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ANALYSIS OF ESSENTIAL AND TOXIC ELEMENTS IN TAP AND BOTTLED WATER FROM THE UK AND ITS COMPARISON WITH LITERATURE DATA FOR DRINKING WATER FROM AFRICAN COUNTRIES: IMPLICATIONS FOR HUMAN HEALTH

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ABSTRACT: *This study compares the presence of essential and toxic elements in UK and African waters. Drinking water samples (n=93) were collected from Leicester, UK [45 bottled drinking water (BDW) samples and 48 tap drinking water (TDW) samples]. Concentrations of 26 elements were determined by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Notably, cadmium (Cd) and lead (Pb) were detected only in TDW samples, with detection percentages of 25% and 60.4%, respectively. In contrast, very low concentrations of arsenic (As) and mercury (Hg) were detected in 82.2% and 100% of BDW samples and in 88.9% and 95.6% of TDW samples, respectively. All detected element concentrations were within World Health Organization safety limits. The hazard quotient (HQ) and Incremental Lifetime Cancer Risk (ILCR) values for toxic elements were below the permissible limits, suggesting no significant long-term health risks. In contrast, recent literature from some African countries has revealed high concentrations of toxic elements, such as Pb and As, with HQ and ILCR exceeding guidelines. Consumption of water can be higher in African countries, which have warmer climates, and this will further increase their exposure to these toxic elements compared to the UK. Furthermore, our recent research has shown high concentration of Pb in some popular African foods. The cumulative effect of exposure to Pb from water and foods is a cause for concern in Africa. There is an urgent need to lower toxic elements in African drinking water through improvements to the water treatment and distribution systems as well as preventing environmental pollution.*

KEYWORDS: ICP-MS, Trace Elements, Toxic Elements, Tap Water, Bottled Water, ILCR, HQ, Africa, UK.

INTRODUCTION

Drinking water is essential for many body functions, but it can also be an important source of essential elements, such as sodium (Na), potassium (K), magnesium (Mg), and calcium (Ca). It can also provide essential trace elements like zinc (Zn), copper (Cu), iron (Fe), cobalt (Co), selenium (Se), manganese (Mn), and nickel (Ni). However, contaminated drinking water may introduce toxic elements such as arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb). Both tap drinking water (TDW) and bottled drinking water (BDW) serve as primary sources of potable water. Accessing clean drinking water according to World Health Organization (WHO) guidelines (WHO, 2014) remains a challenge in many regions. Many developing countries in Africa, including Chad, Ethiopia, Rwanda, Sierra Leone, and the Central African Republic, have limited access to clean water. In contrast, developed countries such as the UK, USA, European countries, Australia, New Zealand, and parts of Asia generally have reliable access to clean water (World Population Review, 2024). Because of these disparities, many studies have focused on drinking water accessibility and safety. Most research investigates the elemental composition of drinking water and evaluates compliance with regulatory standards.

Mineral content of BDW and TDW was compared by Azoulay et al. (2001). Their study highlighted drinking water as a dietary source of essential elements, while also addressing the issue of excessive intake. Another study by Cidu et al. (2011) was conducted on TDW and BDW, investigating their elemental composition (As, B, Cd, Cr, Hg, Pb, Li, Rb, Sr, and U) and compatibility with WHO standards. Even though TDW was found to contain higher toxic elements compared to BDW, both types were shown to be compatible with the WHO guidelines. Their findings suggested that BDW does not offer outstanding quality over TDW, which was consistent with findings of another study (Kalachev et al., 2022). TDW showed lower mineralization levels than BDW as reported by Wysowska et al. (2022). A comparison of BDW to TDW was carried out by Chowdhury (2013) through the investigation of trace elements (Li, B, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn) and other physicochemical parameters. The author concluded that both types met regulatory standards, although TDW showed higher concentrations of heavy metals and fluoride. These facts influenced people’s preferences for different types of drinking water. In fact, BDW consumption has been rising, even in countries with excellent TDW sources (Doria, 2006). Preferences for BDW over TDW are linked to health concerns, risk perception, organoleptic properties, and dissatisfaction with tap water quality. However, a UK study found that most participants did not perceive significant health benefits from bottled water compared to tap water (Ward et al., 2009). Another study (Qian, 2018) associated water choices with safety, hygiene, convenience, and availability. Dinelli et al. (2012) compared the elemental composition of BDW and TDW, finding that BDW reflects groundwater hydrogeochemistry, while TDW comes from rivers, surface water, groundwater, and reservoirs. Some elements, such as Al, Cd, Cu, Fe, Ni, Pb, and Zn, were higher in TDW due to distribution system corrosion. Others, like Be, Cs, Sb, Sn, and Tl, were more common in BDW, with Sb leaching from Polyethylene Terephthalate (PET) containers and others resulting from water–rock interaction.

