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Heavy metals and essential elements in table salt extracted from Bahi wetlands in Central Tanzania

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Abstract

Salt from Bahi wetlands is allegedly containing high concentrations of heavy metals since the wetlands are in the proximity of the prospective uranium mining sites. This means Bahi salt could be an important route through which salt consumers are exposed to high concentrations of heavy metals. This study has analysed 50 salt samples of Bahi salt in order to determine the concentrations of both heavy metals and essential elements using the Energy Dispersive X-Ray Fluorescence Spectrometry (EDXRF). Analytical results show that apart from Na and Cl, Bahi salt is composed of several elements including heavy metals such as Cr, Cd, Pb, Th and U. The salt also contains essential elements such as Mg, K, Ca, Mn, Fe, Co, Zn and Br. The mean concentrations of Cr, Cd, Pb, Th and U ranged from 20 - 25µg/g, 3.8 – 8.85 µg/g, 2.29 – 5.8 µg/g, 6.22– 15.8 µg/g and 6.5 – 9.12 µg/g respectively. All these toxic elements were in higher concentrations than the recommended maximum tolerable limits (MTL). Meanwhile the daily intake rate of essential elements due consumption of Bahi salt leads to the hazard index (HI) greater than 1 for children. This implies that unless purified, Bahi salt may be unsafe for children. Thus, both salt producers and responsible authorities at Bahi wetlands should collaborate to introduce suitable production methods ensuring effective salt purification before it reaches its consumers.

Keywords: Bahi wetlands, EDXRF, Essential elements, Heavy metals, Hazard index, Health risk index

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1. Introduction

Heavy metals are widely present in the earth's crust, air, water and various man made products (Heshmati *et al.*, 2014). Human exposure to heavy metals may be through inhalation or dermal contact. Nevertheless, heavy metals contamination of food products makes the food chain and diet a major exposure path of heavy metals to human beings (Pourgheysari *et al.*, 2012). It follows that, despite the normality that food-borne diseases result from foods contaminated with microorganisms, it is also important to consider food toxicity due to the concentrations of heavy and toxic metals (Shariatifar *et al.*, 2017). Ingested heavy metals have a non□biodegradable and persistent nature, which enables them to accumulate in the vital organs of the human body such as kidneys, bones, and liver (Singh *et al.*, 2010). Since there is no good mechanism for heavy metals elimination from the human body, chronic intake of such metals even in minute amounts may lead to damaging effect on human beings and other animals (Islam 2007). Moreover, bioaccumulation of heavy metals in different organs and tissues may lead to a diversity of toxic effects on a variety of body tissues and organs. These metals disrupt cellular events such as growth, proliferation, differentiation, damage-repairing processes, and apoptosis (Balali-Mood et al., 2021). The most widely known dangerous heavy and toxic metals include lead (Pb), cadmium (Cd), mercury (Hg), and the metalloid arsenic (As). Apart from being toxic in nature, these metals are also known to be neurotoxic, carcinogenic, mutagenic, and teratogenic (Pourgheysari *et al*., 2012). Moreover, heavy metals are associated with gastrointestinal disorders, ataxia, paralysis and convulsion, depression as well as pneumonia (Singh *et al*., 2010). Yet, it is worthy to note that some heavy metals such as, copper and zinc are toxic only when ingested at high concentrations, otherwise, they are essential elements for normal body functioning (Mol, 2010).

Normally, human dietary exposure to heavy metals is thought to be caused by heavy metals contamination of staple foods such as rice, maize and so on (Cheraghali *et al.*, 2010). Nonetheless, contamination of food additives such as table salt, food colours and spices may also play an important role in exposing human being to toxic heavy metals. In fact, most producers and national regulators may overlook the possible contamination of food additives to an extent that the role of these products in exposing humans to heavy metals may easily be underestimated (Cheraghali *et al*., 2010). Consequently, food additives may become a major factor in human dietary exposure to heavy metals.

One of the common and important food additives is table salt, in the form of sodium chloride (NaCl). Although table salt is mainly used to enhance food flavour, it is also commonly used for food preservation. Besides, NaCl is widely used in other human activities, making it perhaps a substance that is used virtually by every human being in the world (Lugendo *et al.,* 2013). The average daily salt intake in most countries is approximately 6 g/day per capita (Ireland et al. 2010). However, the intake of salt in children older than five years is commonly more than 6 g/day (He and MacGregor 2010). This merely universal constant daily intake of salt makes table salt one of the food additives that should be rigorously censored to minimize its chances of exposing human beings to toxic heavy metals. Nevertheless, table salt contains several other metals, which are necessary for the human body functions. Cobalt (Co), copper (Cu), nickel, iron (Fe), manganese (Mn), zinc (Zn), molybdenum (Mo), and selenium (Se) are biologically vital elements for living organisms. These elements are referred as essential elements, yet, they may cause serious health complications if consumed above the safe ranges (Munir *et al.,* 2021). It is therefore equally important to assess the levels of essential elements in table salt as it is for the assessment of heavy metals in the salt.

