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Research article

Health risk assessment of some selected heavy metals in infant food sold in Wa, Ghana

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ABSTRACT

Infants remain a high-risk group as far as exposure to toxic metals is concerned. The levels of lead (Pb), cadmium (Cd), nickel (Ni), chromium (Cr), antimony (Sb), mercury (Hg), and arsenic (As) in twenty-two (22) samples of baby foods and formulas were determined using inductively coupled plasma mass spectrometry. The concentrations in (mg/kg) of As, Cd, Cr, Hg, Mn, Ni, Pb, and Sb were in the ranges 0.006–0.057, 0.043–0.064, 0.113–0.33, 0.000–0.002, 1.720–3.568, 0.065–0.183, 0.061–0.368 and 0.017–0.1 respectively. Health risk assessment indices like the Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Cancer Risk (CR) and Hazard Index (HI) were calculated. EDI values of Hg, Cr, and As were below their recommended tolerable daily intake, that of Ni and Mn were lower in 95% of samples, and Cd was also lower in 50% of the samples. THQ values for As, Cd, Cr, Hg, Mn, Ni, and Pb were 0.32–3.21, 0.75–1.10, 0.65–1.94, 0.00–0.37, 0.21–0.44, 0.08–0.12 and 0.26–1.13 respectively. The CR values were greater than 10^{-6}, making them unacceptable for human consumption. HI values were between 2.68 and 6.83 (greater than 1), which implied that these metals are likely to pose non-carcinogenic health risks to infants.

1. Introduction

Food safety is a vital area for discussion and has been amplified after global scandals, such as China's melamine-contaminated baby milk saga and Mead Johnson and Company having to recall a batch of their infant formula milk due to contamination with metal particles [1]. A report by Ref. [2] indicated that some leading baby foods in the United States were tainted with dangerous levels of arsenic, lead, cadmium, and mercury.

Breast milk provides all the nutrients a baby requires and also fulfils the emotional and psychological needs of both mother and child [3]. However, in some cases such as social reasons, death or absence of the mother from the infant, medical contraindications, or pharmacological treatments that cannot be replaced or withdrawn that pose a risk to the infant breastfeeder; other safe and nutritious alternatives than breastfeeding can be considered [4]. Infant formula (food for infants that simulates human milk and is suitable as a complete or partial substitute for human milk) [5] and baby foods (any soft, easily consumed food that is made especially for babies from birth to twelve (12) months) are such safe alternatives [6].

The chemical, microbiological, and toxicological safety of infant formulas are therefore critical to protect the newborn's health.

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Careful assessment and precise criteria to ensure the highest quality of these baby foods and formulas are critical [7,8]. Scientific research has established the presence of heavy metals such as lead (Pb), mercury (Hg), nickel (Ni), arsenic (As), cadmium (Cd), iron (Fe), zinc (Zn), and chromium (Cr) in infant foods in varying concentrations [9,10]. Unregulated food storage, transportation, and manufacturing processes are all probable causes of the contamination of infant foods by these heavy metals [11]. Water and milk that are used to reconstitute infant formula can also be sources of contamination.

Ingestion of these metals which can constitute important essential micronutrients may cause serious carcinogenic and non-carcinogenic health risks when consumed above their acceptable threshold limits. Exposure to even little amounts of toxic metals such as lead and cadmium at an early age may lead to a low intelligent quotient, behavioural problems, bladder, lung, and skin cancers, cognitive and reproductive problems [12–14]. Studies have indicated that long-term exposure to As can cause damage to a baby's developing brain even at low levels, reduce memory performance, cause stunted growth and breathing problems, and finally cancer as an adult [15–17]. Ingestion of cadmium in children can cause both long and short-term cognitive deficits [18]. Unprocessed raw materials for baby foods or infant formulas that have been exposed to contaminated soils can efficiently absorb and accumulate cadmium. Mercury (Hg) exposure has neurotoxic effects in infants and young children due to the negative effects of methylmercury. Short-term exposure to mercury can increase the risk of cardiovascular disease and weaken the immune system [19]. Lead exposure in infants increases the likelihood of behavioural problems, memory loss, and lower intelligence performance, while prolonged exposure at high levels can cause anaemia, damage to the immune systems, kidneys, and reproductive systems, and eventually death [20]. Exposure to antimony (Sb) has been known to cause severe headaches, diarrhoea, stomach ulcers, severe vomiting, nausea, loss of sleep, and dizziness [21]. Antimony contamination may be due to its uses as an additive and initiator in the manufacture of polyethylene terephthalate and other polymers. Nickel, in small quantities, is an essential element; however, nickel has several adverse health effects when taken in large quantities. Manganese is essential for human life at low concentrations. Excess exposure to this element causes a type of neurodegenerative disorder commonly known as manganism, impaired memory function, and poor academic skills [22,23].