Bottled drinking water has been examined by numerous studies worldwide through the analysis of elemental content. For instance, Aris et al. (2013) investigated several BDW brands for the presence of Ca, K, Mg, Na, Cu, and Zn. Their research showed that treated packaged bottled drinking water exhibited changes in Total Dissolved Solids (TDS) and Electrical Conductivity (EC), indicating elements were removed during the water treatment process. Similarly, major

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and trace elements in mineral and spring-type BDW from Croatia were analysed by Peh et al. (2010), demonstrating that spring water is characterized by a Ca and Mg combination, while mineral water is distinguished by higher levels of Na and K. Notably, all analysed samples complied with Croatian, WHO, and EPA standards. In Saudi Arabia, Brima (2017) investigated 24 elements in BDW, treated water, and groundwater, finding that Fe and Co were less frequently detected in treated drinking water. Additionally, Smedley (2010) observed that BDW contained in PET bottles exhibited higher levels of Sb, whereas BDW in glass bottles had increased concentrations of Al, Ce, Cu, La, Nd, Mn, Sn, W, Zn, and Zr compared to plastic bottles, suggesting that variations in element content can arise from the type of container used. Transitioning to tap water studies, total dissolved solids have been comprehensively examined across multiple countries (Li et al., 2018; Banks et al., 2015; Hori et al., 2024; Rahmanian et al., 2015; Wątor et al., 2021). Most of these investigations agreed that variations in elements, such as Mn, Al, Cu, Pb, Cd, Fe, and Zn, are influenced by geological factors and plumbing systems. Moreover, both the age and composition of water fittings and pipes play a crucial role in heavy metal release.

The BDW and TWD have been widely studied worldwide. However, no study localized the elemental composition of both tap and bottled water in Leicester City, UK, and compared the results with drinking water in African countries. Therefore, the purposes of this study were to: (1) Measure the elemental composition of tap water and bottled drinking water samples on sale in Leicester City. (2) Compare concentrations with recent studies on drinking water from African countries (2020-2025) and with the WHO guideline values. (3) Assess potential health risks using HQ and ILCR calculated values. (4) Provide scientific evidence to inform consumers' choices and public health policies.

MATERIALS AND METHODS

Sample Collection

A total of 93 samples were collected: 45 bottled drinking water (BDW) samples from 25 brands available at Leicester City retailers and supermarkets, and 48 tap drinking water (TDW) samples from various public water points and household taps. Sampling took place between April and May 2024, with all samples stored in polypropylene centrifuge tubes prior to analysis.

Elemental Measurement by Using ICP-MS

In total, 26 elements were measured in all collected samples (n = 46) of 25 BDW brands and TDW from Leicester City, UK. Concentrations of four major elements (Na, K, Mg, and Ca) and 22 trace elements (Li, Be, B, Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Sr, Cd, Te, Ba, Hg, Tl, Pb, and Bi) were measured by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Agilent 7900 ICP-MS, in all samples. The samples were analysed in triplicate (n = 3). Operating conditions for the Agilent 7900 ICP-MS are as follows: Rf power 1550 W; Plasma Gas 15.02 L/min; Carrier Gas 1.03 L/min; Aux Gas 0.9 L/min; Nebulizer pump 0.1 rps; Integration time 0.1s; Sampling period 0.311s; Acquisition time 22.74s; Cell gas He; Sampling depth 8 mm.

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Chemicals, Reagents, and Analytical Method

A single stock solution was prepared from a mixture of 24 elements Al, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, K, Li, Mg, Mn, Na, Ni, Pb, Se, Sr, Te, Tl, and Zn using the ICP Multi-Element Standard Solution VIII (100 mg/L) from Merck KGaA (Darmstadt, Germany). Additionally, two separate stock solutions—arsenic (As) 1 mg/L (Sigma-Aldrich, Switzerland) and mercury (Hg) 1 g/L (Sigma-Aldrich, USA)—were included in the final stock solution.

Calibration standards for trace elements were prepared at concentrations of 5, 10, 20, 40, and 80 µg/L. Four major elements (Na, K, Mg, and Ca), calibration standards were prepared at 5, 10, 20, 40, and 80 mg/L from individual stock solutions of Ca, Na, and Mg (each at 10,000 µg/mL) and K (1,000 µg/mL). All major element stock solutions were from Thermo Scientific (Ward Hill, USA).

Additionally, a stock solution (1,000 mg/L) of scandium (Sc), rhodium (Rh), and germanium (Ge) was obtained from Sigma-Aldrich Chemie (Steinheim, Germany) for use as internal standards. Fresh calibration standards for analysis were prepared daily by diluting stock solutions in 1% HNO_3. Sc was used as an internal standard at a concentration of 100 µg/L, while Rh and Ge were used at 20 µg/L each.

Quality Control

The daily performance of the ICP-MS in terms of sensitivity and background signals was checked using the tuning solution (Li, Mg, Y, Ce, Tl, and Co) from Agilent. The tuning solution contained 1 µg/L for each element in 2% HNO3. Helium (He) gas was used, and detection limits (DLs) for all measured elements were calculated by Agilent's ICP-MS MassHunter 4.2 version C.01.02 Workstation Software.

Limit of Quantification (LOQ) was calculated with the following equation: LOQ = 3.33*DL. DLs and LOQs were as follows (µg/L): Al (0.15 and 0.50), As (0.07 and 0.23), B (0.27 and 0.90), Ba (0.25 and 0.83), Be (0.01 and 0.03), Bi (0.01 and 0.03), Cd (0.03 and 0.099), Co (0.01 and 0.03), Cr (0.03 and 0.10), Cu (0.38 and 1.27), Fe (0.37 and 1.23), Ga (0.002 and 0.01), Hg (0.08 and 0.27), Li (0.01 and 0.03), Mn (0.08 and 0.27), Ni (0.36 and 1.20), Pb (0.01 and 0.03), Se (0.23 and 0.76), Sr (0.25 and 0.83), Te (0.03 and 0.10),Tl (0.01 and 0.03), and Zn (0.7 and 2.33). The major elements were (mg/L) as follows: Na (0.01 and 0.03), K (0.01 and 0.03), Mg (0.01 and 0.03), and Ca (0.05 and 0.17).

