

HEAVY METAL CONTAMINATION AND ASSOCIATED HUMAN HEALTH RISKS OF COMMERCIAL HERBAL BITTERS MARKETED IN PORT HARCOURT, NIGERIA

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Abstract

Background: The increasing consumption of commercial herbal bitters raises concerns about potential heavy-metal contamination and associated health risks. This study determined the concentrations of lead (Pb), arsenic (As), chromium (Cr), cadmium (Cd), nickel (Ni), copper (Cu), and zinc (Zn) in commercially marketed herbal bitters in Port Harcourt, Nigeria, and evaluated their potential non-carcinogenic and carcinogenic health risks.

Methods: A laboratory-based cross-sectional study was conducted on 15 herbal-bitter products purchased from two herbal-medicine outlets in Obio/Akpor, Rivers State, Nigeria, in December 2019. Heavy-metal concentrations were determined using atomic absorption spectrophotometry following acid digestion. Measured concentrations were compared descriptively with selected World Health Organization (WHO) and United States Environmental Protection Agency (USEPA) reference values used as screening benchmarks. Potential health risks were assessed using estimated daily intake (EDI), chronic daily intake (CDI), hazard quotient (HQ), hazard index (HI), and incremental lifetime cancer risk (ILCR).

Results: Heavy-metal concentrations varied considerably among the investigated products. Total chromium recorded particularly elevated concentrations in Supa Akwara (7.0125 mg/L), Cleanser (2.349 mg/L), and Ozor (2.03695 mg/L). All calculated individual HQ and cumulative HI values were below the conventional threshold of 1, suggesting low estimated non-carcinogenic risks under the exposure assumptions applied. However, several products recorded modelled ILCR values exceeding the adopted reference level of 1×10^{-4}, indicating potential carcinogenic concerns requiring further evaluation. These estimates should be interpreted cautiously because their reliability depends on the exposure assumptions, toxicological parameters, and chemical forms of the metals, particularly chromium.

Conclusion: Commercial herbal bitters marketed in Port Harcourt exhibited substantial variation in heavy-metal concentrations, with elevated total chromium levels in selected products. Although estimated non-carcinogenic risks remained below the adopted benchmark, some modelled carcinogenic-risk estimates warrant further investigation. Routine quality surveillance, improved manufacturing controls, and chemical speciation of chromium are recommended to strengthen consumer safety assessments.

Keywords: Herbal bitters; heavy metals; health risk assessment; hazard quotient; hazard index; incremental lifetime cancer risk; Port Harcourt; Nigeria

INTRODUCTION

Herbal medicines occupy an important position in healthcare systems worldwide, particularly in low- and middle-income countries where traditional and complementary medicines remain accessible, culturally familiar, and widely used alongside conventional healthcare. Their continued use reflects not only traditional knowledge but also perceptions of affordability, accessibility, therapeutic usefulness, and naturalness. However, the classification of a product as “herbal” or “natural” does not, by itself, establish its safety. The quality and safety of herbal medicinal products can be influenced by the botanical materials used, environmental conditions, harvesting and processing practices, manufacturing procedures, storage, and the presence of unintended contaminants (World Health Organization [WHO], 2007; Zamir et al., 2022).

Herbal Medicines, Quality, and Consumer Safety

The safety of herbal medicines therefore requires consideration beyond their intended pharmacological or therapeutic constituents. Medicinal plants may acquire contaminants from soil, irrigation water, atmospheric deposition, agricultural inputs, industrial activities, processing equipment, storage containers, or other stages of production. Among these contaminants, potentially toxic metals are of particular concern because some can persist in the environment and may accumulate in biological materials. WHO guidelines consequently identify toxic metals among the contaminants requiring consideration in the quality assessment of herbal medicines, while contemporary reviews have similarly emphasised the need for systematic screening throughout the pathway from cultivation and collection to manufacture and marketing (WHO, 2007; Zamir et al., 2022).

At the same time, the presence of a metal in a herbal product should not automatically be interpreted as evidence of clinically significant toxicity. Several elements, including copper and zinc, have essential physiological functions at appropriate levels, whereas their excessive exposure can become harmful; the toxicological significance of other elements depends on their concentration, chemical form, duration of exposure, and route of intake. Consequently, assessment based solely on whether a metal is detected may provide an incomplete picture of consumer safety. Concentration measurements are more informative when interpreted against appropriate regulatory or health-based reference values and, where possible, incorporated into exposure and risk-assessment models (Wu et al., 2022; Olusola et al., 2021).

Herbal Bitters and Heavy-Metal Exposure

This distinction is particularly relevant to commercial herbal bitters, which are commonly marketed as liquid herbal preparations and may be consumed directly rather than prepared or diluted before use. Studies of herbal bitters in Nigeria have demonstrated considerable variation in their chemical composition and quality characteristics. For example, an evaluation of six herbal bitters distributed in southwestern Nigeria found substantial differences in physicochemical and phytochemical characteristics among products, although the concentrations of Fe, Zn, and Cu examined in that study were within the specified acceptable limits. Such findings indicate that commercially marketed herbal bitters should not necessarily be regarded as chemically interchangeable products simply because they share similar traditional or commercial claims (Olumese, 2017).