In the interest of public health, various regulatory bodies like the Joint FAO/WHO Expert Committee on Food Additives (JECFA), and the European Food Safety Authority (EFSA) have set maximum limits for some of these contaminants. There is therefore an imperative need to assess the safety of baby foods on the Ghanaian market due to the extensive proliferation of local and international baby food brands. This study was therefore initiated to determine the levels of Pb, Hg, Cd, As, Mn, Cr and Ni and assess their potential health risks (if any) in selected infant foods (for ages 6–12 months) sold in the Wa Municipal Area of the Upper West Region of Ghana.

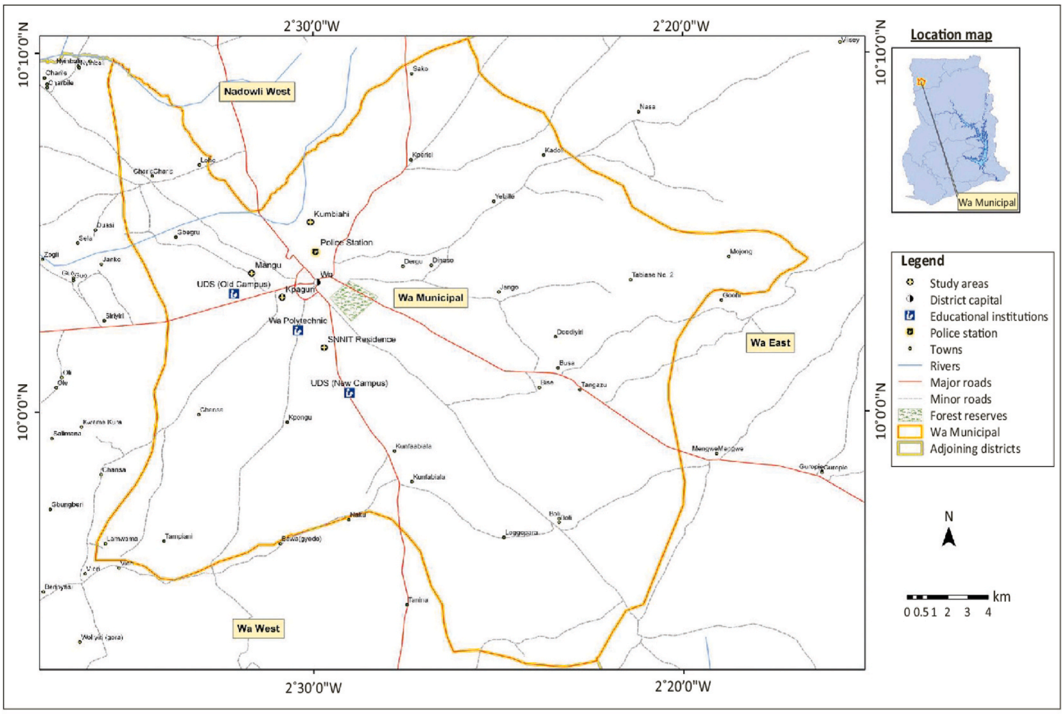

Fig. 1. A map of Ghana showing the Wa Municipal Area.

2. Materials and methods

2.1. Study area

The experimental study was conducted within the Wa municipality, in the Upper West Region of Ghana (Fig. 1).

2.2. Sampling

A total of twenty-two (22) different brands of locally and internationally produced infant formula and baby foods samples, were randomly purchased from different retailers and vendors at the markets and baby care centers in Wa, Upper West Region. All samples were taken to the Department of Dispensing Technology, Dr. Hilla Limann Technical University, and stored at room temperature without any further treatment, such as milling and drying, before subsequent laboratory analyses.

2.3. Sample preparation

Wet digestion is a favourable means of extracting heavy metals from infant formula since this method does not require any automated machinery, is inexpensive, and easy to operate [24]. Exactly 1.0 g of each sample was weighed in a digestion tube, and a 10 mL mixture of nitric acid (HNO_3) and hydrochloric acid (HCl) in a 1:1 ratio, was added to it and shaken. The mixture was heated to a constant temperature of 250 °C until a clear solution was obtained. The clear solution was transferred into a 50 mL volumetric flask, diluted to a volume of 50 mL with deionized water, and then filtered through a 0.45 p.m. pore-size membrane or Whatman No. 1 filter paper. The filtrate was collected in polyethylene bottles before analysis. The concentrations of Pb, Cr, Cd, Ni, As, and Mn in the digests were analyzed using the ICP-MS (PerkinElmer, 2000 series).