Continuing calibration verification (CCV) was also used for a quality control (QC) test for each batch. It was performed by measuring 40 µg/L of a mixed standard of all measured trace elements, and 40 mg/L for major elements. The QCs were measured three times within each batch, after every 20 or 15 samples for trace and major elements, respectively. The QCs recoveries in one batch were as follows: Al (109.4%), As (97.5%), B (104.9%), Ba (97.1%), Be 103.7(%), Bi (100.4%), Cd (99.5%), Co (97.4%), Cr (98.8%), Cu (97%), Fe (102.1%), Ga (101.3%), Hg (109.2%), Li (102%), Mn (96.7%), Ni (95.4%), Pb (99.2%), Se (97.3%), Sr (94.7%), Te (91.7%), Tl (99.9%), and Zn (99.6%). The major elements were as follows: Na (100.7%), K (101%), Mg (99.7%), and Ca (103.6%).

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Quality Assurance (QA)

The accuracy of the measurement was determined by measuring groundwater certified material (ERM-CA616) from the Institute for Reference Materials and Measurements (IRMM) and European Reference Materials (ERM). The results of the measured major elements were similar to those of the ERM-CA616 groundwater (Table 1). Standard Reference Material (SRM)1643f from National Institute of Standards and Technology (NIST) was also used to determine the accuracy of the trace elements measurement. The values for certified (µg/L) and measured (µg/L) in the SRM1643f were presented in Table 1. Furthermore, spiked samples were used for QA. For the major and trace elements, 40 mg/L & 40µg/L of each element was spiked in a sample, and the recoveries were as shown in Table 1.

Statistical Analysis

A descriptive statistic and t-test were performed by using Excel. Significant differences ($p < 0.05$) were evaluated for the parameters (pH, EC, TDS) and the concentrations of all measured elements in all samples of the BDW and TDW.

RESULTS AND DISCUSSION

We have the parameters (pH, EC and TDS) and the concentrations of all measured elements (n =26) in all samples for both types (BDW and TDW). The concentrations (mg/L) of major elements (Na, K, Mg and Ca) and the concentrations (µg/L) of the trace elements (Li, Be, B, Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Sr, Cd, Te, Ba, Hg, Tl, Pb, and Bi) in all samples are presented Table 2 but Te, Be, Ga, and Tl were not detected in either type.

Table 2 shows that the averages of pH, TDS and EC were higher in TDW compared to BDW. The pH average values for both water types are within guideline values (WHO, 20222). The pH showed no significant differences ($p > 0.05$) between BDW and TDW samples. In contrast, TDS and EC values showed significant differences ($p < 0.05$) between BDW and TDW samples, where TDS and EC had higher values in TDW. Both TDS and EC are correlated and serve as quality parameters for drinking water. The difference between the two types of water samples was significant for both TDS and EC, with higher values reported for TDW. This may be because BDW samples underwent processes that lowered TDS and EC values. For example, it was recently reported that one company which sells bottled mineral water was investigated over claims that it used filtration methods to remove contaminants in its mineral water (Foodnavigator, 2025). In our study, both sample types have TDS and EC levels within the tolerance threshold suggested by WHO (2022), which states that consumers can tolerate water hardness above 500 mg/l. TDS represents the total concentration of inorganic and organic substances dissolved in water, including Ca and Mg, which contribute to hardness. Results for Na, K, Mg, and Ca in Table 2 showed no significant differences ($p > 0.05$) between BDW and TDW samples, though TDW samples had slightly higher concentrations. All measured samples had lower concentrations of major elements than the taste thresholds recommended by WHO (2022): 100–300 mg/l for calcium, a lower value for magnesium, sodium above 200 mg/l giving unacceptable taste, with the recommended daily intake for potassium exceeding 3000 mg.

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Although only four elements (Te, Be, Ga, and Tl) were not detected in both types of water, there were five elements (Co, Ni, Cu, Cd, and Pb) that were not detected in BDW samples, and three elements (Al, Cr, and Se) that were not detected in TDW. Li, Fe, Zn, As, Ba, showed significant differences ($p < 0.05$) between BDW and TDW samples, where Fe and Zn had higher concentrations in TDW than BDW samples, and Li and Ba and As had higher concentrations. In contrast, the concentrations of B, Mn, Sr, Hg, and Bi showed no significant differences ($p > 0.05$) between BDW and TDW samples. This could be due to the natural origin of these elements. The median of Li concentration (µg/L) was 4.5 and 4.2 in TDW and BDW, respectively, which is quite similar (Table 2). A study in Hungary (Dobosy, 2023) reported the mean and median Li concentrations to be 8.38 and 8.44 µg/L, and 52.9 and 17.9µg/L in tap water and mineral water, respectively. In their study, it stated that the sources of Li in drinking water are anthropogenic and geogenic. The historical use of Li and recent studies suggested that trace amounts of Li in drinking water might correlate with lower suicide rates and, in some cases, longer life spans. Vita, A. et al. (2015) stated that ‘‘higher lithium levels in drinking water may be associated with reduced risk of suicide.’’ However, the findings are inconsistent and potentially subject to publication bias, with some studies linking higher lithium in water to increased suicide rates (Love, 2024).