In Tanzania, table salt comes from different regions including the coastal regions, the western region and the central region of the country. Some of the processed salt is imported from the neighbouring countries such as Kenya. Salt from the central zone is extracted from Bahi wetlands, which are found in Bahi district of Dodoma region and are well known for supporting several human activities including agriculture and salt production. The wetlands are found in the proximity of the prospective uranium deposits, which are also located in Bahi district. Bahi uranium deposits are surficial (Mbogoro and Mwakipasile 2010) meaning that water and soil around Bahi wetlands may have elevated concentrations of both heavy metals and radioactive elements. This suggestion is supported by the reports of radioactivity levels of ^{238}U, ^{232}Th, ^{40}K and their progenies such as ^{226}Ra and ^{228}Ra in soil from Bahi wetlands that are well above the normal background (Kimaro and Mohammed 2015). On the other hand, Mohammed and Haule in 2018, reported high concentrations of Lead (Pb) and Cadmium (Cd) in spinach grown at Bahi wetlands. The authors attributed their findings to the elevated concentrations of Pb and Cd in the soil and water around the Bahi wetlands.

High concentrations of heavy metals in soil and water at Bahi wetlands are alarming as salt from Bahi is extracted from the salty ground water around the wetlands. The elevated concentrations of heavy metals in Bahi soil and water means that, there is a definite chance that Bahi salt is also contaminated with various metals and possibly contains both heavy metals and essential elements at higher concentrations than the recommended concentrations. This assertion is supported by the fact that Bahi salt is extracted locally using traditional methods such as the use of iron pans for evaporation process. The use of local traditional methods implies that the removal of undesirable metals from the salt during the production stage can hardly be achieved. High concentrations of heavy metals in Bahi salt is a problem since the salt is consumed by a large population in Central Tanzania as well as in the neighbouring countries such as Rwanda and Burundi. This implies that Bahi salt could be a significant agent of heavy metals exposure to its consumers both in Tanzania and in the neighbouring countries. This problem calls for an indispensable task of assessing the levels of both heavy metals and essential elements in Bahi salt. Thus, the current work is the first study that is set to analyse the salt extracted from Bahi wetlands in order to determine the concentrations of both heavy metals and essential elements in the salt. It is hoped that, the findings of this work may assist the relevant authorities to improve the standards and regulations for salt production and consumption.

2. Materials and Methods

2.1 Study area

Bahi district lies between latitude 4ºand 8º South of equator and between longitude 34ºand 38º East as shown in Figure 1. The district is located about 56 km west of the Tanzania´s capital city of Dodoma. It is a semi-arid region with annual average rainfall ranging from 500 to 700 mm and mean monthly temperature of 22.6^{o} C (Swai *et al*., 2012). This area experiences a short rain season extending from December to March and a long dry season from mid-April to late November. Due to weather conditions in Bahi, salt extraction activities at Bahi are normally conducted from April to November. Areas in Bahi that are actively involved in salt production activities are Mpamatwa, Lamaiti, Kigwe and Ilindi wards. All these wards are indicated in Figure 1.