2.4. Quality control and assurance

Reagent blank determinations were used to apply corrections to the instrument readings and assess the validity of the analysis. For validation of the analytical procedure, triplicate analyses of samples against internationally certified standard reference material (SRM) of the National Institute of Standards and Technology were used, and the results were found to lie within ±1% of the certified values. The quality of the results was verified via analysis of matrix spike and matrix spike duplicates for each batch of ten (10) samples of all the heavy metals analyzed. Matrix spike recovery studies for each metal were performed by adding an amount of a standard solution to baby food and baby formula before digestion. The resulting solutions were analyzed for the concentration of each metal.

2.5. Health risk assessment

The estimated daily intake (EDI), the target hazard quotient (THQ), estimated cancer risk (ECR), and the hazard index (HI) were estimated and used to assess the potential health risks of the metals. The EDI in (mg/kg/day) is expressed as the formula in equation (1).

$$\text{EDI} = (\text{C} \times \text{DI}) / \text{BW} \tag{1}$$

Where: C is the metal concentration in mg/kg. DI, the daily dietary formula intake for infants 6–12 months is 160 g, and BW is the reference body weight of 9.3 kg for infants 6–12 months [25]. The EDI values were compared with the recommended provisional tolerable daily intake values (PTDI) established by JEFCA. This was done to check if the recommended daily values were exceeded or not. PTDI values used for this study were 0.001, 0.00357, 0.0021, 5.71E-04, 0.06, and 0.0028 mg kg^{-1} day^{-1} for Cd, Pb, As, Hg, Mn, and Ni respectively.

The target hazard quotient which assesses the potential non-carcinogenic health risk of toxic elements in baby food was calculated using equation (2) below.

$$\text{THQ} = \text{EDI}/\text{RfD} \tag{2}$$

The oral reference doses (RfD) used were 1×10^{-3}, 1×10^{-4}, 2×10^{-2}, 3×10^{-4}, 3×10^{-3}, 1.4×10^{-1}, 4.0×10^{-3} mg/kg/day, for Cd, MeHg (Methylmercury), Ni and As, Cr, Mn, and Pb respectively [26–30]. An HQ value of less than one is considered safe, and a value greater than or equal to one is unsafe and likely to pose an adverse health risk to a population.

The total hazard index (equation (3)), which is the sum of all the estimated hazard quotients, is calculated to assess the overall potential adverse health risk for toxic metals in a particular sample.

$$\text{HI} = \text{HQ}_1 + \text{HQ}_2 + \ldots \text{HQ}_n \tag{3}$$

The cancer risk, CR was estimated using the EDI and cancer slope factor (CSF) (equation (4)).

$$\text{ECR} = \text{EDI} \times \text{CSF} \tag{4}$$

CSF values (mg/kg/day) have been established for only Pb (0.0085) and As (1.5) by the regulatory bodies [31]. Carcinogenic risks within 10^{-4} - 10^{-6} are considered acceptable.

2.6. Statistical analysis

Results obtained were subjected to analysis by SPSS software version 20, data was reported as standard deviation, average, and 95% confidence interval. A sample *t*-test was performed at a significant level of 0.05 and then compared with standard values. Results for statistical analysis are presented in Table 6.

3. Results and discussion

The concentrations of arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), and antimony (Sb) in the twenty-two (22) samples are presented in Table 1. Recovery studies were performed to validate the methodology. The percentage of recoveries in all baby food and baby formula ranged from 98% to 108% (Table 2). From Table 5, one sample T-test showed that all metals were significantly different from their respective standard values, ($P < 0.05$).

Table 1
Concentration of metals (mg/kg) in sample baby foods and formulas (mean ± SD) from Wa Municipal.

