



# Heavy Metals in Alcoholic Beverages Consumed in Awka, South-East Nigeria: Carcinogenic and Non-carcinogenic Health Risk Assessments

Vincent Nwalieji Okafor<sup>1</sup> · Daniel Omeodisemi Omokpariola<sup>1</sup> · Chiamaka Valerine Okabekwa<sup>1</sup> · Emmanuel Chukwuanu Umezina<sup>1</sup>

Received: 14 June 2022 / Accepted: 7 September 2022 / Published online: 22 September 2022  
© The Tunisian Chemical Society and Springer Nature Switzerland AG 2022

## Abstract

Consumption of alcoholic beverages has been a long-standing tradition that dates back to the use of fruit-based cereals and vegetable substrates. Selected international, national, and local-based alcoholic beverages (herbal gin, imported red wine, Heineken, imported dry gin, local dry gin, palm wine, Guinness stout, and whisky) were purchased from popular drinking joints in Awka metropolis, Anambra state, Nigeria, where questionnaires were administered to respondents in order to get the actual consumption rate. Using Atomic Absorption Spectrophotometer (AAS), heavy metals (Cd, Cr, Cu, Fe, Pb, Mn, Ni and Zn) were analysed quantitatively. Background references from the World Health Organization (WHO) and the International Organization of Grapes and Wines (IOGW) were used to assess contamination and pollution potential in heavy metals. After determining the average daily intake (ADI) for non-carcinogenesis and carcinogenesis, the hazard index and overall cancer risk were calculated using reference dosage and cancer slope factor. Heavy metal analysis showed that Cu and Zn were found to be the most prevalent in all alcoholic beverages. Imported dry gin was highest for Cr, whereas Guinness stout was lowest. Local dry gin (0.936 mg/l) and imported red wine (0.075 mg/l) had the highest concentrations of Cu and Fe whereas Heineken (0.024 mg/l) and herbal gin (0.01 mg/l) had the lowest respectively. Local dry gin (0.078 mg/l), imported red wine (0.048 mg/l), Heineken (0.009 mg/l), and Guinness stout (0.33 mg/l) had the highest Pb, Mn, Ni, and Zn concentrations respectively, whereas Guinness stout (0.022 mg/l), Whisky (0.00 mg/l), imported dry gin (0.001 mg/l), and palm wine (0.027 mg/l) had the lowest concentrations respectively. There are no known health risks as a result of the contamination and pollution potential. Heineken and palm wine were both above 1 on the hazard index, indicating that there were potential health issues. However, cancer risk analysis revealed that all beverages were above the US EPA's recommended range of  $1.00E06$ – $1.00E04$ , implying that cancer-related illness is likely in a population of 1 in 1000 to 10,000 people. As a result, alcoholic beverage manufacturers should strive for continuous improvement in order to avoid public health issues.

**Keywords** Toxic metals · Alcohols · Food analysis · AAS · Public health

## 1 Introduction

An alcoholic beverage is a beverage that contains ethanol, a type of alcohol made by the fermentation of grains, fruits, or other sugar sources [1]. Alcohol drinking is common in many cultures including the people of South-Eastern Nigeria where it is used for therapeutic purposes, oath-taking, entertainment, and during marriages, rituals, and festivals [2].

Alcohol is a depressant that promotes euphoria, decreases anxiety, and improves sociability at low amounts [3]. Continuous abuse (long-term overdose) can lead to alcohol disorder, increased risk of bodily tissue and systemic damage, cancer, and physical dependency (addiction) [4]. It induces drunkenness, stupor, unconsciousness, or even death in greater dosages. It is a common knowledge that alcohol is one of the most often used recreational drugs in the world, with approximately 33% of all humans drinking it [5]. As a result of this persistent dependence, consumption, and demand for alcoholic beverages, the worldwide alcoholic business exceeded USD 1 trillion in 2018 [6].

Beers, wines, and spirits with alcohol concentrations ranging from 3 to 50% are categorized as alcoholic

✉ Vincent Nwalieji Okafor  
vno.okafor@unizik.edu.ng

<sup>1</sup> Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, PMB 5025, Awka, Anambra State, Nigeria

beverages [7]. Alcoholic beers include lager, stout, ale, pilsner, and others, whereas alcoholic wines include white wine, red wine, Malbec, sherry, port, Muscat, etc., and alcoholic spirits include gin, brandy, whiskey, vodka, amongst others [8]. Due to the constant demand for alcoholic beverages, the production to packaging process is a series of quality assurance and control requirements where contamination is not required to impact the taste, odour, or colour of the beverages in comparison to other ethical and regulatory procedures, but it is nearly impossible to eliminate contaminants such as metals, heavy metals, particulate matter (aerosols), microbes (viruses, parasites, bacteria, fungi), gaseous emissions (carbon, sulphur, nitrogen, and methane oxides) from the entire process. These contaminants have the potential to increase toxicity in humans after intake due to numerous biochemical processes [9, 10].