Evidence from Nigerian studies nevertheless demonstrates that the possibility of metal exposure through herbal preparations cannot be dismissed. An earlier investigation of Nigerian traditional herbal products detected elevated concentrations of several metals, including Cd, Cu, Ni, Zn, Pb, and other elements, and highlighted the potential for heavy-metal exposure through consumption of herbal remedies (Obi et al., 2006). More recently, Izah et al. (2021) analysed ten liquid herbal medicine formulations sold in Nigeria and reported measurable concentrations of several trace metals, including Cr and Pb. Their risk assessment generally produced HQ and HI values below 1, although variation among products was observed. These findings are important because they demonstrate that the presence of metals does not necessarily translate into an identical level of estimated health risk across products; rather, risk depends on the magnitude of exposure and the toxicological characteristics of the metals involved.

Evidence specifically concerning herbal bitters also presents a mixed picture. In Ilorin, Ayanniyi et al. reported that Cd and Pb concentrations in commonly consumed herbal bitters were generally below the comparison limits used in that study, whereas Fe exceeded the stated permissible limit in some samples. Conversely, an investigation of four brands of herbal bitters marketed in Benin City detected Cd in all examined products and Pb in two products, although Cr was not detected in any of the samples. The differences between these findings may reflect differences in product formulation, raw materials, production processes, geographical sourcing, analytical methods, and sampling periods, and they reinforce the need for product- and location-specific surveillance rather than assuming that findings from one market are representative of all commercially available herbal bitters (Ayanniyi et al., 2017; Afieroho et al., 2018).

Heavy Metals and Human Health Risk

The public-health significance of metal contamination becomes more apparent when exposure is considered over time. Lead, arsenic, cadmium, and certain forms of chromium are of particular toxicological concern because prolonged exposure may affect multiple biological systems. However, the magnitude of risk cannot be inferred from concentration alone because consumption frequency, quantity consumed, body weight, exposure duration, bioavailability, and the toxicological reference value used in the assessment all influence the estimated risk. Accordingly, quantitative approaches such as the estimated daily intake, HQ, HI, and ILCR provide a more

informative framework for distinguishing the detection of a contaminant from the potential magnitude of associated health risk (Zamir et al., 2022; Wu et al., 2022).

Evidence from Nigeria illustrates why such risk-based assessment is necessary. Olusola et al. (2021), for example, reported elevated estimated exposures to several metals among consumers of medicinal plants sold in an urban market in southwestern Nigeria and identified potential non-carcinogenic and carcinogenic concerns for some plant products. In contrast, Izah et al. (2021) found generally low estimated non-carcinogenic risks and carcinogenic risks below the adopted threshold for the liquid herbal formulations they investigated. The apparent differences between these studies do not necessarily represent contradictory evidence; rather, they demonstrate that risk estimates are sensitive to the specific products examined, metal concentrations, consumption assumptions, and toxicological parameters applied.

At the international level, evidence similarly suggests that heavy-metal contamination in herbal medicines is heterogeneous rather than uniform. A large-scale assessment of 1,773 herbal medicine samples reported that approximately 30% contained at least one metal exceeding the comparison limit used by the investigators, while risk estimates varied substantially across herbal products and metals. Such findings support the view that quality assessment should combine analytical determination of contaminants with exposure-based risk assessment rather than relying exclusively on the detection or non-detection of individual metals (Zhang et al., 2021).

Rationale and Knowledge Gap

Despite increasing evidence concerning heavy metals in herbal medicines in Nigeria, important gaps remain. Existing Nigerian investigations have examined herbal remedies, medicinal plants, liquid herbal medicines, and selected brands of herbal bitters in different geographical settings, including Ilorin, Benin City, Ado-Ekiti, and other locations. However, the available evidence is characterised by differences in the metals investigated, product categories, sample sizes, analytical approaches, comparison standards, and risk-assessment methods. In particular, relatively limited evidence is available on the combined occurrence of Pb, As, Cr, Cd, Ni, Cu, and Zn in commercially marketed herbal bitters in Port Harcourt and on the extent to which measured concentrations translate into estimated non-carcinogenic and carcinogenic risks under defined consumption assumptions (Ayanniyi et al., 2017; Izah et al., 2021).

Port Harcourt provides a relevant setting for such an investigation because it is a major commercial centre in the Niger Delta where consumers have access to a wide range of packaged herbal products. Although studies have examined trace metals in liquid herbal medicines sold in Nigeria and heavy metals in other products within the Port Harcourt environment, evidence specifically integrating multi-metal determination and quantitative health-risk assessment of commercially marketed herbal bitters in Port Harcourt remains limited. Recent work on packaged culinary herbs in Port Harcourt further demonstrates continuing scientific interest in metal exposure from consumed plant products, but culinary herbs and formulated herbal bitters represent different exposure matrices and should not be treated as interchangeable sources of evidence.