Code	As	Cd	Cr	Hg	Mn	Ni	Pb	Sb
PMV	0.035 ± 0.0002	0.053 ± 0.0007	0.130 ± 0.0010	0.0002 ± 0.0002	2.039 ± 0.0025	0.097 ± 0.0006	0.061 ± 0.0007	0.054 ± 0.0036
PVB	0.022 ± 0.0002	0.055 ± 0.0008	0.138 ± 0.0010	ND	2.244 ± 0.0073	0.113 ± 0.0006	0.132 ± 0.0008	0.080 ± 0.0009
PYP	0.023 ± 0.0001	0.047 ± 0.0008	0.124 ± 0.0009	0.0016 ± 0.0016	1.794 ± 0.0010	0.065 ± 0.0003	0.368 ± 0.0003	0.061 ± 0.0008
PYAG	0.039 ± 0.0001	0.052 ± 0.0030	0.136 ± 0.0003	0.0002 ± 0.0001	2.016 ± 0.0007	0.079 ± 0.0004	0.091 ± 0.0008	0.087 ± 0.0007
PVC	0.006 ± 0.0001	0.049 ± 0.0012	0.113 ± 0.0002	0.0003 ± 0.0002	1.787 ± 0.0007	0.071 ± 0.0004	0.137 ± 0.0007	0.055 ± 0.0021
CGE	0.026 ± 0.0002	0.049 ± 0.0004	0.148 ± 0.0010	0.0003 ± 0.0002	2.003 ± 0.0007	0.093 ± 0.0005	0.084 ± 0.0008	0.042 ± 0.0005
CGR	0.021 ± 0.0002	0.048 ± 0.0006	0.145 ± 0.0013	0.0003 ± 0.0002	1.895 ± 0.0006	0.089 ± 0.0004	0.072 ± 0.0005	0.100 ± 0.0004
HPB	0.020 ± 0.0002	0.047 ± 0.0007	0.129 ± 0.0038	0.0009 ± 0.0004	1.799 ± 0.0007	0.183 ± 0.0009	0.164 ± 0.0093	0.034 ± 0.0005
HWL	0.033 ± 0.0001	0.052 ± 0.0005	0.128 ± 0.0005	0.0004 ± 0.0002	2.038 ± 0.0005	0.116 ± 0.0006	0.076 ± 0.0085	0.040 ± 0.0055
HCP	0.007 ± 0.0003	0.043 ± 0.0008	0.137 ± 0.0011	0.0007 ± 0.0004	1.720 ± 0.0006	0.106 ± 0.0005	0.076 ± 0.0004	0.036 ± 0.0006
TL2	0.028 ± 0.0003	0.055 ± 0.0006	0.255 ± 0.0007	0.0008 ± 0.0004	1.931 ± 0.0002	0.089 ± 0.0011	0.176 ± 0.0003	0.045 ± 0.0006
TL1	0.057 ± 0.0003	0.064 ± 0.0008	0.294 ± 0.0006	0.0005 ± 0.0004	2.287 ± 0.0007	0.128 ± 0.0009	0.262 ± 0.0007	0.076 ± 0.0005
TNI	0.029 ± 0.0003	0.047 ± 0.0008	0.250 ± 0.0054	ND	1.865 ± 0.0005	0.093 ± 0.0006	0.230 ± 0.0010	0.070 ± 0.0008
CFM	0.024 ± 0.0023	0.047 ± 0.0009	0.288 ± 0.0011	0.0001 ± 0.0001	2.124 ± 0.0006	0.072 ± 0.0007	0.177 ± 0.0008	0.044 ± 0.0056
CWM	0.029 ± 0.0002	0.047 ± 0.0008	0.273 ± 0.0007	0.0006 ± 0.0002	2.097 ± 0.0006	0.068 ± 0.0003	0.075 ± 0.0006	0.063 ± 0.0006
YVW	0.039 ± 0.0001	0.050 ± 0.0006	0.295 ± 0.0006	0.0002 ± 0.0002	2.282 ± 0.0003	0.088 ± 0.0008	0.094 ± 0.0009	0.058 ± 0.0002
CRM	0.020 ± 0.0002	0.050 ± 0.0006	0.300 ± 0.0008	0.0016 ± 0.0008	2.062 ± 0.0144	0.079 ± 0.0073	0.125 ± 0.0006	0.017 ± 0.0008
YMW	0.028 ± 0.0008	0.052 ± 0.0016	0.312 ± 0.0008	0.0021 ± 0.0017	2.157 ± 0.0060	0.080 ± 0.0005	0.102 ± 0.0008	0.065 ± 0.0007
CMM	0.042 ± 0.0004	0.058 ± 0.0058	0.339 ± 0.0008	0.0002 ± 0.0001	2.452 ± 0.0006	0.130 ± 0.0008	0.161 ± 0.0003	0.059 ± 0.0003
CD	0.056 ± 0.0023	0.051 ± 0.0004	0.301 ± 0.0010	0.0007 ± 0.0004	2.419 ± 0.0005	0.127 ± 0.0008	0.114 ± 0.0006	0.069 ± 0.0007
LTB	0.015 ± 0.0003	0.047 ± 0.0008	0.270 ± 0.0007	0.0003 ± 0.0002	3.568 ± 0.0006	0.145 ± 0.0009	0.124 ± 0.0007	0.042 ± 0.0005
CGAS	0.017 ± 0.0009	0.047 ± 0.0012	0.138 ± 0.0014	0.0003 ± 0.0002	1.998 ± 0.0007	0.085 ± 0.0001	0.123 ± 0.0005	0.042 ± 0.0002
Mean	0.028	0.051	0.211	0.001	2.117	0.100	0.137	–
Dev	0.013	0.005	0.081	0.001	0.375	0.029	0.072	0.019
MRL	0.1	0.04	–	0.05	2.3	0.5	0.01	–

*ND = Not Detected.