Heavy metals, which have a specific density of more than  $5 \text{ g cm}^{-3}$ , can be found in all strata of the earth, where they are entangled with various natural and anthropogenic activities. Heavy metals in food, water, soil, and beverages that exceed the maximum permissible levels (MPL) constitute a health risk to consumers [11]. Exogenous sources (heavy metals that come from substances added during production and contamination from industrial equipment used for fermentation, conditioning, filtration, carbonation, and packing) and endogenous sources (natural components such as water, yeast, barley used in the production process) are both sources of heavy metals in alcoholic drinks [12].

Hence, it is essential to monitor the suitability of consumption of some alcoholic beverages by residents of Awka, Anambra State, Nigeria. Due to health concerns regarding heavy metal pollution of foods, drinks, waterways, and soils, many investigations on groundwater [13–15], surface water [16, 17], soil [18, 19], sediments [20, 21], plants and vegetables [22–24], and beer [25–29] have been published. Nonetheless, there is little or no literature on concentration levels and risk assessments of heavy metal contamination of alcoholic beverages consumed in Awka, Anambra State, Nigeria. As a result, determining the amounts of heavy metals in alcoholic beverages and assessing their carcinogenic and non-carcinogenic health hazards becomes critical for regulatory bodies, and industrial players have a broader understanding for action plan and process controls.

## 2 Experimental

### 2.1 Procurement of Materials

Eight (8) different brands of alcoholic beverage were used for the investigations (herbal gin, imported red wine, Heineken, imported dry gin, local dry gin, palm wine, Guinness stout, and whisky with sample codes HG, IRW, H,

IDG, LDG, PW, GS, and W respectively) were purchased from popular drinking joints (pubs) at Club Road (popularly called Abakiliki street, Awka, Anambra State, Nigeria). Reagents and heavy metal standards used for the analysis were purchased from BDH Chemical Ltd, UK, and Sigma-Aldrich Chemie GmbH, Germany.

### 2.2 Sample Analysis and Quality Control/Quality Assurance

Reagents used for the analyses were of high-quality analytical grade. Detergents and deionized water were used to wash the glassware and sample bottles, which were thereafter soaked overnight with equal solutions of 10%  $\text{HNO}_3$  and 1% HCl. Thereafter, deionized water was used for final rinse. Heavy metal analysis by Atomic Absorption Spectrophotometric technique as described by Omokpariola et al. [30]; Omokpariola and Omokpariola [31]; Okafor et al. [32], Okafor [33] and Jorge et al. [34]. Briefly,  $10 \text{ cm}^3$  of perchloric acid and  $10 \text{ cm}^3$  concentrated  $\text{HNO}_3$  were added to  $2 \text{ cm}^3$  of the sample in a  $250 \text{ cm}^3$  beaker. This was boiled in a fume cupboard on a hot plate until white vapours began to emerge. The digestive system was then recharged and heated until white fumes were released. The addition of  $20 \text{ cm}^3$  of deionized water was then made. The mixture was then boiled for another 20 min until it was particle-free. The digested sample was brought down and cooled to room temperature under the hood. The filtrate was collected in a  $50 \text{ cm}^3$  volumetric flask after being filtered through No. 11 Whatman filter paper. Before the combined filtrate was made up to mark and placed into a sample container,  $20 \text{ cm}^3$  of deionized water was used to rinse the filter paper. Standards were made from the salts of the metals to be analysed, and lamps for the analysis were set up. This was done for Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn. The diluents of the sample were aspirated into an Agilent AA500F Atomic Absorption Spectrophotometer.

All of the samples were examined in triplicate, and the metal concentrations were averaged out. The reagent blank, as well as reference material, were analyzed for quality control. The limit of detection (LOD) was determined to be 3 times the standard deviation (SD) of the blank findings, and the limit of quantitation (LOQ) was determined to be 2 times the LOD value [35]. The reference material was used to test the analytical method's accuracy. Metal recovery rates varied from 93.5% for Cd to 105.5% for Ni. The relative standard deviation (RSD) of reference material ranged from 0.013 to 0.155% in terms of repeatability. During the concentration computation, a blank reading was used to make necessary corrections. The concentrations of the investigated metals indicated in the blank tests were taken into account in the final results for the respective heavy metals.

## 2.3 Human Health Risk Assessment

### 2.3.1 Daily Intake Estimate of Heavy Metals Through Alcoholic Beverage Consumption

The average daily intake (ADI) in mg/(kg day) is used to quantify the oral exposure dosage for deleterious substances and was estimated using Eq. 1 [36].

$$ADI = \frac{C \times IR \times ED \times EF}{BW \times AT}, \quad (1)$$

where C represents heavy metal content (mg/l) IR: ingestion rate (L/day), ED: exposure duration (30 years), EF: exposure frequency (350 day/year), BW: reference body mass (80 kg), and AT: average time (non-carcinogenic = ED × 365 days; carcinogenic = 70 × 365).

The ingestion rate (IR) was determined using a questionnaire that was administered to fifty participants who regularly visit the popular drinking joint in Awka in relation to alcoholic brands purchased. The data obtained from respondents were analysed using descriptive statistics such as mean and standard deviation (SD) to determine the average quantity of alcoholic beverages consumed in the study area per day.