Therefore, a location-specific assessment of commercially available herbal bitters is warranted to determine whether the products contain potentially toxic metals at concentrations of regulatory

concern and whether the resulting exposure estimates indicate potential health risks. Such evidence can contribute to the growing Nigerian literature on the quality and safety of herbal products while providing locally relevant information for consumers, manufacturers, researchers, and regulatory authorities. The present study consequently assessed the concentrations of Pb, As, Cr, Cd, Ni, Cu, and Zn in selected commercially marketed herbal bitters in Port Harcourt, Nigeria, and estimated their potential non-carcinogenic and carcinogenic health risks using HQ, HI, and ILCR.

Conceptual and Empirical Basis of the Study

Heavy-Metal Contamination of Herbal Products

The safety of herbal medicines is closely linked to the quality of the botanical materials, environmental conditions under which plants are cultivated or collected, and processes involved in formulation, handling, and storage. Medicinal plants can absorb and accumulate potentially toxic metals from contaminated soil, irrigation water, atmospheric deposition, and other environmental sources, with the extent of uptake influenced by plant species, soil characteristics, metal bioavailability, and prevailing environmental conditions (Alengebawy et al., 2021; Vaikosen & Alade, 2017). In the Niger Delta region of Nigeria, Vaikosen and Alade (2017) detected cadmium in all nine medicinal plant species examined and reported that metal concentrations varied according to collection site, plant species, and soil physicochemical characteristics. Their findings illustrate that contamination of botanical materials may originate from environmental pathways before the materials are incorporated into herbal preparations.

Evidence from finished herbal preparations further demonstrates that metal occurrence is neither uniform across products nor necessarily consistent across geographical locations. In Ilorin, Nigeria, Ayanniyi et al. (2017) detected cadmium, lead, and iron in commonly consumed herbal bitters, although cadmium and lead were generally below the comparison limits used by the investigators, whereas iron exceeded the stated limit in some samples. Similarly, Afieroho et al. (2018) detected cadmium in all four herbal-bitter brands examined in Benin City and lead in two brands, while chromium was not detected in any of the products. These findings demonstrate substantial inter-product variation in both the presence and concentration of metals.

The heterogeneous nature of contamination is also evident beyond Nigeria. In a large-scale investigation involving 1,773 herbal-medicine samples, Luo et al. (2021) reported that 30.51% of the samples contained at least one of five investigated metals cadmium, lead, arsenic, mercury, or copper above the limits applied in their assessment. The study also demonstrated that the presence of metals did not translate uniformly into estimated health risk across all herbal materials, emphasizing the importance of considering both concentration and exposure when evaluating product safety.

Taken together, the available evidence indicates that heavy-metal occurrence in herbal products is product-, plant-, and location-dependent**.** Differences in botanical composition, growing or collection conditions, processing procedures, manufacturing practices, and environmental exposure can contribute to variation in measured concentrations. Consequently, findings obtained from herbal products in one geographical setting cannot automatically be generalized to products

marketed in another setting. This supports the need for location-specific assessment, particularly where herbal products are widely available for direct human consumption.

The relevance of exposure is further demonstrated by evidence on the use of herbal bitters in Nigeria. In a cross-sectional study of 1,000 students in southwestern Nigeria, Showande and Amokeodo (2014) reported that 40.9% of respondents used herbal bitters; 82.4% of users reported oral administration, while 22.1% reported use extending beyond 12 weeks. The study also documented concurrent use of different herbal bitters and co-administration with conventional medicines among some participants. These findings suggest that the potential significance of contaminants in herbal bitters cannot be considered solely from analytical concentrations; patterns of consumption and duration of exposure are also relevant to interpretation of potential health risks.

Importantly, evidence from the study setting itself provides additional justification for continued investigation. Aigberua (2019) examined selected liquid and powdered herbal products sold in Port Harcourt and found substantial variation in concentrations of copper and manganese among liquid products, while chromium and cadmium were below the reported detection limits in the liquid products examined. In contrast, cadmium was detected in all five powdered products and exceeded the comparison limit used by the investigator in some samples. Although that study considered a different set of metals and included both liquid and powdered preparations, its findings establish that metal occurrence in herbal products marketed in Port Harcourt warrants continued product-specific investigation.

From Metal Concentration to Toxicological Risk

The detection of a metal in a herbal product is an important quality and safety finding, but concentration alone does not fully determine the magnitude of human-health risk. Metals differ in their biological functions, toxicological properties, dose-response relationships, and routes of exposure. Tchounwou et al. (2012) identified arsenic, cadmium, chromium, and lead among metals of substantial toxicological importance and emphasized that their effects are influenced by factors including dose, route of exposure, and chemical characteristics. Similarly, Balali-Mood et al. (2021) described multiple mechanisms involved in heavy-metal toxicity, including oxidative stress, reactive oxygen species generation, and disruption of antioxidant defenses, enzyme inactivation, and interference with cellular processes.

