rich aquifer bearing rock formation.
5) To evaluate the suitability of different borehole locations for quality groundwater consumption and to educate the inhabitants of the satellite towns and suburbs the potential problems associated with NORM and toxic elements in water–rock interaction.

1.1. Geology and hydrogeology of the study area

The area of study forms part of the Basement Complex of north-central Nigeria; with lithologic units falling under three main categories which include: (1) Undifferentiated migmatite complex of Proterozoic to Archean origin, (2) Meta-volcano Sedimentary rocks of late proterozoic age and (3) Older Granite Complex of Late Precambrian – Lower Paleozoic age also known as Pan-African Granites. All these rocks have been affected and deformed by the Pan-African thermotectonic event. Detailed reports of the lithological description, age, history, structure and geochemistry of the basement complex of Nigeria are given in Oyawoye, 1972; Black et al., 1979; Ajibade et al., 1978; Rahaman, 1988; Caby, 1989 and Dada, 2008. Fig. 1 shows the geologic map of the study area. Fig. 2 shows the accessibility map of the study area with greenish dot at Dei -Dei and Kubwa indicating the positions of Vertical Electrical Sounding (VES) for borehole points. In the study area, all the three major rock categories mentioned above are well represented in Fig. 1. The rocks are generally weathered into reddish micaceous sandy clay to clay materials, capped by laterite. The hydrogeology of basement areas is simple since there is an inherent limitation to the occurrence of groundwater. However, where the regolith is thick and there is a dense network of fractures, the potentials for the accumulation of groundwater in basement complex rocks may increase. Limitations of yield may be due to the fact that the aquifers are often localized. This makes the search for a feasible borehole site imperative in the area. Generally, the life span of boreholes is much lower in the area than in most areas that are underlain by porous sedimentary materials.

2. Experimental and analytical method

2.1. Sample analysis using ELAN 9000 instrument and technique

Measurement using ICP-MS was performed at the Universiti Tun Hussein Onn Malaysia Environmental and Soil Science Laboratory. The results were reliable because of the duplicates which were comparable to each other. The ELAN 9000 instrument performs analyses at the parts-per-trillion level and lower. The custom resolution feature allows the selectively adjust resolution for individual masses while maintaining nominal resolution across the mass range, minimizing spectral interferences, extending working ranges and improving detection limits. The unique Auto Lens feature optimizes the lens voltage for each element. This powerful system maximizes analyte signals and minimizes matrix interferences during multi-element runs, providing maximum sensitivity. The sample introduction system uses an integrated