### 2.3.2 Non-carcinogenic Risk

The human non-carcinogenic risk assessment for local people was calculated using the reference dose (RfD) (see Table 1) previously established by the Joint FAO (Food and Agriculture Organization)/WHO (World Health Organization), Expert Committee on Food Additives (ECFA) [37] and the United States Environmental Protection Agency (US EPA) [38]. The hazard quotient (HQ), a ratio of average daily intake (ADI) and RfD [39], characterizes the health

risk of non-carcinogenic adverse effects due to exposure to toxicants is given in Eq. 2:

$$HQ = \frac{ADI}{RfD}, \quad (2)$$

where RfD is the estimated maximum permissible dose for humans through daily exposure. If HQ < 1, adverse health effects would be unlikely experienced, whereas potential non-carcinogenic effects would occur when HQ ≥ 1 [40]. The hazard index (HI) is calculated to evaluate the potential risk of adverse health effects from a mixture of chemical elements in alcoholic drinks. The HI was calculated as the sum of HQ [41] (assuming additive effects) as shown in Eq. 3.

$$HI = \sum HQ. \quad (3)$$

If HI < 1, chronic risks are assumed to be unlikely to happen, whereas non-cancer risks are likely to occur in case HI ≥ 1 [42].

### 2.3.3 Carcinogenic Risk

The cancer risk (CR) was calculated by multiplying the average daily intake over a lifetime with a cancer slope factor (SF) according to Eq. 4. CR is estimated as the incremental probability of an individual developing cancer over a lifetime. For example, a CR of 10<sup>-4</sup> indicates a probability of 1 in 10,000 individuals developing cancer [43]. The CR of local people caused by potential carcinogen exposure over a lifetime was calculated according to the following equation [39]:

$$CR = ADI \times SF, \quad (4)$$

$$CR_t = \sum CR. \quad (5)$$

If multiple carcinogenic elements are present, the cancer risks (CR<sub>t</sub>) from all carcinogens are summed (assuming additive effects). Risks in the range of 10<sup>-6</sup> to 10<sup>-4</sup> are acceptable [41]. Cr, Cd, and Ni were treated as potential carcinogenic contaminants, whereas Pb and Mn were regarded as non-carcinogenic elements, based on the order of classification group defined by the International Agency for Research on Cancer [44]. Table 1 shows the oral RfD and SF values for heavy metals in food.

### 2.3.4 Contamination and Pollution Indicators

The impact of different processes can affect the quality of alcoholic beverages using different toolkits such as contamination factor (CF), degree of contamination (Cdeg), pollution load index (PLI), and Nemerow pollution index (NPI),

**Table 1** Reference doses (RfD) and slope factors (SF) of eight heavy metals

Heavy metal	Classification by IARC*	RfD (mg/kg/day)	SF (mg/kg/day) <sup>-1</sup>
Cd	1	5 × 10 <sup>-4</sup>	6.3
Cr	1	3 × 10 <sup>-3</sup>	5 × 10 <sup>-1</sup>
Cu	–	4 × 10 <sup>-2</sup>	–
Fe	–	7 × 10 <sup>-1</sup>	–
Pb	2B	3.6 × 10 <sup>-3</sup>	8.5 × 10 <sup>-3</sup>
Mn	–	1.4 × 10 <sup>-1</sup>	–
Ni	1	8.4 × 10 <sup>-1</sup>	2 × 10 <sup>-2</sup>
Zn	–	3 × 10 <sup>-1</sup>	–

\*International Agency for Research on Cancer

Source: Zeng et al. [45]; Vetrinurugan et al. [46]; Edokpayi et al. [47]; Boateng et al. [48]

as described extensively by Okafor et al. [49] and Umeh et al. [50].

## 2.4 Statistical Analysis

The statistical analysis was performed in R software version 4.1.1 (R Core Team 2021) [51, 52]. Microsoft Excel 2019 was used to plot the graph (Pareto chart, percentage stark column) and assess statistical evaluation with XReal Stats add-ins package for Windows performed at  $p$  value = 0.05 significant level.

## 3 Results and Discussion

### 3.1 Method Validation

Table 2 presents the findings of the method's sensitivity. Regression ( $R^2$ ) values should be more than 0.995 in order to be considered acceptable, according to [53] and [54]. The  $R^2$  for all metals was in the 0.9959 to 0.9996 range, showing acceptable linearity, good correlation, and hence good calibration of the device. For Cd, Cr, Cu, Fe, Pb, Mn, Ni and Zn respectively, the LOD values were 0.15, 1.25, 0.31, 0.003, 0.27, 1.09, 0.22 and 0.003 mg/l, whereas the LOQ values were 0.30, 2.50, 0.62, 0.006, 0.54, 2.18, 0.44 and 0.006 mg/l. These values show that the instrument could be sensitive as they are lower than the maximum allowable limit for these metals in alcohols.