These five elements (Co, Ni, Cu, Cd, and Pb) were only detected in TDW samples (Table 2). Moreover, As and Hg were detected in both water types. This finding aligns with a study by Bradham et al. (2023), which investigated the concentrations of As, Cu, and Pb in household drinking water using samples from 678 homes in the U.S., focusing on public health implications. Their study reported that the presence of As, Cu, and Pb in drinking water was primarily due to plumbing materials, such as brass, and that levels were higher in private wells compared to public water supplies. Elevated As concentrations were predominantly associated with groundwater sources (private wells). These results are also consistent with another study by Dinelli et al. (2012) on TDW samples, which concluded that elements, such as Cd, Cu, Fe, Mn, Pb, Sn, and Zn, originated from plumbing systems.

The presence of Co in drinking water is attributed to natural and human activities (Atashi et al., 2009). Cobalt chloride and sulphate are classified as possibly carcinogenic to humans (Barceloux, 1999; WHO, 2006), although Co is a micronutrient. Co and other micronutrients such as Cr, Cu, and Zn have adverse effects on human health in case of excessive or deficiency levels (Louria et al., 1972; Hart & White, 2006).

Plumbing and distribution systems have a role in the presence of Cd in drinking water, which can leach from galvanized pipes and steel pipes. Additionally, industrial materials (alloy synthesis, batteries, TV screens, and pigments) are considered other sources of Cd (WHO, 1996; Brady & Gray, 2010). Cadmium is toxic and causes kidney dysfunction based on long-term exposure. Cd is considered carcinogenic in humans (WHO, 1996).

Our study shows the mean and median of As concentrations were 0.6 and 0.3 µg/L, and 0.2 and 0.2 µg/L in BDW and TDW, respectively; these were far lower than the WHO guideline value. Arsenic is a metalloid and is a toxic element prevalent in groundwater that has been linked to different types of diseases (Smith et al., 1992).

Table 2 shows Ba levels that are significantly ($p < 0.05$) different between BDW and TDW samples. The average concentration of Ba in BDW is more than 1.5 times that in TDW samples. However, both values were far less than the WHO guideline. Both anthropogenic and geogenic

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sources contribute to the presence of Ba in drinking water. The anthropogenic sources included using Barium compounds in industrial materials producing paints, bricks, glass, and rubber. Moreover, using $BaSO_4$ to create drilling muds to lubricate drill bits is considered another source of contamination (WHO, 2016). The geogenic source is due to the leaching and erosion of ore deposits leading to contamination of the groundwater.

In general, based on our results, there is a characteristic elemental profile of Co, Ni, Cu, Cd, and Pb for TDW and Li, Ba and As for BDW.

IMPLICATION FOR HUMAN HEALTH

Human Health Risk Assessment

All detected toxic elements (As, Cd, Cr, Hg, and Pb) in this study were lower than the WHO guideline. Average daily dose (ADD) and chronic daily intake (µg/L) will affirm the safety of the bottled and tap drinking water for a long lifetime. The following two equations (1, 2, and 3) were used to calculate ADD or CDI, HQ, and ILCR (USEPA, 1996; USEPA, 2011; USEPA, 2011a)

$$\text{ADD or CDI} = (C \times IR \times EF \times ED)/(BW \times AT) \quad (1)$$

where ADD average daily dose and CDI chronic daily intake are interchangeable terms with same units (mg/kg/day), C = individual element concentrations (mg/L), IR = the ingestion rate (L/day), EF = exposure frequency (days/year), ED = exposure duration (year), BW = the average body weight (kg/person), AT = the average time (ED x 365 in days). The following values were used for the abbreviations: IR = 2L, EF = 365 days/year, ED = 70 years, BW = 60 kg, and AT = (70 x 365) = 25,550 days (for cancer). For non-cancer values, ED = 30 years and AT = 30 x 365 = 10,950 days. The calculated values are presented in Table 3 for non-carcinogenic and carcinogenic elements; none of the results exceeded the guideline values of RfD for each element.

The hazard quotients (HQs) for each element were calculated by the following Equation (2). All HQs are presented in Table 3. None of the determined elements in both water types has HQ higher than > 1, which is considered non-toxic and may not cause adverse health effects.

$$HQ = ADD / RfD \quad (2)$$

where HQ is unitless and is a ratio between the ADD and the reference dose (RfD) of each element with the same units (mg/kg/day). Table 3 shows the Calculated ADD and HQ for BDW and TDW samples. The total hazard quotient (∑HQ) or Hazard index (HI) for all non-carcinogenic and carcinogenic elements in both water types was calculated as in the following Equation (2A).

$$\sum HQ = HQLi + HQB + HQAl + HQMn + HQFe + HQCo + HQNi + HQCu + HQZn + HQSe + HQSr + HQBa + HQHg + HQBi + HQAs + HQCd + HQCr + HQPb \quad (2A)$$

The values of the total hazard quotients (∑HQ) in both water types for all measured elements did not exceed 1. The ∑HQ for BDW and TDW were 2.7×10^{-1} and 1.7×10^{-1}, respectively. Therefore, both water types (BDW & TDW) are considered safe and potable.