The distinction between measured concentration and health risk is particularly important because not all metals have identical biological significance. Some elements, including copper and zinc, are essential micronutrients at physiologically appropriate levels but may produce adverse effects at sufficiently high exposures. Conversely, metals such as lead, cadmium, and arsenic have well-established toxicological significance even at relatively low levels of exposure. Furthermore, toxicity may depend on chemical speciation. Chromium provides an important example because different chromium species have substantially different toxicological properties. Therefore, a measurement reported as total chromium does not, by itself, establish the proportion attributable to the more toxic species or permit species-specific toxicological interpretation (Balali-Mood et al., 2021; Tchounwou et al., 2012).

Accordingly, two related but distinct questions arise in the assessment of contaminated herbal products. The first is whether the concentration of a detected metal exceeds a relevant regulatory, guideline, or health-based comparison value. The second is whether the quantity potentially ingested by consumers, under specified exposure assumptions, is sufficient to produce a level of estimated risk of toxicological concern. The distinction is reflected in studies that have moved beyond concentration measurements to estimate exposure and health risk. For example, Luo et al. (2021) combined measured concentrations in herbal medicines with exposure estimates and risk characterization and identified certain herbal materials for which estimated non-carcinogenic risks exceeded the criteria applied in their assessment.

Evidence from Nigeria similarly illustrates the value of integrating concentration measurements with exposure assessment. Olusola et al. (2021), in their investigation of herbal plants sold in an urban market in Ado-Ekiti, assessed estimated daily intake, hazard-related measures, and cancer risk in addition to metal concentrations. Their findings showed that estimated exposures varied across metals and consumer groups, demonstrating that health-risk interpretation requires consideration of the relationship between contaminant concentration and human exposure rather than reliance on concentration data alone.

This distinction is central to the present study. A herbal bitter containing a metal above a selected comparison value should be regarded as warranting further safety consideration, but such an exceedance should not be interpreted as proof of a specific adverse clinical outcome. Conversely, an estimated risk below a conventional toxicological benchmark should not be interpreted as proof that the product is entirely free of health concern. Concentration analysis therefore characterizes the measured chemical burden**,** whereas exposure and risk assessment provide a model-based estimation of its potential toxicological significance under defined assumptions**.**

Exposure–Dose–Risk Framework

The present study is conceptually anchored in an **exposure–dose–risk framework**, which links the measured concentration of metals in herbal bitters with potential human-health implications. The framework recognizes that the presence of a contaminant is the starting point of risk assessment rather than its endpoint. In simplified form, the relationship may be represented as:

This conceptual sequence is consistent with established approaches to environmental and food-related contaminant risk assessment, in which measured concentrations are combined with exposure parameters to estimate the dose received by an exposed population and subsequently characterize potential adverse effects. Heavy-metal toxicity is similarly understood to depend on exposure characteristics, including dose, route, duration, and chemical form (Tchounwou et al., 2012; Balali-Mood et al., 2021).

Within this framework, the measured concentrations of lead (Pb), arsenic (As), chromium (Cr), cadmium (Cd), nickel (Ni), copper (Cu), and zinc (Zn) constitute the contamination component of the study. Consumption of the herbal bitters, together with relevant exposure parameters such as intake rate, body weight, exposure frequency, and exposure duration, provides the basis for estimating human exposure. The estimated dose can then be compared with an appropriate toxicological reference value to characterize potential non-carcinogenic risk. This approach has

been applied in investigations of heavy metals in herbal medicines and medicinal plants, including studies that calculated estimated daily intake and hazard-based risk measures (Luo et al., 2021; Olusola et al., 2021).

The hazard quotient (HQ) provides an estimate of the potential non-carcinogenic risk associated with exposure to an individual metal by comparing the estimated exposure dose with the corresponding reference dose. The hazard index (HI) extends this approach by combining relevant hazard quotients to provide an estimate of cumulative non-carcinogenic risk from multiple contaminants, subject to the assumptions underlying the method. An HQ or HI below the conventional benchmark of 1 is generally interpreted as indicating that the estimated exposure is below the reference level used for the assessment; however, it should not be interpreted as proof of the absence of adverse effects. Conversely, values above the benchmark indicate that further attention to the exposure scenario is warranted. Luo et al. (2021) and Olusola et al. (2021) provide empirical examples of the application of hazard-based approaches to contaminated herbal materials.

For contaminants with established carcinogenicity parameters, the incremental lifetime cancer risk (ILCR) provides a model-based estimate of the additional lifetime cancer risk associated with the exposure scenario. Unlike HQ and HI, which address non-carcinogenic effects, ILCR is concerned with potential carcinogenic outcomes over a defined lifetime exposure period. Its interpretation depends on the toxicity value, exposure assumptions, and reference risk range adopted in the assessment. Consequently, ILCR values should be presented as estimated risks under specified exposure assumptions**,** rather than as predictions that an individual consumer will develop cancer.