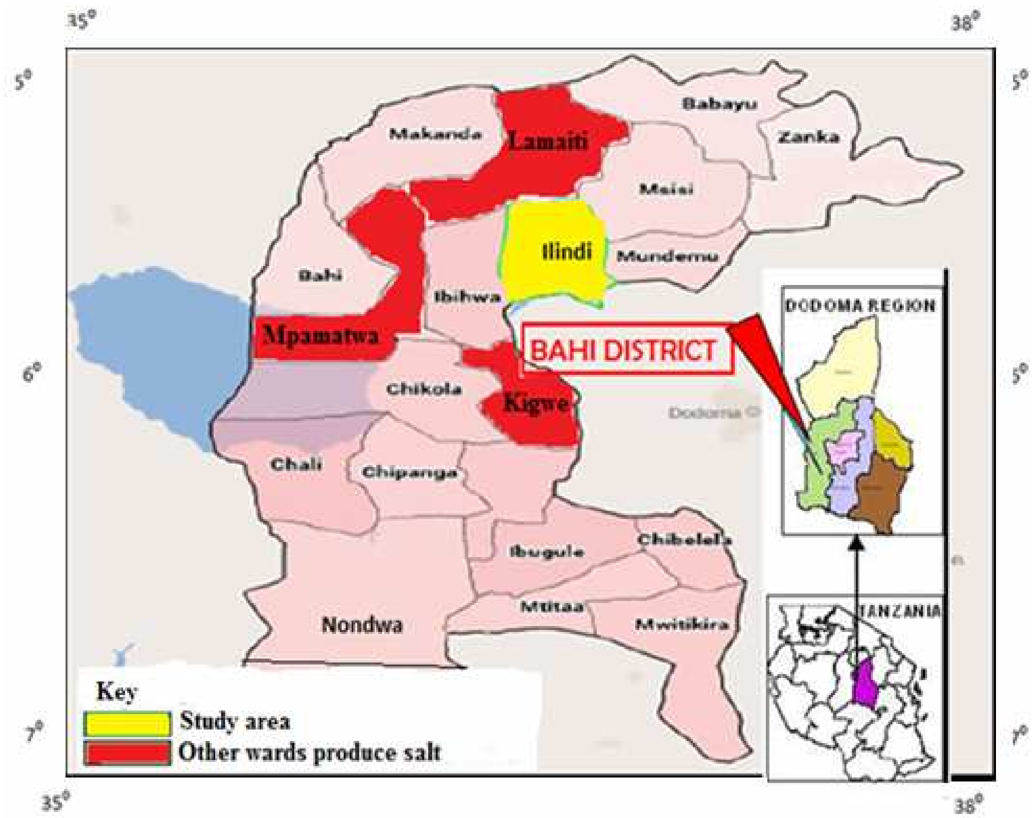

Figure 1: Map of Bahi district showing the study area of Ilindi ward (Bessell *et al*., 2018)

2.2 Sample collection

Among the four salt producing wards at Bahi district, Ilindi is the ward that is closest to the prospective uranium-mining site. In fact, uranium-mining activities had already begun at Ilindi before being halted by the Tanzanian government due to unsettled conflicts between the mining company and the Ilindi people. The closeness of Ilindi salt extraction sites to the uranium-mining site hints at the possibility that salt extracted at Ilindi may contain higher concentrations of heavy metal impurities as compared to salt produced at other wards. Therefore, this study looked to investigate salt samples from Ilindi salt extraction sites. At least 10 samples of freshly extracted salt were collected from each of the five salt extraction sites found in Ilindi. These sites were Mwalambano, Chibuga, Korongoni, Chikulo and Ilindi as displayed in Figure 2. The sites are respectively tagged as sites A, B, C, D and E. The collected samples were placed in separate pans and left to dry under the sun for 20 hours. After 20 hours, 0.5 kg of salt from each sample was carefully packed in clean clear plastic bags which were then sealed to avoid external contamination. Each plastic bag was labelled with a capital letter to indicate the site from which it was taken and a numerical subscript to indicate the sample number. For instance, samples from site A were labelled as A_1, A_2, A_3 … A_{10}. Then, the sealed and labelled sample bags were transported to the analytical laboratory at the Tanzania Atomic Energy Commission (TAEC) in Arusha for preparation and analysis.

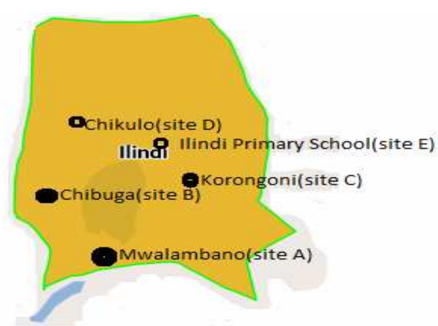

Figure 2: Sketch map of Ilindi ward showing salt extraction sites

2.3 Sample preparation

In the laboratory, all the salt samples left to dry overnight in an oven set at a temperature of 75° C. Upon removal from the oven, dried samples were left to cool in the desiccators for 2 hours according to the IAEA Technical Document (1997). To make the samples homogenous with the matrix similar to that of the reference materials, all dry salt samples were ground to fine salt powder using motor and pestle.

From each salt powder sample, three sub samples each of 4 g were measured using a digital balance. Each sub sample was mixed with 0.9 g of cellulose binder so as to improve the binding property of the salt powder. To make the mixture of salt powder and cellulose binder homogenous, the mixture of each sub sample and binder was put in a pulveriser along with four spherical steel balls each of radius 3 mm and then pulverised for 10 minutes at a speed of 180 revolutions per minute (rpm) (Croffie *et al.*, 2020). The homogenized mixture of each sub sample was then subject to a pressure of about 15 tonnes using a hydraulic pressing machine (Lugendo *et al.*, 2013). Pressing the sub sample mixtures led to the formation of pellets with intermediate thickness and outer diameter of 32 mm. Thus, three pellets from each salt sample were made. These pellets were placed in clean and labelled plastic containers, which were subsequently stored in the desiccators ready for EDXRF analysis.

2.4 Instruments

All samples were analysed using the Energy Dispersive X-Ray Fluorescence Spectroscopy (EDXRF). The EDXRF system used was a bench top Spectro-Xepos EDXRF with serial number 4R0138 manufactured by Spectro analytical instruments Boschstrasee 10 D-4753 Kleve. The machine uses a 0.003" beryllium window X-ray tube with ceramic envelope and copper body anode with palladium target having serial number 47885-5Y. In this system, x-rays spectra are collected using a Si (Li) detector with spectral resolution (FWHM) of Mn Kα ≤ 160 eV. This equipment has also an inbuilt Turbo quant (Tq 9232) algorithm for matrix effect correction. Meanwhile, the system has inbuilt analysis software that analyses the x-rays spectra and calculates the concentrations of each element present in the sample. At the end of each run, a file of all elements with their respective concentrations is saved in the control desktop computer in the excel format.