Table 2
Recovery test results.

Metal	Sample ID	Amount in sample (mg)	Amount added (mg)	Amount found (mg)	Amount recovered (mg)	% Recovery
As	PMV	0.035	0.050	0.084	0.049	98.0 ± 1.2
Cd	CRM	0.050	0.050	0.101	0.051	102.0 ± 1.1
Cr	CRM	0.300	0.500	0.798	0.498	99.6 ± 4.3
Hg	HPB	0.001	0.005	0.006	0.005	100.0 ± 1.2
Sb	CGR	0.100	0.500	0.610	0.510	102.0 ± 1.6
Pb	TL1	0.260	0.500	0.758	0.498	99.6 ± 1.5
Ni	PMV	0.100	0.500	0.640	0.540	108.0 ± 4.8
Mn	PMV	2.000	1.000	3.080	1.080	108.0 ± 4.2

3.1. Heavy metal concentration

3.1.1. Arsenic

The mean arsenic concentration was 0.028 mg/kg with a range of 0.006–0.057 mg/kg. TL1 recorded the highest arsenic concentration of 0.057 mg/kg, which is approximately 57% above the maximum allowed limit of 0.1 mg/kg for infants set by the European Food Safety Authority (EFSA) and the US Food and Drug Administration (USFDA) [32,33]. PVC recorded the lowest As concentration of 0.006 mg/kg.

Arsenic levels of this study were greater than that of [34] who recorded a mean concentration of 0.001 mg/kg for infant formulas sold in Cross River State, Nigeria. A mean concentration of 0.428 mg/kg was reported by Ref. [35] for Australian infant formulas. Also [36], reported a mean concentration of 0.031 mg/kg for infant formulas on the Serbian market.

3.1.2. Cadmium

The main source of human exposure to Cd is food [37]. In this study, the mean cadmium concentration was 0.051 mg/kg, with a range of 0.0043–0.064 mg/kg. The [38] has set the maximum permissible level for Cd for ready-to-eat baby foods and infant formulas at 0.040 mg/kg.

The mean Cd concentration for this study was greater than that reported by Ref. [34], who reported a mean cadmium concentration of 0.032 mg/kg. [39], also reported a mean Cd concentration of 0.12 mg/kg for infant formula sold in Damanhour, Egypt.

3.1.3. Mercury

A mean Hg concentration of 0.001 mg/kg with a range of not detected to 0.002 mg/kg was recorded in this study. The mean Hg was lower than that stated by Ref. [40] who recorded a mean concentration of 0.024 mg/kg for baby foods sold in the United States, and [10] who reported a mean concentration of 0.004 mg/kg for examined baby foods from Sarajevo, Bosnia Herzegovina.

YMW recorded the greatest Hg concentration of 0.002 mg/kg which is about 4% below the Codex and World Health Organization (WHO) maximum permissible limit of 0.05 mg/kg.

3.1.4. Chromium

This study reported a mean Cr concentration of 0.211 mg/kg with a range of 0.113–0.339 mg/kg. This value was greater than that reported by Refs. [34,39]. [27,41] reported mean Cr concentrations of 3.88 mg/kg and 0.21 mg/kg for infant formulas sampled from Egypt and China respectively.

3.1.5. Lead

The maximum permissible limit (MPL) of Pb proposed by the WHO for infant formulas and baby foods aligns with that established by the United States food and Drug Administration (USFDA) and the European Union [38,42,43]. The mean lead concentration was 0.137 mg/kg, with a range of 0.061–0.368 mg/kg. This Pb concentration was greater than the 0.06 mg/kg reported by Ref. [44] for cereal-based baby foods from the Greater Accra Region, Ghana, and the 0.07 mg/kg in infant formula from the European Community [45]. The high levels of lead in this study present an issue of concern due to the bio-accumulative nature of lead, this can be however be avoided if more iron is taken into the body to help in the chelation and excretion of Pb [46].

3.1.6. Antimony

The mean antimony concentration for this study was 0.056 mg/kg, with a range between 0.017 and 0.100 mg/kg. [8], reported a lower mean Sb concentration of 0.002 mg/kg in milk-based infant formulas sold in Italy.