Table 3 presents the results of the tests for precision and accuracy. The average percentage recoveries for the metals under study in the beverages varied from 93.50 to 105.50%, which is within the permissible recovery value range of 80–120% for metal analysis [55]. The % RSD for precision determination ranged from 0.013 to 0.155% (Table 3), which was under the acceptable limits of  $\leq 11\%$  [56]. Further used to monitor precision was the coefficient of variation (CV). The World Health Organization [57] states that the CV value

**Table 2** Regression ( $R^2$ ), limit of determination (LOD) and limit of quantification (LOQ) of each metal determined by AAS in alcoholic beverages

Heavy metal	$R^2$	LOD (mg/l)	LOQ (mg/l)
Cd	0.9959	0.15	0.30
Cr	0.9978	1.25	2.50
Cu	0.9996	0.31	0.62
Fe	0.9979	0.003	0.006
Pb	0.9988	0.27	0.54
Mn	0.9967	1.09	2.18
Ni	0.9989	0.22	0.44
Zn	0.9996	0.003	0.006

**Table 3** Accuracy and precision test results of metals for alcoholic beverages

Heavy metal	Recovery (%)	RSD (%)	CV (%)
Cd	93.50 ± 2.02	0.057	0.28
Cr	96.38 ± 1.80	0.013	0.68
Cu	101.29 ± 0.53	0.123	0.20
Fe	95.37 ± 1.22	0.096	0.78
Pb	98.45 ± 2.13	0.155	3.25
Mn	99.72 ± 0.35	0.137	4.13
Ni	105.50 ± 2.84	0.084	2.30
Zn	99.05 ± 1.96	0.103	0.55

should be less than 5%. Table 3 shows the CV range for all metals, which is 0.20 to 4.13%. Therefore, based on these findings, it can be concluded that the proposed method had good metal determination precision and accuracy.

### 3.2 Heavy Metals Concentration in the Alcoholic Beverages

The amount of heavy metal contamination in alcoholic beverages is affected by the raw materials utilized, the fermentation and brewing process, storage, and equipment used in the packaging process [58]. Table 4 and Fig. 1 show the concentrations of Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn. The maximum permissible limit (MPL) of some metals, as depicted by the International Organization for Grapes and Wines and World Health Organisation [59, 60], showed that levels of Cu, Fe, Pb, Mn, Ni, and Zn were within the permissible limit, whereas Cd in IDG, LDG, and W alcoholic beverages exceeded MPL, and IDG's Cr value was above the PML of 0.05 mg/l. A deeper look at Table 4 reveals that IDG was highest for Cr, whereas GS was lowest. LDG (0.936 mg/l) and IRW (0.075 mg/l) had the highest concentrations of Cu and Fe, respectively, whereas H (0.024 mg/l) and HG (0.01 mg/l) had the lowest. LDG (0.078 mg/l), IRW (0.048 mg/l), H (0.009 mg/l), and GS (0.33 mg/l) have the highest Pb, Mn, Ni, and Zn concentrations respectively, whereas GS (0.022 mg/l), W (0.00 mg/l), IDG (0.001 mg/l), and PW (0.027 mg/l) have the lowest concentrations respectively.

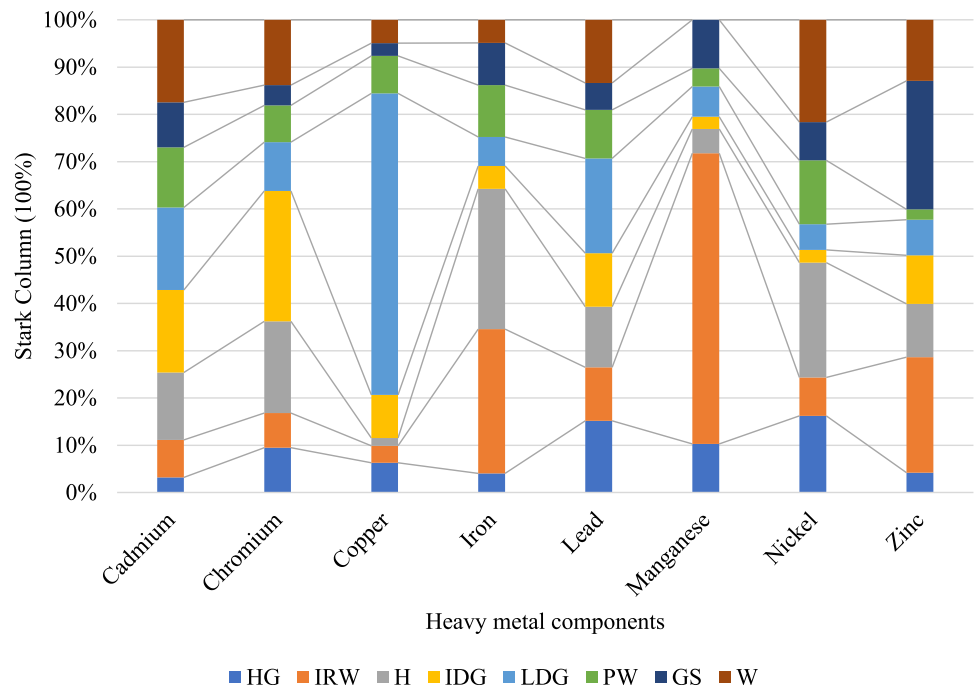
The Cd, Cr, Pb, and Ni concentrations in PW were higher than those of Richard et al. [61] who detected no concentration of these metals (Cd, Cr, Pb, and Ni) in their analysis whereas Fe (0.554–0.983 mg/l) and Zn (0.157–0.319 mg/l) also obtained by the same authors were higher than the result of this present study, which they attributed to location, preparation procedure, and storage containers. The concentrations of Cu and Fe were greater than those obtained by Charehez et al. [62] who detected Cu (14.99–137.94  $\mu$ g/l) and Fe (392–1454.14  $\mu$ g/l), as they