2.5 Sample and data analysis

The EDXRF machine used in this study can be loaded with six sample pellets at a time. During a single run, each pellet is analysed separately for about 15 minutes. Thus, a single machine run took a total of 90 minutes to analyse all loaded pellets. All measurements were done twice, making analysis time for six pellets to be 180 minutes. At the end of each run, the machine was left to cool for 30 minutes. The sample holders were then cleaned and new pellets were loaded ready for another round of analysis. Since three pellets were made from each sample and each pellet was analysed twice, we obtained six readings for each salt sample. This number of readings was deemed enough to ensure smooth statistical analyses of the obtained data. Data files were stored in a special folder created on the computer that is connected to the EDXRF machine. The obtained data were analysed using Microsoft Excel 2010 and Origin statistical tools. All data were expressed as mean ± standard deviation (SD) and comparisons as well as significance tests were done at 95% confidence level.

2.6 Quality assurance

The EDXRF system was calibrated weekly using spectro-turboquant algorithm which is a special tool embedded with the EDXRF system software. The calibration process was done for 25 minutes to ensure proper energy calibration for the multi-channel analyser. The accuracy and precision of both the EDXRF machine and the analytical tool were studied by making five rounds of measuring the Montana II (SRM2711a) standard reference material obtained from the International Atomic Energy Agency (IAEA). Analysis of accuracy and precision of the EDXRF system was performed by using 15 selected elements. The five measurements of each selected element along with the standard deviation values for each element are presented in Table 1. The relative standard deviations (RSD) from the five measurements ranged from 0.02 % to 21.08 %. This indicates a fairly good precision of the EDXRF system used in this study.

Table 1: Precision of the EDXRF system

SN	Element	Measurement					Average	Standard	RSD
		M_1	M_2	M_3	M_4	M_5	$(\overline{M})$	Deviation (δ)	(δ %)
1	Na	11095	11085	12996	11095	13996	12053.40	1363.55	11.31
2	Mg	11705	10715	10710	10715	11709	11110.80	544.26	4.90
3	Al	66009	66019	66010	67009	66019	66213.20	444.89	0.67
4	K	25301	25311	25300	25300	25311	25304.60	5.86	0.02
5	Ca	24209	24209	24219	24210	24209	24211.20	4.38	0.02
6	V	89	89	87	81	80	85.20	4.38	5.14
7	Cr	54	53	54	52	52	53.00	1.00	1.89
8	Mn	675	675	676	676	675	675.40	0.55	0.08

Table 1 (cont'd): Precision of the EDXRF system

SN	Element	Measurement					Average ($\overline{M}$)	Standard Deviation (δ)	RSD (δ %)
		M_1	M_2	M_3	M_4	M_5			
9	Fe	28205	28215	28212	28210	28200	2808.40	5.94	0.21
10	Co	10	9	10	9	9	9.40	0.55	5.83
11	As	106	107	106	106	105	106.00	0.71	0.67
12	Cd	61	56	55	55	56	56.60	2.51	4.43
13	Pb	1409	1405	1410	1412	1409	1409.00	2.55	0.18
14	Th	16	16	15	16	14	15.40	0.89	5.81
15	U	3	2	3	2	3	2.60	0.55	21.08

Meanwhile, the average concentration for each element was calculated from the five measurements of the standard sample. The obtained average was considered the concentration of that particular element in the standard sample. Then, the measured average concentration of each element was compared to the respective concentration given in the reference material data sheet. This comparison revealed the deviations between the measured concentrations and the presumed true concentration given in the reference data sheet. These deviations were found to range from 0.0002% to 6.312% indicating good accuracy of the system. The comparison between the standard reference values and the measured concentrations along with the respective percentage deviations are shown in Table 2.

Table 2: Comparison between the measured elemental concentrations in the standard reference material Montana II soil (SRM2711a) and the concentration given in the standard data sheet.

SN	Element	Concentration (μg/g)			
		Measured Concentration ($\overline{M}$)	Expected Concentration (E_v)	Deviation (Δ)	Percentage Deviation (Δ %)
1	Na	12003.42	12000.00	3.42	0.03
2	Mg	10701.80	10700.00	1.80	0.02
3	Al	67203.75	67200.00	3.75	0.01
4	K	25300.60	25300.00	0.60	0.002
5	Ca	24011.21	24010.00	1.21	0.01
6	V	80.30	80.70	-0.40	0.50
7	Cr	53.34	52.30	1.04	1.99
8	Mn	675.41	675.00	0.41	0.06
9	Fe	28200.40	28200.00	0.40	0.001
10	Co	9.82	10.00	-0.18	1.78
11	As	106.18	107.00	-0.82	0.77
12	Cd	56.70	54.10	2.60	4.81
13	Pb	1401.00	1400.00	1.00	0.07
14	Th	15.50	15.00	0.50	3.35
15	U	2.82	3.01	-0.19	6.31

3. Results and Discussion

The concentrations of elements in salt samples from different selected salt extraction sites at Bahi wetlands are presented in Table 3. Apart from Na and Cl, which are the main constituents of table salt, Bahi salt was found to consist of several other elements, which can be grouped as heavy metals, essential and non-essential elements.