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The following Equation (3) was used to calculate Incremental lifetime cancer risk (ILCR):

ILCR = ADD or CDI x CSF --------------------(3)

where ILCR is unitless: Incremental Lifetime Cancer Risk, CSF is cancer slope factor (mg/kg/day). The CSF are 1.5, 15, 0.5, and 0.0085 for As, Cd, Cr and Pb, respectively (USEPA, 2011; Mohammadi et al., 2019). The Hg does not have a CSF because it is not considered to cause cancer (Gnonsoro et al., 2022). The ILCR $\geq 1 \times 10^{-4}$ is a health threat; the permissible limits are 10^{-6} and $<10^{-4}$ (USEPA, 2002; Tepanosyan et al., 2017).

The ILCR in TDW for As, Cd, Cr and Pb are 8.6×10^{-6}, 4.3×10^{-5}, (not detected)??? and 7.3×10^{-8}, respectively. The ILCR in BDW for As, Cd, Cr and Pb are 2.6×10^{-5}, not detected, 4.3×10^{-6}, and not detected, respectively. All ILCR values of the As, Cd, Cr and Pb are lower than the permissible levels ($10^{-6} < ILCR < 10^{-4}$) in both water types (TDW and BDW). We conclude that the amount of these toxic elements in the measured samples in both types will not be a cause of cancer in a long lifetime. However, a comprehensive study is recommended for a larger number of samples from diverse sources.

Table 4 presents results from various studies in African countries, comparing the elemental composition of water samples analysed using ICP-MS. Drinking water contributes both essential and toxic elements to dietary intake. Therefore, understanding the elemental composition of drinking water from different sources and countries is important, especially when comparing developed and developing nations. Such comparisons help ensure the quality of drinking water in each country.

Figure 1 shows a comparison of the average concentrations (µg/L) for (Fig. 1a) toxic elements and (Fig. 1b) essential elements in tap water between the UK and Ghana. Ghana's results recorded the highest levels in both toxic and essential elements. However, the UK and Ghana tap water samples were within the WHO guidelines. The results of the elemental composition of drinking water from several African countries show that some elements exceed national and international guidelines (WHO, USEPA). At the same time, African drinking water contains higher concentration of some essential elements such as Zinc (see Fig 1b). Therefore, drinking water can contribute positively towards meeting the needs of such essential elements that are often deficient in African diets. However, considering that water intake is higher in hot climates, the presence of higher concentrations of toxic elements in drinking water from African countries is a concern, as most of these countries have hot and warm climates. Furthermore, our own research has shown that toxic elements, such as Pb and As, are present at high concentrations in African foods (Brima E.I. et al., 2025), and another study reported higher urinary concentrations of Pb and As in African populations, especially in Ghana (Jorgensen, J.A. et al., 2025). Therefore, the combined exposure to toxic elements in drinking water and foods could have health impacts for Africans that need to be addressed.

CONCLUSION

The UK TDW is characterised by five trace elements (Co, Ni, Cu, Cd, and Pb) that were not detected in BDW samples on sale in the UK. Both water types are considered potable as the measured parameters comply with WHO guidelines. HQ and ∑HQ were both less than 1; hence, it is safe drinking water for both types associated with the measured elements.

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Additionally, the incremental lifetime cancer risk (ILCR) for the detected toxic elements was below permissible limits. However, the presence of Pb in tap water could pose negative health impacts and more effort needs to be made to further reduce the concentration of this potent neurotoxic element. To further ensure public health safety, we recommend conducting elemental analysis on a larger number of BDW and TDW samples in the UK to mitigate any potential toxicity concerns. African drinking waters have higher concentrations of of some essential elements (such as Zinc) and toxic elements (such as Pb) compared to UK samples. The HQ and ILCR values that exceeded set guideline values for the toxic elements. This is a cause for concern as our own research has shown high concentration of Pb in African foods. The cumulative effect of exposure to Pb from drinking water and from foods could be harming the health of millions of Africans. We recommend further improvements to water treatment and distribution systems in African countries to reduce exposure to toxic elements such as Pb

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TABLES

Table 1: Results for the ICP-MS analysis of certified material (ERM-CA616) major elements in water and standard reference materials NIST SRM1643f trace elements in water, and recoveries (%) of spiked samples.