3.1.7. Nickel

The results of this study indicated that the mean concentration of nickel was 0.100 mg/kg, with a range between 0.065 and 0.183 mg/kg. Our mean concentration of Ni was greater than that reported by Ref. [34] who recorded a mean concentration of 0.001 mg/kg [35,36]. recorded mean concentrations of 0.428 mg/kg and 0.031 mg/kg respectively. No maximum residue level has been set for Ni in infant food by any of the regulatory bodies [47,48] but an MPL of 0.02 mg/kg has been set by EFSA for drinking water [49].

3.1.8. Manganese

The concentrations of Mn in this study was between 1.720 and 3.568 mg/kg with a mean of 2.117 mg/kg. This mean concentration was greater than those reported by Refs. [23,50]. Greater Mn concentrations were however, recorded by Refs. [1,36] for baby foods sold on the Spanish and Nigerian markets respectively An MPL of 2.3 mg/kg has been set by Ref. [20].

3.2. Health risk assessment

3.2.1. Estimated daily intake (EDI) and provisional tolerable daily intake (PTDI)

The estimated daily intake (EDI) values of all the samples are presented in Table 3. The EDI values of Cd in 50% of the samples were above the Provisional Tolerable Daily Intake (PTDI) value of 8.3×10^{-3} mg/kg. For Hg, Cr, and As, 100% of the samples recorded EDI values below their recommended PTDI values. Ninety-five (95%) of the samples recorded EDI values of Ni and Mn lower than their PTDI values [27]. recorded EDI values between 0.08-0.031, 0.073–0.256, and 0.0025–0.0090 for As, Cr, and Cd respectively for milk-based infant formula sold in China.

3.2.2. Target hazard quotient (THQ)

Target Hazard Quotient (THQ) values less than 1, imply that the exposed or target population is not likely to experience any adverse health effect concerning a particular toxicant. From Table 4, As is likely to pose the greatest adverse health risk, with approximately 82% of the samples recording THQ values above 1. Adverse health risk can be attributed to Cd and Pb in only 5% of the samples. Mercury, Ni, and Mn are not likely to pose any non-carcinogenic health risk to infants because they recorded THQ values below 1. [34], recorded THQ values between nil and 1.04 for heavy metals in selected infant formula foods in Nigeria [50]. recorded THQ values between 6.85×10^{-2} and 1.04×10^{-1} for cereal-based baby foods in Egypt [27]. also recorded THQ values between 0.0015 and 0.103 for milk-based formulas in China. The hazard index (HI), which is the sum of the hazard quotients, is also presented in Table 4. This estimates the cumulative toxic effects of all the metals under consideration. Unfortunately, HI values in this study, were greater than the acceptable limit of 1, with As and Cr contributing the greatest risk. These HI values indicate that frequent consumption of these baby food and formula, can likely cause non-carcinogenic health risks to infants. Vigorous routine assessment and monitoring of baby foods on the Ghanaian market are necessary to solve the elevated HI values of this study.

3.2.3. Cancer risk (CR)

Generally, a CR value lower than 10^{-6} is considered negligible, above 10^{-6} is considered unacceptable, and those between 10^{-4} and 10^{-6} are considered acceptable [51]. From Table 5, all the infant foods used for this study have a likelihood to cause cancer, if infants should ingest them over a prolonged period.

3.3. Shortcomings to the study

This study may have shortcomings as a result of using samples from only one region in Ghana. Greater and larger sampling to

Table 3
Estimated daily intake and provisional tolerable daily intake values (mg/kg) (bw/day) for 6–12 Months old infants.