Table 3: Mean concentrations of elements in salt samples from different salt extraction sites at Bahi wetlands [Mean (μg/g) ± RSD (%), n = 6].

SN	Element	Mean Concentration (μg/g)				
		Site A	Site B	Site C	Site D	Site E
1	Na	369601.00 ± 0.03	388040.00 ± 0.03	372038.00 ± 0.03	155984.00 ± 0.03	363872.00 ± 0.03
2	Mg	90490.00 ± 0.03	91540.00 ± 0.03	93342.00 ± 0.03	106369.00 ± 0.03	99735.00 ± 0.03

Table 3 (cont'd): Mean concentrations of elements in salt samples from different salt extraction sites at Bahi wetlands [Mean (µg/g) ± RSD (%), n = 6].

SN	Element	Mean Concentration (µg/g)				
		Site A	Site B	Site C	Site D	Site E
3	Al	4441.00 ± 0.03	4571.00 ± 0.03	4575.00 ± 0.03	5032.00 ± 0.03	6484.00 ± 0.03
4	Cl	367494.00 ± 0.03	365977.00 ± 0.03	365238.00 ± 0.03	210606.00 ± 0.03	347525.00 ± 0.03
5	K	804.000 ± 0.003	833.000 ± 0.003	1122.00 ± 0.03	3689.00 ± 0.03	3809.00 ± 0.03
6	Ca	4443.00 ± 0.03	4381.00 ± 0.03	4974.00 ± 0.03	5454.00 ± 0.03	5190.00 ± 0.03
7	V	1142.00 ± 0.03	1123.00 ± 0.03	1118.00 ± 0.03	258.00 ± 0.03	668.00 ± 0.03
8	Cr	20.00 ± 0.03	20.18 ± 0.02	21.08 ± 0.02	24.63 ± 0.02	25.77 ± 0.02
9	Mn	45.00 ± 0.02	44.62 ± 0.02	43.63 ± 0.03	85.60 ± 0.03	29.13 ± 0.03
10	Fe	57.21 ± 0.02	57.51 ± 0.02	57.38 ± 0.02	709.50 ± 0.03	592.52 ± 0.03
11	Co	7.52 ± 0.03	7.57 ± 0.03	7.29 ± 0.03	7.33 ± 0.03	7.50 ± 0.03
12	Zn	3.60 ± 0.03	3.11 ± 0.03	7.85 ± 0.03	3.61 ± 0.03	3.60 ± 0.03
13	Br	928.00 ± 0.03	937.03 ± 0.03	956.95 ± 0.03	976.63 ± 0.03	1025.00 ± 0.03
14	Cd	7.50 ± 0.03	8.85 ± 0.02	7.74 ± 0.03	3.81 ± 0.03	6.02 ± 0.03
15	Pb	5.80 ± 0.03	5.79 ± 0.03	5.69 ± 0.04	2.29 ± 0.04	4.95 ± 0.02
16	Th	15.69 ± 0.03	15.80 ± 0.03	15.81 ± 0.03	6.22 ± 0.02	12.85 ± 0.02
17	U	8.31 ± 0.02	8.17 ± 0.02	8.50 ± 0.02	6.50 ± 0.02	9.12 ± 0.02

3.1 Heavy metals in Bahi salt

Metals such as lead (Pb), cadmium (Cd), mercury (Hg) and arsenic (As) and other similar metals are identified as heavy metals and are known to play toxic roles in the biochemical reactions of the body. Hence, these metals are also known as toxic metals (Maia *et al*., 2006; Saeed *et al*., 2007). When ingested, toxic metals combine with the body's bio-molecules, such as proteins and enzymes to form stable bio-toxic compounds, thereby mutilating their structures and hindering them from the bio-reactions of their functions (Holum, 1983). Although toxicity and the resulting health threat of any contaminant are, of course, a function of concentration, it is well-known that chronic exposure to heavy metals and metalloids at relatively low levels can also cause adverse effects (Castro-González and Méndez-Armenta, 2008). This makes the information about exposures, intakes and absorption of heavy metals by humans one of the major world health concerns. Therefore, several international organizations have set Maximum Tolerable Limits (MTLs) of heavy metals in foodstuffs including salt. This study observed that Bahi salt contains Cr, Cd, Pb, Th, U and Cr with concentrations ranging from 20 – 25 µg/g, 3.8 – 8.85 µg/g, 2.29 – 5.8 µg/g, 6.22 – 15.8 µg/g and 6.5 – 9.12 µg/g respectively. All these concentrations are significantly higher than the MTLs of 5 µg/g, 0.5 µg/g, 2 µg/g, 0.005 µg/g and 0.005 µg/g for Cr, Cd, Pb, Th and U respectively as opined by several international organizations (ATSDR 2003, 2004, 2007, 2008, Codex 2015). Comparisons of the heavy metals concentrations in Bahi salt from different sites of extraction as well as comparisons with the respective MTLs are shown in Table 4.

Table 4: Comparison of concentrations of heavy metals in Bahi salt with MTLs set by different International Organizations.