Element	Certified concentration (mean±SD)	Measured concentration (mean±SD)	Recoveries (%)
Groundwater certified material (**ERM-CA616**) from the Institute for Reference Materials and Measurements (IRMM) European Reference Materials (ERM)			**Spiked sample**
Na	27.9 ± 0.8	28.6 ± 0.49	104.6
K	5.79 ± 0.15	6.8 ± 0.03	99.4
Mg	10 ± 0.3	11.7 ± 0.16	97.6
Ca	42.6 ±1.4	42 ± 0.84	102.4
Standard Reference Material **(SRM)1643f** from National Institute of Standards and Technology (NIST)			**Spiked sample**
Al	32.5± 1.2	129.6± 41.8	104.7
As	54.90± 0.4	58.3± 0.3	104.6
B	150.8± 6.6	144.3± 1.3	108.5
Ba	513.1± 7.3	517.2± 0.03	101.3
Be	13.53± 0.1	13.2± 0.4	104
Bi	12.50± 0.1	14.7± 0.0	86.6
Cd	5.83± 0.1	5.9± 0.1	106.5
Co	25.05± 0.2	24.7± 0.5	95.4
Cr	18.32± 0.1	18.3± 0.4	99.9
Cu	21.44± 0.7	19.1±0.6	92.3
Fe	92.51± 0.8	92.7± 0.5	96.7
Li	16.42± 0.4	15.8± 0.2	101
Mn	36.77± 0.6	35.8± 0.1	97.8
Ni	9.2± 1.4	57.1± 0.3	95.1
Pb	18.3± 0.1	18.4± 0.2	104.4
Se	11.583± 0.1	11.0± 0.8	111.9
Sr	311± 18	308.1± 1.7	112.7
Te	0.97± 0.01	1.3± 0.2	118.5
Tl	6.8± 0.03;	6.9± 0.1	106.9
Zn	73.7± 1.7	67.9± 1.6	100.5
Ga	NA	NA	109.5
Hg	NA	NA	87.9

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Table 2: The means, median and ranges of parameters (pH, TDS and EC), trace elements (Li, Be, B, Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Sr, Cd, Te, Ba, Hg, Tl, Pb, and Bi), and major elements (Na, K, Mg, and Ca) in all samples of the BDW and TDW. Te, Be, Ga, and Tl were not detected in either type.

Element	**BDW (n = 45)**			**TDW (n = 48)**			**WHO** (2017)
	mean	median	range	mean	median	range	**Guideline values**
pH	7.7	7.8	6.4-8.2	7.8	7.8	7.4-8.6	6.5-8.5
TDS (mg/)	149.6	120	20-430	195.8	190	120-260	1000
EC (µS/cm)	308.2	240	50-860	399.2	390	260-520	-
Na (mg/L)	14.8	7.6	0.01-92.2	16.8	16.2	15.4-24.0	-
Mg(mg/L)	9.7	7.2	0.8-50.1	10.6	10.4	9.2-12.6	-
K(mg/L)	2.0	1.3	0.1-11.6	3.6	3.4	2.8-5.1	-
Ca (mg/L)	35.1	31	3.4-84.6	50.5	48.9	42.9-65.8	-
Li (µg/L)	9.3	4.2	0.1-105.3	4.8	4.5	1.4-10.3	-
B (µg/L)	39.4	10.8	1.8-587.1	30.5	29.7	20.2-44.3	500
Al (µg/L)	1.3	0.5	0.2-6.5	<DL	<DL	<DL	200
Cr (µg/L)	0.3	0.2	0.1-1.1	<DL	<DL	<DL	50
Mn (µg/L)	1.1	0.7	0.1-3.9	0.7	0.6	0.1-1.9	400
Fe (µg/L)	1.2	0.5	0.4-5.5	4.0	3.3	0.6-13.4	300
Co (µg/L)	<DL	<DL	<DL	0.1	0.1	0.1-0.6	-
Ni (µg/L)	<DL	<DL	<DL	2.2	0.2	1.2-6.3	70
Cu (µg/L)	<DL	<DL	<DL	23.9	14.5	1.0-128.9	2000
Zn (µg/L)	3.2	3.2	1.7-4.7	24.9	17.1	2.9-94.6	3000
As (µg/L)	0.6	0.3	0.1-2.9	0.2	0.2	0.1-0.3	10
Se (µg/L)	1.7	1.4	0.6-3.7	<DL	<DL	<DL	10
Sr (µg/L)	148.6	94.2	19.7-624.8	166.2	156.1	141.6-232.0	-
Cd (µg/L)	<DL	<DL	<DL	0.1	0.1	0.1-0.2	3
Ba (µg/L)	111.5	46.9	0.4-504.3	71.2	67.7	55.4-94.5	700
Hg (µg/L)	0.4	0.2	0.1-1.5	0.3	0.2	0.1-2.0	6
Pb (µg/L)	<DL	<DL	<DL	0.3	0.2	0.1-1.0	10
Bi (µg/L)	0.4	0.3	0.1-0.9	0.3	0.1	0.1-1.0	-

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Table 3: Calculated average daily dose (ADD) and hazard quotient (HQ) for bottled drinking water (BDW) samples and tap drinking water (TDW) samples.