CODE	As	Cd	Cr	Hg	Mn	Ni	Pb	Sb
PMV	6.07E-04	9.07E-04	2.23E-03	4.17E-06	3.51E-02	1.66E-03	1.05E-03	9.29E-04
PVB	3.84E-04	9.49E-04	2.38E-03	2.77E-07	3.86E-02	1.95E-03	2.27E-03	1.37E-03
PYP	3.97E-04	8.16E-04	2.13E-03	2.77E-05	3.09E-02	1.11E-03	6.34E-03	1.05E-03
PYAG	6.79E-04	8.89E-04	2.35E-03	3.91E-06	3.47E-02	1.35E-03	1.57E-03	1.49E-03
PVC	9.73E-05	8.47E-04	1.94E-03	5.64E-06	3.07E-02	1.22E-03	2.36E-03	9.38E-04
CGE	4.53E-04	8.48E-04	2.55E-03	5.83E-06	3.45E-02	1.59E-03	1.44E-03	7.30E-04
CGR	3.60E-04	8.32E-04	2.50E-03	4.49E-06	3.26E-02	1.53E-03	1.25E-03	1.71E-03
HPB	3.39E-04	8.08E-04	2.22E-03	1.48E-05	3.10E-02	3.15E-03	2.82E-03	5.84E-04
HWL	5.70E-04	8.99E-04	2.20E-03	7.02E-06	3.52E-02	1.99E-03	1.32E-03	6.86E-04
HCP	1.17E-04	7.47E-04	2.36E-03	1.22E-05	2.96E-02	1.82E-03	1.31E-03	6.27E-04
TL2	4.87E-04	9.54E-04	4.40E-03	1.43E-05	3.32E-02	1.53E-03	3.03E-03	7.68E-04
TL1	9.83E-04	10.99E-04	5.06E-03	7.99E-06	3.93E-02	2.19E-03	4.50E-03	1.30E-03
TNI	4.91E-04	8.07E-04	4.30E-03	5.52E-07	3.21E-02	1.59E-03	3.95E-03	1.20E-03
CFM	4.09E-04	8.16E-04	4.95E-03	2.00E-06	3.66E-02	1.23E-03	3.05E-03	7.58E-03
CWM	5.00E-04	8.10E-04	4.70E-03	9.58E-06	3.61E-02	1.18E-03	1.30E-03	1.09E-03
YVW	6.63E-04	8.64E-04	5.08E-03	3.57E-06	3.93E-02	1.52E-03	1.61E-03	9.93E-04
CRM	3.46E-04	8.58E-04	5.17E-03	2.68E-05	3.55E-02	1.36E-03	2.14E-03	2.97E-04
YMW	4.74E-04	8.90E-04	5.37E-03	3.68E-05	3.71E-02	1.38E-03	1.75E-03	1.12E-03
CMM	7.21E-04	9.95E-04	5.83E-03	3.07E-06	4.22E-02	2.23E-03	2.78E-03	1.02E-03
CD	9.62E-04	8.74E-04	5.18E-03	1.29E-05	4.16E-02	2.19E-03	1.97E-03	1.19E-03
LTB	2.52E-04	8.10E-04	4.64E-03	5.22E-06	6.14E-02	2.50E-03	2.13E-03	7.19E-04
CGAS	2.86E-04	8.09E-04	2.38E-03	5.39E-06	3.44E-02	1.46E-03	2.12E-03	7.23E-04
PTDI	2.10E-03[a]	0.8.33E-04[a]	0.3[b]	5.71E-04[a]	6.00E-02[b]	2.8E-03[b]	3.57[a]E−03	–

[a] Codex Alimentarius WHO/FAO (General Standard for Contaminants and Toxins in Food and Feed, CXS 193–1995) amended in 2019.
[b] COT (Committee on Toxicity of Chemicals in Food, Consumer Products, and the Environment, TOX/2015/32), 2015.

Table 4
Target hazard quotient for infants.

Code	As	Cd	Cr	Hg	Mn	Ni	Pb	HI
PMV	2.02	0.91	0.74	0.04	0.25	0.08	0.26	4.31
PVB	1.28	0.95	0.79	0.00	0.28	0.10	0.57	3.97
PYP	1.32	0.82	0.71	0.28	0.22	0.06	1.58	4.98
PYAG	2.26	0.89	0.78	0.04	0.25	0.07	0.39	4.68
PVC	0.32	0.85	0.65	0.06	0.22	0.06	0.59	2.75
CGE	1.51	0.85	0.85	0.06	0.25	0.08	0.36	3.95
CGR	1.20	0.83	0.83	0.04	0.23	0.08	0.31	3.53
HPB	1.13	0.81	0.74	0.15	0.22	0.16	0.70	3.91
HWL	1.90	0.90	0.73	0.07	0.25	0.10	0.33	4.28
HCP	0.39	0.75	0.79	0.12	0.21	0.09	0.33	2.68
TL2	1.62	0.95	1.46	0.14	0.24	0.08	0.76	5.26
TL1	3.28	1.10	1.69	0.08	0.28	0.11	1.13	7.66
TNI	1.64	0.81	1.44	0.01	0.23	0.08	0.99	5.18
CFM	1.36	0.82	1.65	0.02	0.26	0.06	0.76	4.93
CWM	1.67	0.81	1.57	0.10	0.26	0.06	0.32	4.78
YVW	2.21	0.86	1.69	0.04	0.28	0.08	0.40	5.56
CRM	1.15	0.86	1.72	0.27	0.25	0.07	0.54	4.86
YMW	1.58	0.89	1.79	0.37	0.27	0.07	0.44	5.40
CMM	2.40	0.99	1.94	0.03	0.30	0.11	0.69	6.48
CD	3.21	0.87	1.73	0.13	0.30	0.11	0.49	6.83
LTB	0.84	0.81	1.55	0.05	0.44	0.12	0.53	4.34
CGAS	0.95	0.81	0.79	0.05	0.25	0.07	0.53	3.46

Table 5
Cancer risk for infants.