The framework also incorporates an important source of uncertainty concerning chromium. Because total chromium measurements do not distinguish among chromium species, a risk estimate based on total Cr may not adequately represent species-specific toxicity. Chromium speciation is therefore relevant when interpreting health-risk estimates, particularly where the estimated contribution of chromium to carcinogenic risk is substantial. Balali-Mood et al. (2021) emphasized the importance of chemical form in heavy-metal toxicity, supporting cautious interpretation of risk estimates where analytical measurements do not provide species-specific information.

METHODS

Study Design and Sample Collection

A laboratory-based cross-sectional study was conducted to determine heavy-metal concentrations and associated human health risks in commercial herbal bitters marketed in Port Harcourt, Nigeria. Fifteen herbal-bitter products were purchased in December 2019 from two herbal-medicine outlets in Obio/Akpor Local Government Area, Rivers State. Products were selected based on vendors' reports of frequent consumption, and only samples within their stated shelf-life were included. Samples were refrigerated at 4 °C until laboratory analysis.

Determination of Heavy-Metal Concentrations

The concentrations of lead (Pb), arsenic (As), chromium (Cr), cadmium (Cd), nickel (Ni), copper (Cu), and zinc (Zn) were determined using a Varian AA240 atomic absorption spectrophotometer. Briefly, 1 mL of each sample was digested with 6 mL concentrated nitric acid and 3 mL concentrated perchloric acid, followed by 25 mL distilled water. The mixture was heated until a clear solution was obtained and reduced to approximately 10–20 mL. The digest was filtered into a 50-mL volumetric flask and diluted to volume with distilled water before analysis. Metal concentrations were expressed in mg/L and compared descriptively with selected World Health Organization (WHO) and United States Environmental Protection Agency (USEPA) reference values adopted as screening benchmarks.

Human Health-Risk Assessment

Potential health risks associated with oral exposure to the detected metals were assessed using estimated daily intake (EDI), chronic daily intake (CDI), hazard quotient (HQ), hazard index (HI), and incremental lifetime cancer risk (ILCR). The indices were calculated using the following equations:

$$EDI=\frac{C\times AI}{BW}$$

$$CDI=\frac{C\times DI\times ABS\times EF\times ED}{BW\times AT}$$

$$HQ_i=\frac{CDI_i}{RfD_i}$$

$$HI=\sum_{i=1}^{n}HQ_i$$

$$ILCR_i=CDI_{i,\mathrm{lifetime}}\times CSF_i$$

Where C represents metal concentration (mg/L), AI and DI denote daily consumption of herbal bitters (L/day), BW is body weight (kg), ABS is the absorption fraction, EF is exposure frequency (days/year), ED is exposure duration (years), and AT is averaging time (days). RfD represents the metal-specific oral reference dose (mg/kg/day), while CSF denotes the applicable oral cancer slope factor [$(mg/kg/day)^{-1}$]. Lifetime-averaged CDI was used for carcinogenic-risk estimation.

HQ and HI values below 1 were interpreted as indicating non-carcinogenic risk estimates below the conventional screening threshold. ILCR values between 10^{-6} and 10^{-4} were considered within the adopted screening range, while values exceeding 10^{-4} indicated elevated modelled carcinogenic risk. Chromium was measured as total chromium; therefore, chromium-related carcinogenic-risk estimates were interpreted cautiously because individual chromium species were not determined.

Data Analysis

Heavy-metal concentrations and estimated health-risk indices were analysed descriptively and presented in tables. Metal concentrations were compared across the 15 herbal-bitter products and

evaluated against the adopted screening reference values, while HQ, HI, and ILCR estimates were interpreted using their respective health-risk benchmarks.

RESULTS

Heavy-Metal Concentrations in Herbal Bitters

The concentrations of lead (Pb), arsenic (As), chromium (Cr), cadmium (Cd), nickel (Ni), copper (Cu), and zinc (Zn) varied considerably across the 15 commercial herbal-bitter products (Table 1). Chromium exhibited the highest concentration among the investigated metals, particularly in Supa Akwara (7.0125 mg/L), Cleanser (2.349 mg/L), and Ozor (2.03695 mg/L). The highest arsenic concentration was recorded in Madam F. Kayes (0.2138 mg/L), while Supa Akwara had the highest lead concentration (0.093 mg/L).

Cleanser recorded the highest nickel (1.7145 mg/L) and copper (2.6945 mg/L) concentrations, whereas Assurance had the highest zinc concentration (3.53185 mg/L). Cadmium concentrations were comparatively low, ranging from 0.0002 mg/L to 0.0029 mg/L. The results demonstrated substantial differences in metal concentrations among the investigated herbal-bitter products.