**Table 4** Heavy metal (mg/l) concentration of alcoholic beverage

Alcoholic drink	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Manganese (Mn)	Nickel (Ni)	Zinc (Zn)
HG	0.002	0.022	0.092	0.01	0.059	0.008	0.006	0.051
IRW	0.005	0.017	0.053	0.075	0.044	0.048	0.003	0.297
H	0.009	0.045	0.024	0.073	0.05	0.004	0.009	0.137
IDG	0.011	0.064	0.134	0.012	0.044	0.002	0.001	0.125
LDG	0.011	0.024	0.936	0.015	0.078	0.005	0.002	0.091
PW	0.008	0.018	0.116	0.027	0.04	0.003	0.005	0.027
GS	0.006	0.01	0.04	0.022	0.022	0.008	0.003	0.33
W	0.011	0.032	0.072	0.012	0.052	No Data	0.008	0.157
MPL	0.01 <sup>a</sup>	0.05 <sup>b</sup>	1.00 <sup>a</sup>	0.30 <sup>b</sup>	0.20 <sup>a</sup>	0.40 <sup>b</sup>	0.02 <sup>b</sup>	5 <sup>a</sup>

All data are presented in mg/l. No data—analytical data unavailable

MPL maximum permissible limits of heavy metals as specified by International Organization for grapes and wines (OIV, 2008)<sup>a</sup>, World health organization for drinking water (WHO, 2017)<sup>b</sup>

**Fig. 1** Percentage stark column of heavy metals in alcoholic beverages

ascribed that the fermentation process of barley, rye, oat and wheat used in alcoholic beverage production absorb these elements from the soil leading to an increase in toxic concentration in beers.

The cadmium (Cd) concentration in selected alcoholic beverages showed that gins and spirit were slightly above MPL of 0.01 mg/l which was similar to Bodo rice beer which ranged between 0.004 and 0.010 mg/l [58], as Van-Wyk et al. [63] assessment in spirit and beer beverages. Extensive studies have shown that cadmium exposure can lead to different types of cancer-related illnesses including lungs, prostate, nasopharynx, pancreas, and kidney, as cadmium contamination are predominantly from groundwater contamination from industrial effluents [64–67].

The Cr concentration of IDG was above MPL of 0.05 mg/l, while others were below MPL as Van-Wyk et al. [63] assessments of commercial brandies, spirits, and wines were within a reasonable limit. The usage of electroplated chromium alloys has the ability to contribute to chromium at insignificant concentrations as high chromium levels could come via storage or fermentation processes in stainless steel, or via pigmentation of stainless bottles and severe temperatures [64, 68].

The concentration of Fe was within the MPL limit of 0.30 mg/l (WHO 2017), which was lower than that reported by Van-Wyk et al. [63] (19.167–632.361 µg/l) and Okareh et al. [69] (720–4220 µg/l). Fe can come via water/process container leaching, and in high enough concentrations, it



can give the beverage an unpleasant taste. Although it is an essential element in the human body for blood formation and oxygen transfer, iron poisoning or overdose from accumulation in the human body can cause nausea, gastrointestinal pain, diarrhea, hepatic failure, multiple organ failure, and even death [63, 70–72].

It is seen from the Table that Pb was within MPL, but it is known that Pb is a non-essential element with no good effect and is classified as a carcinogen with public health concern for causing harmful health disorders. Pb could come through product handling and storage equipment, and it's impossible to rule out soil contamination via automotive emissions, contaminated irrigation sources, and pesticide use [70].

Mn levels were lower than MPL of 0.40 mg/l in all samples, and also were lower than Doudu et al. [73] which ranged from 0.152 to 0.808 mg/l in comparison to Van Wyk et al. [63], Amidži et al. [74] and, Woldemariam and Chandravanshi [68]. Mn levels exceeding 0.1 mg/l in water supplies, according to WHO [60], can affect the taste and odour of alcoholic beverages, as well as cause colour and turbidity concerns. Mn is a nutritionally significant metal that aids bone formation, lowers bleeding, and improves central nervous system performance. Mn contamination exceeding 0.2 mg/l can be caused by leaching from process and storage water [70].

The concentration of Ni was below MPL of 0.02 as shown in Table 4, which was higher than that documented by Osei et al. [70] in local alcoholic beverages in Accra, Kumasi, and the north of Ghana, as Abdel-Rahman et al. [75] had similar high concentration in fruit juice and yoghurt drinks in Egypt in tandem with Doudu et al. [73], as it is reported that high nickel above a reasonable concentration can cause lung and nasal cavity cancer, dizziness, asthma, and allergies [76]. Despite the fact that the Ni content was lower than the MPL, bioaccumulation could occur across diverse alcoholic beverages [77].