Code	As	Pb	CR
PMV	9.10E-04	8.91E-06	9.11E-04
PVB	5.76E-04	1.93E-05	5.95E-04
PYP	5.95E-04	5.38E-05	6.49E-04
PYAG	1.02E-03	1.34E-05	1.03E-03
PVC	1.46E-04	2.01E-05	1.66E-04
CGE	6.80E-04	1.22E-05	6.92E-04
CGR	5.40E-04	1.06E-05	5.51E-04
HPB	5.08E-04	2.40E-05	5.32E-04
HWL	8.55E-04	1.12E-05	8.66E-04
HCP	1.75E-04	1.12E-05	1.86E-04
TL2	7.31E-04	2.58E-05	7.57E-04
TL1	1.47E-03	3.83E-05	1.51E-03
TNI	7.37E-04	3.36E-05	7.71E-04
CFM	6.14E-04	2.59E-05	6.40E-04
CWM	7.50E-04	1.10E-05	7.61E-04
YVW	9.94E-04	1.37E-05	1.01E-03
CRM	5.19E-04	1.82E-05	5.37E-04
YMW	7.11E-04	1.49E-05	7.26E-04
CMM	1.08E-03	2.36E-05	1.08E-03
CD	1.44E-03	1.67E-05	1.61E-04
LTB	3.77E-04	1.81E-05	3.95E-04
CGAS	4.28E-04	1.80E-05	4.46E-04

Table 6
One sample T-test analysis of heavy metals.

Heavy metals	MRL (mg/kg)	t-stats	P value one tail ($\alpha = 0.05$)	95% Confidence interval of the difference	
				Lower	Upper
As	0.10	25.60	1.28E-17	0.022	0.034
Cd	0.04	10.90	1.95E-10	0.049	0.053
Cr	0.004	11.80	4.48E-11	0.175	0.247
Hg	0.05	37.60	4.60E-21	0.003	0.008
Mn	2.30	2.24	0.02	1.950	2.290
Ni	0.50	64.60	5.88E-26	0.087	0.113
Pb	0.01	8.18	2.84E-08	0.105	0.170
Sb	0.002	13.10	6.33E-12	0.048	0.065

include other regions of Ghana will make the findings more enriched. Considering different infant formulas (based on their primary ingredients) and different age groups (0–6 months, 1–2 years, 6 months to 2 years) may be necessary to enhance the data to make it more representative.

4. Conclusion

A total of 22 baby food samples (both local and imported brands) obtained from the Wa market in the Upper West Region of Ghana were analyzed for As, Cd, Cr, Hg, Mn, Ni, Pb, and Sb by ICP-MS. The results of this study indicated that the concentrations of As, Cr, Hg, Ni, and Sb were below the maximum safety limits (MPL) established by WHO or EFSA and other authors but Cd, Mn, and Pb concentrations in some of the samples were above their respective maximum allowed limits. Infant dietary exposure to As, Cr, and Hg was below the provisional tolerable daily intake established by WHO. Mn and Ni exceeded their PTDI values in 5% of the samples, while Pb exceeded in 14%.

Furthermore, the health risk indices (HQ) of Hg, Ni, and Mn were below the threshold value of 1 while that of As, Cr, Pb, and Cd in 82%, 50%, 9%, and 5% of the samples recorded HQ values above 1 respectively. This implies that baby foods from within the Wa municipality are likely to pose non-carcinogenic health risk to the general infant population if they consume these foods for a long time. Carcinogenic risk values were greater than 10^{-4}, making them unacceptable for human consumption and also indicating a long-term potential adverse health risk to infants. Elevated levels of Cd, Pb, and Mn likewise As, Cr, Hg, Ni, and Sb, in baby foods demand routine assessment and rigorous implementation of regulations to avoid health implications due to the bio-accumulative nature of these toxic metals.

Author contribution statement

Flora Amarh: Conceived and designed the experiments; wrote the paper.
Eric Selorm Agorku, Ray Voegboelo: Performed the experiments, materials, analysis tools.
Gerheart Ashong, George Atongo Atiah: Contributed reagents, materials, analysis data.

Data availability statement

Data will be made available on request.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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