Table 1: Heavy-metal concentrations in commercial herbal bitters (mg/L)

Herbal bitter	Pb	As	Cr	Cd	Ni	Cu	Zn
Origin	0.0003	0.01915	0.1804	0.00025	0.00025	0.24	1.3175
Action	0.0121	0.04115	0.2105	0.0002	0.007	0.2525	2.149
Tombo	0.0009	0.03785	0.21055	0.0008	0.00795	0.18715	1.756
Super Man Fire Dego	0.04895	0.0272	1.297	0.0002	0.17715	1.6035	0.4748
Assurance	0.0002	0.0349	0.27475	0.0025	0.14315	2.3041	3.53185
God's Power Healing	0.00015	0.01325	0.3742	0.0003	0.0518	1.1697	1.499
Madam F. Kayes	0.0132	0.2138	1.1694	0.0022	0.0514	0.61365	0.31645
Ozor	0.0025	0.004	2.03695	0.0023	0.0122	1.2065	0.6205
Vital	0.0002	0.0378	1.3663	0.00065	0.69745	2.61155	1.4977
Morning Action	0.0415	0.0178	0.02685	0.0029	0.13505	0.36955	2.345
Ghana Swagger	0.0004	0.0037	0.3911	0.00025	0.02765	1.3296	0.7745
Razah	0.0424	0.00025	1.242	0.0026	0.0455	0.2787	0.4387
Aishetu Adams	0.0002	0.0252	0.6177	0.0003	0.03915	0.0068	1.4998
Cleanser	0.01755	0.02475	2.349	0.0025	1.7145	2.6945	3.1155
Supa Akwara	0.093	0.00405	7.0125	0.00025	0.0025	0.29465	0.09775

Non-Carcinogenic Health Risks

The estimated individual hazard quotients (HQs) for the investigated metals were below the conventional benchmark of 1 across all 15 herbal-bitter products. Arsenic contributed substantially to the calculated non-carcinogenic hazard estimates, with the highest arsenic HQ recorded in Madam F. Kayes (3.054×10^{-4}), followed by Action (5.879×10^{-5}), Tombo (5.407×10^{-5}), and Vital (5.400×10^{-5}).

The cumulative hazard index (HI) also remained below 1 for all products, ranging from 5.544×10^{-7} in Razah to 3.056×10^{-4} in Madam F. Kayes (Table 2). These results indicated that the estimated non-carcinogenic exposure levels were below the adopted screening threshold under the exposure assumptions applied.

Incremental Lifetime Cancer Risk

The estimated total incremental lifetime cancer risk (ILCR) ranged from 6.906×10^{-7} in Morning Action to 1.236×10^{-4} in Supa Akwara (Table 2). Supa Akwara recorded the highest calculated ILCR, followed by Cleanser (4.198×10^{-5}), Ozor (3.581×10^{-5}), and Vital (2.429×10^{-5}).

Only Supa Akwara exceeded the adopted upper screening reference value of 1×10^{-4}. Morning Action recorded an ILCR below 1×10^{-6}, while the remaining 13 products had values between 1×10^{-6} and 1×10^{-4}.

Table 2: Hazard index and total incremental lifetime cancer risk of commercial herbal bitters

Herbal bitter	Hazard index (HI)	Total ILCR
Origin	2.739×10^{-5}	3.184×10^{-6}
Action	5.883×10^{-5}	3.772×10^{-6}
Tombo	5.411×10^{-5}	3.732×10^{-6}
Super Man Fire Dego	3.908×10^{-5}	2.305×10^{-5}
Assurance	4.993×10^{-5}	4.909×10^{-6}
God's Power Healing	1.900×10^{-5}	6.604×10^{-6}
Madam F. Kayes	3.056×10^{-4}	2.076×10^{-5}
Ozor	6.022×10^{-6}	3.581×10^{-5}
Vital	5.424×10^{-5}	2.429×10^{-5}
Morning Action	2.546×10^{-5}	6.906×10^{-7}
Ghana Swagger	5.358×10^{-6}	6.887×10^{-6}
Razah	5.544×10^{-7}	2.200×10^{-5}
Aishetu Adams	3.609×10^{-5}	1.089×10^{-5}
Cleanser	3.577×10^{-5}	4.198×10^{-5}
Supa Akwara	6.820×10^{-6}	1.236×10^{-4}

HI = hazard index; ILCR = incremental lifetime cancer risk.

The findings demonstrated substantial variation in heavy-metal concentrations and estimated health risks among the commercial herbal bitters. Although all individual HQ and cumulative HI values were below 1, the calculated ILCR for Supa Akwara exceeded the adopted carcinogenic-risk screening benchmark. These estimates were based on the toxicological parameters and exposure assumptions applied in the dissertation and should be interpreted cautiously, particularly because chromium was measured as total chromium rather than as individual chemical species.

Discussion

The present study revealed considerable variation in the concentrations of heavy metals in commercial herbal bitters marketed in Port Harcourt, Nigeria. Chromium, arsenic and, in selected products, lead, nickel and copper were the principal elements of concern. Although all individual hazard quotients (HQs) and cumulative hazard indices (HIs) were below the conventional benchmark of 1, the calculated incremental lifetime cancer risk (ILCR) exceeded the adopted screening reference value of 1×10^{-4} in only one product, Supa Akwara. These findings demonstrate the importance of interpreting measured metal concentrations alongside exposure-based health-risk estimates rather than relying on either indicator independently (WHO, 2007; Luo et al., 2021).