The Zn concentration in this study ranged from 0.051 to 0.33 mg/l, which was lower than the MPL of 5 mg/l, as reported by Doudu et al. [73], who found Zn levels in pito alcoholic beverages in Accra, Ghana, ranging from 0.456 to 0.910 mg/l, and Harmankaya et al. [78], who observed Zn levels in alcoholic beverages in Turkey ranging from 0.19 to 8.62 mg/kg. Zn is a vital nutrient for human growth, development, and well-being [79] which could come in beverages from process water and its substrates, according to Gazuwa et al. [80], because severe amounts beyond the MPL of 5 mg/l can cause prostate enlargement [81].

### 3.3 Pareto Analysis of Alcoholic Beverages

Single-factor Pareto chart was conducted to assess the relationship, which allows for rapid identification of variables accessed (Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn) in alcoholic

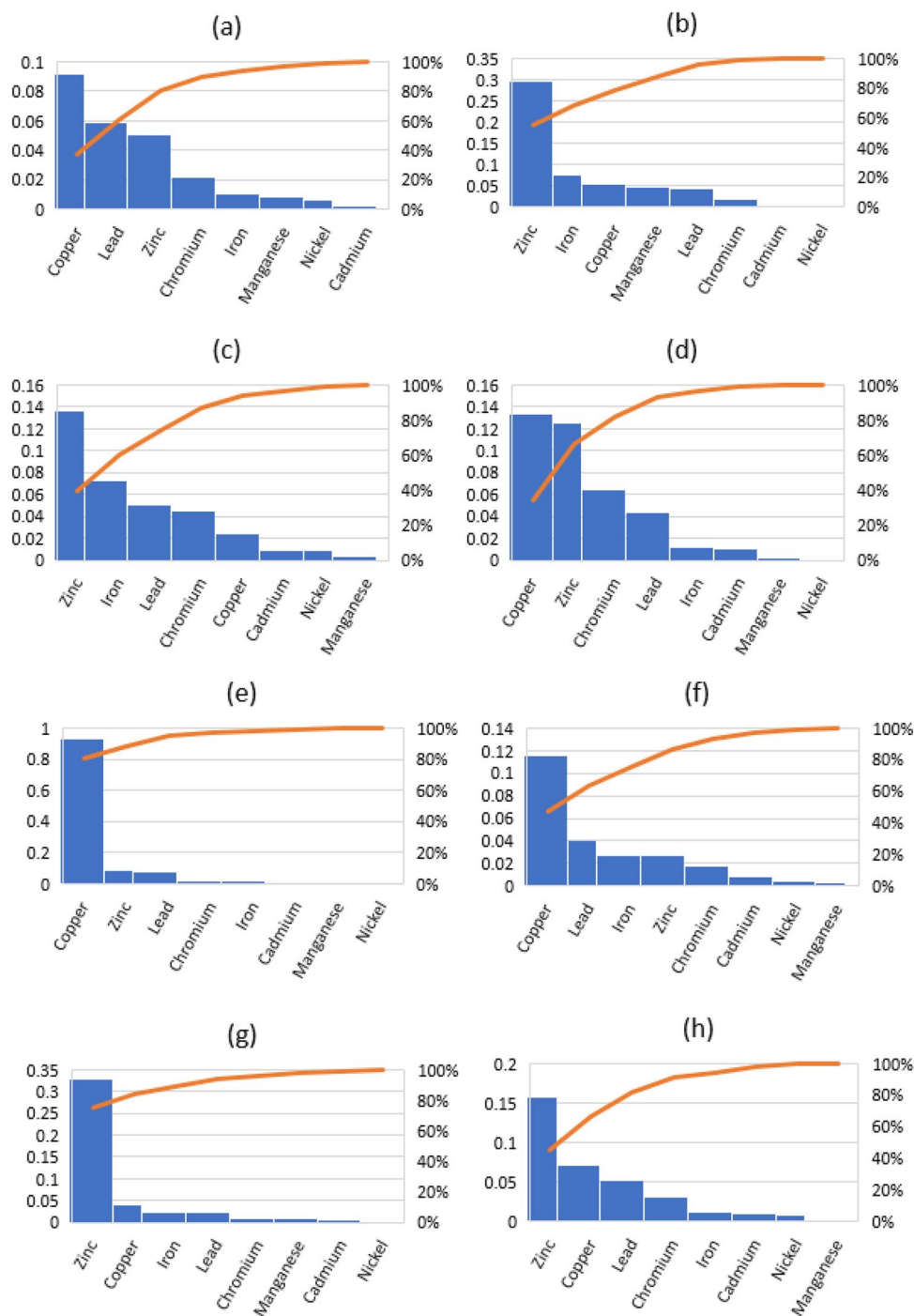
beverages (HG, IRW, H, IDG, LDG, PW, GS, and W) [82] consumed in Awka, South-East Nigeria. Figure 2a–d, e–h shows the Pareto chart evaluated, as we can see, Cu was dominant across the HG, IDG, LDG, and PW between 80 and 92% cumulative variance, while Zn was dominant in IRW, H, GS and W between 82 and 90% cumulative variance, whereas other heavy metals fell below 60%. Cu and Zn impacted the Pareto line with a steady increase from 36 to 100% across all alcoholic beverages from heavy metals.