SN	Element	Mean Concentration (µg/g)					MTL (µg/g)
		Site A	Site B	Site C	Site D	Site E	
1	Cr	20.00 ± 0.03	20.18 ± 0.02	21.08 ± 0.02	24.63 ± 0.02	25.77 ± 0.02	5.00
2	Cd	7.50 ± 0.03	8.85 ± 0.02	7.74 ± 0.03	3.81 ± 0.03	6.02 ± 0.03	0.50
3	Pb	5.80 ± 0.03	5.79 ± 0.03	5.69 ± 0.04	2.29 ± 0.04	4.95 ± 0.02	2.00
4	Th	15.69 ± 0.03	15.80 ± 0.03	15.81 ± 0.03	6.22 ± 0.02	12.85 ± 0.02	0.005
5	U	8.31 ± 0.02	8.17 ± 0.02	8.50 ± 0.02	6.50 ± 0.02	9.12 ± 0.02	0.005

The concentrations of heavy metals in salt samples from all extraction sites are merely similar. However, the salt from site D was observed to have the lowest concentrations of all metals when compared to other sites. This observation may be attributed to the geographical location of site D since it is farthest from the uranium mining sites. On the other hand, all toxic heavy metals present in Bahi salt from all extraction sites have concentrations higher than their recommended MTLs. While the concentrations of Cr in salt samples from all sites were 4 to 8 times higher than the MTL, the concentrations of Cd were 6 to 16 times higher than the recommended MTL. Furthermore, the concentrations of Pb were 1 to 3 times higher than the MTL while Th had its concentrations 12000 to 30000 times higher than its respective MTL. Meanwhile, the concentrations of Uranium were found to be 12000 to 18000 times higher than the recommended MTL.

Overall, the concentrations of heavy metals in Bahi salt were observed to be above the recommended permissible limits. Because of its higher concentrations of heavy metals, consumption of Bahi salt may lead to several adverse effects. For instance, Cr is reported to increase the risk of kidney or liver damage, allergic reactions, irregular heartbeats and headaches (Duruibe *et al.*, 2007, Shahid *et al.*, 2017). On the other hand, Pb may lead to brain and kidney damage, muscular weakness, hypertension and arthritis. It also causes mental retardation and birth defects especially to vulnerable populations such as children and pregnant women (Jaishankar *et al.*, 2014). Furthermore, high concentrations of Arsenic (As) can cause skin cancers and various skin problems, suppress the erythrocyte and leucocyte production and hypertension. Moreover, Cd can lead to kidney and skeletal damage, reduced haemoglobin and haematocrit concentration as well as stomach irritation (Jarup, 2003). Meanwhile, apart from being the major sources of natural radioactivity, U and Th can accumulate in the body leading to renal and respiratory problems, effects in the nervous system and cancer (Keith *et al.*, 2015).

These findings suggest not only the poor quality of Bahi salt for iodine fortification but also the possibility of several health complications that may arise from the consumption of unrefined Bahi salt. The poor quality of Bahi salt can be affirmed by comparing its composition with other salts reported in literature. While Table 5 shows the comparison of Bahi salt with other salts, a detailed assessment of health risks associated with consumption of unrefined Bahi salt is done in the proceeding section. The reported concentrations of Ca and K in salts from Pemba and Lake Gendabi were almost 4 times lower than the concentrations found in Bahi salt. Meanwhile, Mg, Al, V, Mn, Co, Br, Sr and Y, which have been found to have high concentration in Bahi salt, were not reported in all other places. The concentrations of Pb and Cd in Bahi salt are higher compared to those reported in all literatures reviewed in this study. On the other hand, the concentrations of U and Th have been reported by only two literatures, yet, the both elements are in higher concentration in Bahi salt. Generally, Bahi salt is observed to have elements that are more non-essential and toxic heavy metals indicating its poor quality.

Table 5: Comparison of Bahi salt with other salts reported in literature

Elements	**Concentrations (μg/g)**								
	Different Bahi sites					**Literature**			
	A	**B**	**C**	**D**	**E**	**Pemba**	**Gendabi**	**Nigeria**	**Thailand**
Al	4441	4571	4575	5032	6484	-	-	-	-
Ca	4443	4381	4974	5454	5190	1731	1101	-	-
K	804	833	1122	3689	3809	8274	4185	-	-
Mg	90490	91540	93342	106369	99735	-	-	-	-
Mn	45	44	43	85	29	-	-	-	-
Fe	57	57	57	709	592	130	351	0.1	0.1
V	1142	1123	1118	258	668	-	-	-	-
Zn	3.60	3.10	7.85	3.61	3.59	2.24	2.02	2.13	0.2
Br	928	937	956	976	1025	-	-	-	-
Pb	5.790	5.78	5.68	2.29	4.94	3.15	2.45	ND	2.00
Co	7.550	7.56	7.28	7.35	7.49	-	-	-	-
Cd	7	8	7	3	6	11	4	0.10	4.50
I	BDL	BDL	BDL	BDL	BDL	177	12	-	-
Sr	142.00	140.00	146.0	196.00	150.0	-	-	-	-
Y	10.82	10.92	10.11	10.09	10.00	-	-	-	-
Cr	20.59	20.16	21.08	21.62	24.76	54.0	29	-	-
Th	15.68	15.78	15.79	6.21	12.85	5.09	3.03	-	-
U	8.31	8.16	8.50	6.49	9.11	4.47	4.10	-	-