Element		**BDW (n = 45)**			**TDW (n = 48)**		
	RfD[a] (mg/Kg/day)	**mean (mg/L)**	**ADD[b] (mg/Kg/day)**	**HQ[c]**	**mean (mg/L)**	**ADD[b] (mg/Kg/day)**	**HQ[c]**
Non-Carcinogenic							
Li	2.00E-03	9.30E-03	2.66E-04	1.33E-01	4.80E-03	1.37E-04	6.86E-02
B	2.00E-01	3.94E-02	1.13E-03	5.63E-03	3.05E-02	8.71E-04	4.36E-03
Al	1.43E-01	1.30E-03	3.71429E-05	2.60E-04	<DL	NA	NA
Mn	1.40E-01	1.10E-03	3.14286E-05	2.24E-04	7.00E-04	2.00E-05	1.43E-04
Fe	8.00E-01	1.20E-03	3.42857E-05	4.2857E-05	4.00E-03	1.14E-04	1.43E-04
Co	2.00E-02	<DL	NA	NA	1.00E-04	2.86E-06	1.43E-04
Ni	2.00E-02	<DL	NA	NA	2.20E-03	6.29E-05	3.14E-03
Cu	4.30E-02	<DL	NA	NA	2.39E-02	6.83E-04	1.59E-02
Zn	3.00E-01	3.20E-03	9.14286E-05	3.05E-04	2.49E-02	7.11E-04	2.37E-03
Se	5.00E-03	1.70E-03	4.85714E-05	9.71E-03	<DL	NA	NA
Sr	6.00E-01	1.49E-01	0.004245714	7.08E-03	1.66E-01	4.75E-03	7.91E-03
Ba	2.00E-01	1.12E-01	0.003185714	1.59E-02	7.12E-02	0.002034286	1.02E-02
Hg	3.00E-04	4.00E-04	1.14286E-05	3.81E-02	3.00E-04	8.57143E-06	2.86E-02
Bi	8.00E-02	4.00E-04	1.14286E-05	1.43E-04	3.00E-04	8.57143E-06	1.07E-04
Carcinogenic							
As	3.00E-04	6.00E-04	1.71429E-05	5.71E-02	2.00E-04	5.71429E-06	1.90E-02
Cd	1.00E-03	<DL	NA	NA	1.00E-04	2.85714E-06	2.86E-03
Cr	3.00E-03	3.00E-04	8.57143E-06	2.86E-03	<DL	NA	NA
Pb	3.60E-03	<DL	NA	NA	3.00E-04	8.57143E-06	2.38E-03

a: https://iris.epa.gov/AtoZ/; b: ADD = (C*IR*ED*EF)/ (BWx AT(ED x 365) = mg/Kg/day, non-carcinogenic: C = mg/L; IR = 2L; ED= 30 years; EF = 365 days; BW =70 Kg; AT = (365x30) = 10950days*years & carcinogenic: C = mg/L; IR = 2L; ED= 70 years; EF = 365 days; BW =70 Kg; AT = (365x70) = 25550days*years ;c: HQ = AAD/RfD.

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Table 4: Summary of some articles regarding the use of ICP-MS for element analysis in drinking water from various African countries between 2020 and 2025.

Water sample type	Measured elements	Key findings	Country	Reference
Bottled water and tap water	Li, B, Al, Mn, Fe, Co, Ni, Cu, Zn, Se, Sr, Ba, Hg, Bi, As, Cd, Cr, Pb, plus (Ca, Mg, Na, K)	All elements were within the WHO guidelines, and HQ, ∑HQ/HI, and ILCR values are within permissible levels.	UK	This study (2025)
Bottled water	Sr, Al, Ba, Mn, Cu, Cr, Zn, Fe, As, Co , U , Ni , Cs, Pb , Cd , Hg, plus (Ca, Mg, Na, K)	Only Al, and Mn in some samples exceeded guideline values. HQ, HI, and ILCR values are within permissible levels.	South Africa	John, S. O. et al., (2024)
Groundwater	As, B, Ba, Bi, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mn, Mg, Mo, Na, Ni, Pb, P, Sb, S, Se, Si, Sr, Ti, Tl, U, V, Zn	91.3% of sampling sites had HI / TLCR above safe thresholds; elevated risk for adults & children.	Ghana	Peasah, M. Y. et al., (2024)
Groundwater (GW) and surface water (SW)	Na, Mg, K, Ca, Si, Se, Fe, Mo, Sr, As, Co, Ni, Zn, Pb, Sb, Ag, Cd, Mn, Cu, Cr	Some samples contaminated with As, Cd, Cr, Co, Mo, Pb, and Se and had HRI>1	Nigeria	Ikpi, G.E., et.al., (2024)
Ground water	Cu, Co, Mn, Fe, S, Si, Ca, Mg, Al, and K	Concentrations of Cu, Mn, Fe, and Al exceed the WHO standards	DR Congo	Tshanga, M., et.al., (2025)
Tap water and bottled water	*Ca, Mg, Cu, Fe, Na	Only one tap water sample was found to contain Coliform bacteria. All tap water samples had iron concentrations above the WHO recommended limits	Uganda	Onyutha, C., et. Al., (2022)
River, groundwater, and tap water	As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn	44 % of the total concentration exceeding maximum permissible limits. HQ >1, HQ = 1823	Ethiopia	Asefa, E.M., et. Al., (2024)