### 3.4 Contamination and Pollution Potential of Alcoholic Beverages

Contamination and pollution are misused terms that are misinterpreted across various environmental and health-related discussions, but contamination is the presence of foreign materials or substances from adulteration above the recommended background limit, whereas pollution is contamination that has an adverse effect, as contamination factor (CF) conducted shows that Cd was a major contaminant, while Cr was present across the accessed samples (Table 5). Cd and Cr contamination was found in IDG, LDG, and W due to the usage of process instruments and storage utensils, while other heavy metals were found at levels that were almost negligible when compared to the reference background values. The degree of contamination (Cdeg) was assessed to know the impact of contamination factor (CF) assessed in terms of anthropogenic or natural contamination, as such, using the rationale for assessing Cdeg: low Cdeg (0–2), medium Cdeg (> 2–4), high Cdeg (> 4–8), Table 5 shows that HG, IRW, PW, and GS had low Cdeg, whereas other alcoholic beverages were within medium Cdeg from the cumulative influence of all heavy metals in each of the alcoholic beverages [83, 84].

The pollution load index (PLI) is the arithmetic mean of CF to the  $n^{\text{th}}$  number of heavy metal contaminants of interest, with  $PLI < 1$  indicating no pollution and  $PLI > 1$  indicating pollution, which shows that all alcoholic beverages were not polluted in anyway (Table 5), which implies no associated illness will be predominant [85]. Nemerow pollution index (NPI) assesses the effect of heavy metal pollution from contamination influences using the arithmetic mean of CF and maximum CF. NPI is graded as  $NPI < 1$  (unpolluted),  $1 \leq NPI < 2.5$  (slightly polluted),  $2.5 \leq NPI < 7$  (moderately polluted) and  $NPI > 7$  (heavily polluted). From Table 5 and according to NPI, it is observed that all the beverages were free of pollution by any heavy metal, although it is nearly impossible to eliminate heavy metals from a variety of processes involved in the production of alcoholic beverages, quality assurance and control regulations require that process plants involved in food and beverage production be regularly cleaned at all times to maintain high standards [86].

**Fig. 2** a–d Pareto chart of heavy metal components in alcoholic beverages (HG, IRW, H, IDG). e–h Pareto chart of Heavy metal components in alcoholic beverages (LDG, PW, GS, W)



### 3.5 Human Health Risk Assessment

A health risk assessment can be used to prioritize and rank contaminants of interest, as well as devise a strategy for avoiding exposure. Risk is known as toxicity or severity versus toxicity, as risk assessment is currently an important topic that is being discussed extensively because of numerous exposures to contaminant above reasonable or background values that is within tolerable levels [87, 88].

Therefore, the influence of human-based exposures has been studied extensively by US EPA, WHO, IARC, Canadian. Environmental protection agency (CEPA), European Environmental Agency (EEA) and other partner countries have developed a number of exposure pathways, which include oral (ingestion), dermal (skin contact), inhalation and injection that are dependent of water, food, aerosol particulate, pharmaceutical skin peels, and medical procedures in tandem with injection [44, 89]. The extent of toxicity as earlier

**Table 5** Contamination factor (CF), degree of contamination (Cdeg), pollution load index (PLI) and Nemerow pollution index (NPI) of alcoholic beverages

Alcoholic drink	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	N	Cdeg	PLI	NPI
HG	0.2	0.44	0.1	0	0.3	0.02	0.3	0	8	1.391	0.091	0.554
IRW	0.5	0.34	0.1	0.3	0.22	0.12	0.15	0.1	8	1.692	0.164	0.596
H	0.9	0.9	0	0.2	0.25	0.01	0.45	0	8	2.805	0.14	0.791
IDG	1.1	1.28	0.1	0	0.22	0.005	0.05	0	8	2.854	0.1	0.905
LDG	1.1	0.48	0.9	0.1	0.39	0.013	0.1	0	8	3.087	0.147	0.862
PW	0.8	0.36	0.1	0.1	0.2	0.008	0.25	0	8	1.829	0.094	0.717
GS	0.6	0.2	0	0.1	0.11	0.02	0.15	0.1	8	1.259	0.097	0.615
W	1.1	0.64	0.1	0	0.26	No Data	0.4	0	7	2.543	0.182	0.842
Ref.	0.01	0.05	1	0.3	0.2	0.4	0.02	5	-	-	-	-

Ref. Reference utilized using International Organization for grapes and wines (OIV 2008) [52], World health organization for drinking water (WHO 2017) [58]

stated related to average daily intake or chronic daily intake from a number of factors, which are age, sex, body weight, exposure amount, exposure frequency, and time that invariably can lead to adverse health issues or vice versa [90–92].

The average daily intake (ADI) of heavy metals was evaluated in relation to the amount consumed by the participants in Awka metropolis, South-East Nigeria as shown in Table 6, to get the possible daily intake of each of the heavy metals from non-carcinogenic and carcinogenic standpoints, thereby leading to probable health effect or cancer risk (Table 7). The non-carcinogenic average daily intake (NC-ADI) shows that the range of all heavy metals in assessed alcoholic beverages are cadmium (3.31E-05–4.11E-04), chromium (2.37E-04–1.34E-03), copper (7.16E-04–9.26E-03), iron (1.47E-0–2.18E-03), lead (5.38E-04–2.06E-03), manganese (No data–1.20E-03) nickel (1.22E-05–2.69E-04) and zinc (8.44E-04–1.09E-02). The carcinogenic average daily intake (C-ADI) ranges are cadmium (1.42E-05–1.76E-04), chromium (1.02E-04–5.76E-04), copper (3.07E-04–3.97E-03), iron (6.29E-05–9.34E-04), lead (2.31E-04–8.82E-04), manganese (No data–5.14E-04) nickel (5.24E-06–1.15E-04) and zinc (3.62E-04–4.68E-03).