3.2 Health risks associated with heavy metals in Bahi salt

The intake of heavy metals through the food chain including additives such as salt has been widely discussed by various researchers. Therefore, this study deemed necessary to evaluate the health risks associated with the dietary exposure to heavy metals due to consumption of Bahi salt. The health risks were studied by estimating the Hazard Index (HI) and the Health Risk Index (HRI) of heavy metals present in the Bahi salt using Equations 1 and 2 respectively. The calculation of HIR depends on the heavy metal concentration (HC), the salt ingestion rate (IR), the exposure frequency (EF), the exposure duration (ED), the body weight (BW), the oral reference dose (RfD) and the average time (AT).

$$HRI = \frac{HC \times IR \times EF \times ED}{BW \times AT \times RfD} \quad (1)$$

$$HI = HRI_{Cr} + HRI_{Pb} + HRI_{Cd} \quad (2)$$

For this evaluation, HC is the element's concentration obtained from the EDXRF analysis of Bahi salt samples. The IR was taken to be 5750 mg/day while the RfD was taken to be 0.009, 0.0035 and 0.005 mg/kg/day for Cr, Pb, and Cd, respectively (USEPA IRIS 2013). The RfD for Th and U was considered to be 0.003 mg/kg/day. On the other hand, EF, ED, and AT were 365 days/year, 30 years and 365 × 70 days respectively. The BW was taken to be 70 kg for adults and 16 kg for children (USEPA IRIS 2013). While HRI projects the health risks of individual heavy metals, HI expresses the collective risk associated with all heavy metals present in the salt. Both HRI and HI due to consumption of Bahi salt for adults and children are presented in Table 6.

Table 6: Health Risk Index (HRI) and Hazard index (HI) due to consumption of Bahi salt

Population	Site	HRI					HI
		Cr	Cd	Pb	Th	U	
Adults	**A**	0.080	0.052	0.057	0.184	0.09	0.463
	B	0.079	0.062	0.057	0.185	0.09	0.474
	C	0.082	0.054	0.057	0.186	0.09	0.469
	D	0.155	0.026	0.029	0.073	0.076	0.359
	E	0.166	0.042	0.049	0.151	0.107	0.515
Children	**A**	0.355	0.240	0.257	0.806	0.427	2.085
	B	0.344	0.280	0.257	0.811	0..419	2.111
	C	0.355	0.240	0.251	0.812	0.436	2.100
	D	0.655	0.120	0.114	0.319	0.334	1.542
	E	0.711	0.180	0.228	0.659	0.468	2.246

An element is considered detrimental to human health if its respective HRI is greater than 1 (USEPA 2002). From Table 6, no element has HRI >1 for both adults and children. This indicates that despite their high concentrations, individually, heavy metals in Bahi salt pose no significant health risk to its consumers. Nevertheless, salt from all study sites were observed to have HI >1for children. Since in this case HI is greater than 1, it is asserted that the collective concentration of heavy metals in Bahi salt is significantly detrimental to children who consume the salt. Therefore, despite having concentrations of heavy metals above the lowest permissible limits, Bahi salt is deemed safe when consumed by adults. Nonetheless, Bahi salt may not be safe for consumption by children as its collective concentrations of heavy metals may lead to several adverse health effects to children.

3.3 Essential elements in Bahi salt

Apart from heavy metals, results presented in Table 3 reveal that Bahi salt also contains several other elements including essential elements at various concentrations. Such elements include Na, Mg, Cl, K, Ca, Mn, Fe, Co, Zn, and Br. Although normal functioning of the human being requires minute quantities of essential elements, yet, these elements may become toxic if consumed in excess concentrations. It is thus important to assess the contribution of Bahi salt to the intake of essential elements by its consumers. Meanwhile, Vanadium (V) is not known to be essential to human being yet, it is said to be toxic for high daily intakes leading to the necessity of assessing its daily intake. Assessment of the contribution of Bahi salt to the intake of essential elements was accomplished by calculating the daily intake rate (DIR) of essential elements due to the consumption of Bahi salt using Equation 3.

$$DIR\ (\text{mg/day}) = C_i \times D_{si} \quad (3)$$

where,

C_i = Concentration of an element

D_{si} = Daily salt intake

The daily salt intake (Dsi) was considered 5750 mg/day for adults as proposed by USDA and USDHHS (2010). The obtained DIRs were then compared to the recommended upper limits (UL) which are defined as the measure of the amount of a specific substance in foodstuffs that can be ingested on daily basis over a lifetime without appreciable health risk. Table 7 shows the calculated DIRs for different essential elements in Bahi salt along with their respective recommended upper limits.

Table 7: The daily intake rate (DIR) of essential elements via consumption of Bahi salt from different extraction sites with their respective upper limits (UL).