Variation in Heavy-Metal Concentrations and Its Significance

The marked differences in heavy-metal concentrations among the investigated products suggest considerable heterogeneity in their chemical composition. Total chromium concentrations were particularly elevated in Supa Akwara (7.0125 mg/L), Cleanser (2.349 mg/L), and Ozor (2.03695 mg/L). Madam F. Kayes recorded the highest arsenic concentration (0.2138 mg/L), while Cleanser contained comparatively high concentrations of nickel (1.7145 mg/L) and copper (2.6945 mg/L). These variations indicate that contamination patterns differed across products, with some preparations exhibiting relatively high concentrations of individual metals and others presenting broader multi-metal profiles. Similar findings have been reported in Nigeria. Afieroho et al. (2018) detected cadmium in four brands of herbal bitters marketed in Benin City and lead in two brands, although chromium was not detected. Ayanniyi et al. (2017) also reported measurable concentrations of cadmium, lead and iron in herbal bitters sold in Ilorin. The differences between these findings and the present study suggest that heavy-metal profiles are not uniform across commercial herbal preparations. This observation is further supported by Aigberua (2019), who investigated potentially toxic metals in herbal medicines marketed in Port Harcourt, and Vaikosen and Alade (2017), who documented variations in metal concentrations among medicinal plants obtained from different environments in the Niger Delta.

Comparable variations have been documented outside Nigeria. Luo et al. (2021), in an investigation involving 1,773 herbal-medicine samples, reported that 30.51% contained at least one metal exceeding the comparison limits adopted in their study. Wu et al. (2022) similarly demonstrated differences in trace-metal concentrations and estimated health risks among herbal materials. These findings support the observation that metal contamination varies with product characteristics, botanical materials and environmental or processing conditions. The sources of the metals detected in the present study could not be established because the investigation was limited to finished herbal-bitter products. Contamination may occur during cultivation, harvesting, processing, formulation or storage, but identifying the contribution of each pathway would require additional environmental and manufacturing assessments. WHO (2007) emphasizes the importance of controlling contaminants and residues throughout herbal-medicine production. Consequently, the relatively elevated metal concentrations observed in selected products provide a basis for targeted quality surveillance and further investigation rather than definitive attribution to particular contamination sources.

Non-Carcinogenic and Carcinogenic Health Risks

The non-carcinogenic health-risk assessment indicated that all individual HQ values were below 1. Similarly, cumulative HI values ranged from 5.544×10^{-7} in Razah to 3.056×10^{-4} in Madam F. Kayes, remaining below the conventional screening benchmark across all 15 products. Arsenic contributed substantially to the estimated non-carcinogenic hazard in several preparations, particularly Madam F. Kayes, which recorded the highest individual arsenic HQ of 3.054×10^{-4}. These findings suggest that the estimated exposure doses were below the adopted non-carcinogenic reference levels under the consumption assumptions applied. However, an HQ or HI below 1 does not establish the complete absence of health risk, particularly where actual consumption patterns, exposure duration and individual susceptibility may differ from those assumed in the model. The distinction between contaminant concentrations and exposure-based risk is consistent with established toxicological assessment approaches (EPA, 2011; Luo et al., 2021). The findings are comparable with those of Deswal et al. (2022), who reported relatively low estimated exposure and hazard-index values for selected Ayurvedic herbal products under the consumption scenarios investigated. Conversely, Luo et al. (2021) identified herbal medicines with non-carcinogenic risk estimates exceeding the adopted benchmarks. Olusola et al. (2021) also reported elevated estimated metal exposures and selected non-carcinogenic risk measures in herbal plants marketed in Ado-Ekiti, Nigeria. These differences demonstrate that estimated health risks depend not only on measured metal concentrations but also on consumption patterns and the toxicological reference values applied.

The corrected carcinogenic-risk assessment presented a more restricted pattern of potential concern than previously indicated. Total ILCR values ranged from 6.906×10^{-7} in Morning Action to 1.236×10^{-4} in Supa Akwara. Only Supa Akwara exceeded the adopted upper screening benchmark of 1×10^{-4}, whereas 13 products recorded estimates between 1×10^{-6} and 1×10^{-4}. Morning Action had an estimated ILCR below 1×10^{-6}. Cleanser (4.198×10^{-5}), Ozor (3.581×10^{-5}), and Vital (2.429×10^{-5}) recorded comparatively higher estimates among the products that remained below 1×10^{-4}. These findings indicate that the modelled carcinogenic-risk concern was concentrated in a limited number of preparations, particularly Supa Akwara, rather than being uniformly elevated across the investigated products. Nevertheless, the calculated ILCR values should be interpreted as screening estimates rather than direct evidence of cancer occurrence. Their reliability depends on the assumptions concerning consumption, exposure duration, averaging time and the applicability of the cancer slope factors used (EPA, 2011; Zamir et al., 2022).