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		and 762 for children and adults respectively. Higher risks associated with As and Pb in river drinking water.		
Surface and groundwater	Al, Si, Se, Fe, Cr, Co, and Cu	Al above the permissible limits set by the WHO, for surface and groundwater. HQ>1 for Al, Fe, and Se.	Cameroon & Central Africa	Ngwese, S. N., et. Al., (2025)
Tap water	Pb, Cd, Cr, Hg, Tl and Ni	Elements levels were below the standard limits set by WHO.	Kenya	Kinuthia, G.K., et al., (2020)
Surface water	Li, Rb, Cs, Be, Sr, Ba, Al, V, Cr, Mn, Co, Ni, Cu, Zn, Mo, Ag, Cd, Sn, Pb, Bi, As, Sb, U	High level of As exceeded the WHO (10µg/L).	Chad	Vicat, J.P., et. al., (2023)
Groundwater	£Cu, Zn, Pb, and Cd	In the wet season groundwater from some wells showed high levels of , Zn, Pb, and Cd, exceeding the WHO standards.	Liberia	Charles, J.F., et. Al., (2020)
Tap water	#Al and Fe	Mineral contents were compatible with WHO guidelines. However, Majority of the samples are non-compliant, containing fecal , and contamination germs.	Ivory Coast	Yapo, W.T., et. al., (2024)
Surface water & Ground water	$As, Cd, Hg, Pb	All measured concentrations (As, Cd, Hg, and Pb) were below WHO guidelines values. Only Hg was higher than Benin standards.	Benin	Kondo, K.F., at. Al., (2025)
Tap water and Groundwater	As, Cd, Hg, Pb, Cr, Cu, Mn, Ni, Se, Zn	Pb exceeded the WHO guidelines, in only 9% of the all samples. Geography and system didn't	Ghana, Niger, Mali	Fisher, M.B., et al., (2021)

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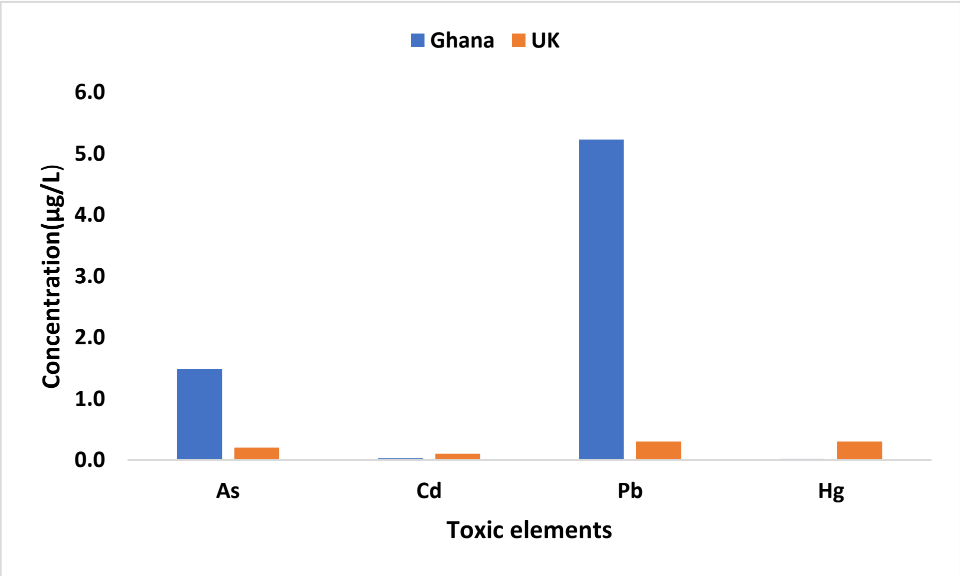
		affect the results significantly.		

ICP-MS was not used in analysis the following studies: *Atomic absorption spectrometer (AAS). #Spectrophotometer. $ICP-OES. £ Colorimeter.

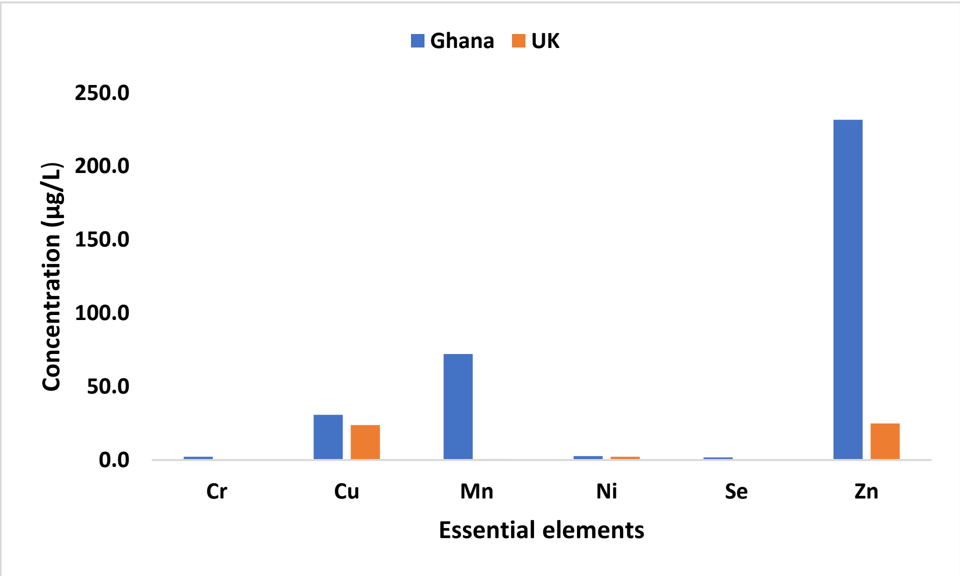
FIGURES

Figure 1: Comparison of the average concentrations (µg/L) for (a) toxic elements and (b) essential elements in tap water between the UK and Ghana.

(a)



(b)



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