Element	DIR (mg/day)						Reference
	Site A	Site B	Site C	Site D	Site E	UL	
Na	2125	2231	2139	896	2092	2300	EFSA (2019)
Mg	520	526	537	612	573	350	EFSA (2015)
Al	25.50	26.28	26.31	28.93	37.28	10	EFSA (2008)
Cl	2113	2104	2100	1210	1998	NAD	EFSA (2019)
K	5	5	6	21	21	3700	EFSA (2006)
Ca	25	25	28	31	29	2500	EFSA (2006)
V	6.56	6.46	6.43	1.48	3.84	4.5	EFSA (2011)
Mn	0.260	0.256	0.250	0.492	0.167	10	USEPA (2003
Fe	0.330	0.330	0.329	4.080	3.406	18	WHO (1996)
Co	0.04	0.04	0.04	0.04	0.04	NAD	EFSA (2019)
Zn	0.020	0.017	0.045	0.031	0.020	15	WHO (1996)
Br	5.34	5.39	5.50	5.62	5.89	NAD	McCall et al. (2014)

*NAD = No Adequate Data

Table 7 reveals that, apart from Mg, Al and V, the DIRs of essential elements due to consumption of Bahi salt are well below the recommended ULs. Elements such as Cl, Co and Br have no ULs since there are no adequate data (NAD) for deriving the ULs. The ranges of the contribution to the daily intake of essential elements due to the consumption of Bahi salt only were 36.5 – 97%, 0.13 - 0.57%, 1 – 1.24%, 1.67 - 4.92%, 1.83 – 22.6% and 0.11 – 0.3% for Na, K, Ca, Mn, Fe and Zn respectively. It was also observed that, the contribution of Bahi salt to the DIR of Mg is 1.4 to 1.7 times higher than the recommended UL of 350 mg/day. On the other hand, the salt's contribution to the DIR of Al is 2.5 to 3.7 times higher than the UL of 10 mg/day while for the contribution to the DIR of V is approximately 1.4 times higher than the UL of 4.5 mg/day. High concentration of Mg in food is mostly associated with mild diarrhoea and rarely causes hypotension or muscular weakness (EFSA 2006). Nevertheless, the kidney has a mechanism of eliminating excess Magnesium in the body through urine so that magnesium toxicity has a limited effect on the human body (Musso 2009). Hence, the observed higher DIR of Mg due to consumption of Bahi salt is not a serious concern. Studies in humans have shown that ingestion of high concentrations of Vanadium may cause gastrointestinal disturbances. Besides, animal studies show that Vanadium can affect kidneys and disturb the reproduction system (EFSA 2006). Meanwhile, high concentration of Al in the diet has been linked with neurological disorders including the Alzheimer disease (Shaw and Marler 2013). Although the kidneys removes most of the dietary Al, children and adults with kidney problems are in a greater risk of being affected by dietary Al (Shaw and Marler 2013). Thus, the higher DIR of Al due to consumption of Bahi salt is alarming and measures to reduce the amount of Al in this salt are necessary.

4. Conclusion

This is the first study to reveal that Bahi salt contains several heavy metals as well as essential elements. The concentrations of all heavy metals are higher than the recommended tolerable values set by international organizations. Comparison studies have shown that the salt extracted from Chikulo (Site D) has the lowest concentrations of all elements. Furthermore, the study of health index (HI) revealed that HI is less than 1 for adults and greater than 1 for children. This implies that Bahi salt may not be problematic to adults but to children. It is also worthy to note that, the daily salt intake for children is greater than the intake rate for adults. This puts children at a greater risk of facing health issues associated with heavy metals in salt. Thus, both salt producers and the responsible authorities are urged to employ suitable production methods that will ensure salt purifications before it reaches its consumers.

Meanwhile, the daily intake of essential elements due to consumption of Bahi salt only was found to range from 0.13 to 22.6% of the upper tolerable limits for several elements. Moreover, the consumption of Bahi salt result to the intake of Mg above its recommended upper limit. Besides, the DIRs of elements such as Al and V due to the consumption of Bahi salt are also higher than the maximum limits. Although the DIRs of other elements present in Bahi salt may be below the upper limits, the overall dietary intake of these metals may exceed the tolerable limits. Thus, it follows that, there is a need of assessing the food basket consumed by Tanzanian people especially those in the proximity of Bahi district.

Apart from the direct health hazards of high concentrations of both heavy metals and essential elements in table salts, these elements may influence the table salt iodization exercise. It is therefore recommended that further studies should be conducted to assess the ability of Bahi salt to retain iodine concentrations after iodine fortification. Furthermore, Bahi wetlands are in the proximity of the prospective uranium deposits suggesting that Bahi salt may have elevated concentrations of radioactive elements as well. This hypothesis is affirmed by the fact that high activity concentrations of ^{238}U, ^{232}Th, ^{40}K and their progenies such as

^{226}Ra and ^{228}Ra have been reported in soil from Bahi wetlands (Kimaro and Mohammed 2015). Since this study is limited to heavy and essential elements only, the authors recommend that, a comprehensive work should be done to assess the radioactivity levels in Bahi salt.

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