A major uncertainty concerns chromium, which was measured as total chromium rather than as individual chemical species. Trivalent chromium [Cr(III)] and hexavalent chromium [Cr(VI)] differ substantially in toxicological behaviour, and species-specific cancer-risk parameters cannot automatically be applied to total chromium concentrations. The EPA (2024) emphasizes the importance of chromium speciation in risk assessments where valence-specific toxicity values are relevant. Therefore, although the elevated total chromium concentration in Supa Akwara warrants further investigation, the magnitude of its modelled carcinogenic risk cannot be considered definitive without chemical speciation and verification of the toxicological parameters applied. The contrasting non-carcinogenic and carcinogenic findings reinforce the importance of considering different toxicological endpoints separately. While the HQ and HI results did not indicate elevated non-carcinogenic hazard under the adopted exposure scenario, the ILCR

assessment identified one product exceeding the selected carcinogenic-risk screening reference. This does not establish that the product causes cancer, but it supports prioritising it for confirmatory analysis and more detailed exposure assessment.

Contribution of the Study and Implications for Public Health

The present study contributes to existing evidence by documenting the concentrations of seven heavy metals in 15 commercial herbal-bitter products marketed in Port Harcourt and integrating these measurements with quantitative health-risk assessment. Earlier Nigerian investigations, including those conducted in Benin City, Ilorin and Port Harcourt, established that potentially toxic metals may occur in herbal preparations, although the concentrations and predominant metals differed across locations (Afieroho et al., 2018; Ayanniyi et al., 2017; Aigberua, 2019). An important contribution of the present investigation is the demonstration that measured contamination and modelled health risks do not necessarily follow identical patterns. Some products contained comparatively elevated metal concentrations but recorded low non-carcinogenic hazard estimates. Similarly, although several products contained measurable chromium, only one exceeded the adopted ILCR screening benchmark. These findings support the integration of analytical measurements, exposure estimates and toxicological risk indicators when assessing the chemical safety of commercial herbal preparations.

The findings also have implications for regulatory surveillance and manufacturing quality assurance. The variation observed among products suggests that routine testing should focus on individual formulations and batches rather than assuming uniform quality across commercial herbal bitters. Particular attention should be given to preparations with comparatively elevated chromium, arsenic, lead, nickel or copper concentrations. WHO (2007) recommends systematic quality-control procedures for herbal medicines, including the monitoring of contaminants and residues. However, the findings should be interpreted within the limitations of the study. Only 15 products obtained from two outlets were investigated, restricting the generalisability of the results to the wider herbal-bitter market. The study did not assess manufacturing sources, actual consumption patterns or biological markers of exposure among consumers. Furthermore, chromium was not chemically speciated, and the modelled health-risk estimates require verification of the exposure assumptions and toxicological parameters. These limitations indicate the need for larger studies incorporating multiple production batches, broader geographical coverage, validated analytical quality-control procedures and more detailed exposure assessments.

Tthe study demonstrates that the heavy-metal profiles of commercial herbal bitters are product-specific and that their potential health implications depend on both contaminant concentrations and exposure conditions. The findings support strengthened quality surveillance, particularly for products with elevated total chromium, while highlighting the need for cautious interpretation of modelled carcinogenic risks.

CONCLUSION

This study demonstrated considerable variation in the concentrations of Pb, As, Cr, Cd, Ni, Cu and Zn among 15 commercial herbal-bitter products marketed in Port Harcourt, Nigeria. Total chromium concentrations were particularly elevated in Supa Akwara, Cleanser and Ozor. Although all individual hazard quotients and cumulative hazard indices remained below 1, the calculated incremental lifetime cancer risk exceeded the adopted screening benchmark of 1×10^{-4} in Supa Akwara alone. The findings indicate that heavy-metal contamination and associated health-risk estimates vary across products. However, the carcinogenic-risk estimates require cautious interpretation because chromium was measured as total chromium without chemical speciation. Routine product-quality surveillance, confirmatory testing and improved exposure assessment are therefore necessary to strengthen the safety evaluation of commercial herbal bitters.

RECOMMENDATIONS

The findings support strengthening routine heavy-metal surveillance of commercial herbal bitters, particularly products containing comparatively elevated concentrations of chromium, arsenic, lead, nickel and copper. Manufacturers should implement appropriate quality-control procedures covering raw materials, processing conditions and finished products. Products with elevated metal concentrations should undergo confirmatory laboratory testing, including chromium speciation where relevant, before definitive toxicological or regulatory conclusions are reached.

Further investigations should incorporate larger product samples, multiple production batches and broader geographical coverage. Future health-risk assessments should also document consumption rates, exposure duration, body weight, reference doses and cancer slope factors to improve the reproducibility and reliability of estimated non-carcinogenic and carcinogenic risks.

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