The non-carcinogenic average daily intake (NC-ADI) and carcinogenic average daily intake (C-ADI) were assessed

using RfD and cancer SF, as stated in Table 1 to get the hazard quotient and cancer risk. Hazard quotient and hazard index are unitless values that depict the associated adverse health effect from heavy metal exposure. From the present study (Table 7 and Fig. 3), the concentration of Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn showed that hazard quotients were all less than one (1) across all alcoholic beverages, as the hazard index (total hazard quotient) showed that H (1.48) and PW (1.89) were above one (1), which implies significant health effect or illness is possible for a period of time, whereas HG (0.51), IRW (0.80), IDG (0.73), LDG (0.75), GS (0.80) and W (0.97) were less than one (1) indicating no apparent potential health risk such as intoxication, drunkenness, vomiting, overdose in tandem to death, oxidative damage, chronic inflammatory diseases, premature aging and lung embolism [63, 79, 93–95].

The cancer risk (Table 8) evaluates the incremental chance that a respondent (adult) develops cancer-based issues over a period of time from a carcinogen [93, 95].

It is evidence from Fig. 4 that the risk total of the heavy metals (Cd, Cr, Pb, and Ni) were above the recommended limit of 1.00E-06–1.00E-04), which implies that HG, IRW, IDG, LDG, GS, and W can lead to significant cancer risk for an adult population of 1 in 10,000, whereas H and PW

**Table 6** Mean quantity (liters/day) of beverages consumed per day for different brands

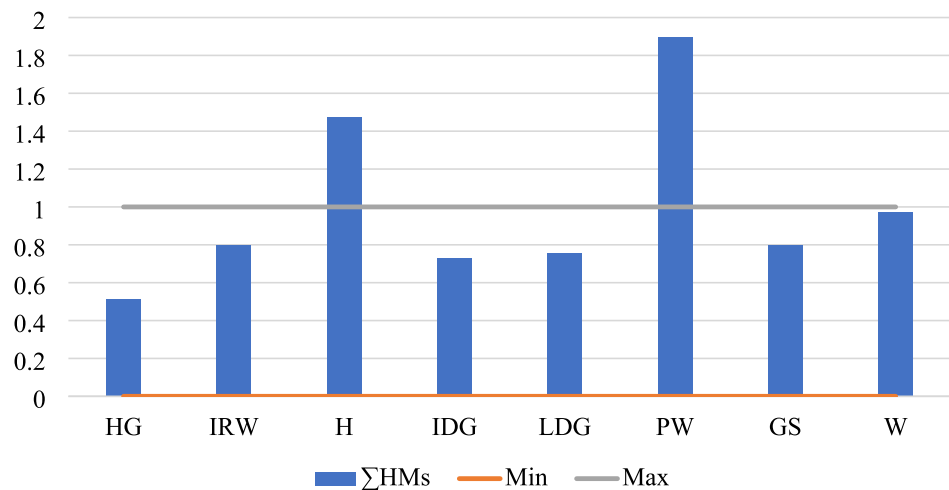
Beverage	Sample ID	Number of respondents (N)	Mean ± SD
Herbal gin (Action Bitters <sup>R</sup> )	HG	50	1.38 ± 1.01
Imported Red wine (Baron De Valla <sup>R</sup> )	IRW	50	2.09 ± 1.59
Heineken	H	50	2.49 ± 1.88
Imported dry gin (Lord's Gin <sup>R</sup> )	IDG	50	1.02 ± 0.67
Local dry gin	LDG	50	0.83 ± 0.61
Palm wine	PW	50	4.29 ± 2.01
Guinness stout	GS	50	2.76 ± 1.14
Whisky	W	50	1.62 ± 0.64



**Table 7** Non-carcinogenic average daily intake (NC-ADI) and carcinogenic average daily intake (C-ADI) of heavy metals from consumption of alcoholic beverages

Non carcinogenic average daily intake (NC-ADI)								
Alcoholic drink	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Nickel	Zinc
HG	3.31E-05	3.64E-04	1.52E-03	1.65E-04	9.76E-04	1.32E-04	9.92E-05	8.44E-04
IRW	1.25E-04	4.25E-04	1.32E-03	1.87E-03	1.10E-03	1.20E-03	7.50E-05	7.42E-03
H	2.69E-04	1.34E-03	7.16E-04	2.18E-03	1.49E-03	1.19E-04	2.69E-04	4.09E-03
IDG	1.34E-04	7.82E-04	1.64E-03	1.47E-04	5.38E-04	2.45E-05	1.22E-05	1.53E-03
LDG	1.09E-04	2.37E-04	9.26E-03	1.48E-04	7.71E-04	4.94E-05	1.98E-05	9.00E-04
PW	4.11E-04	9.26E-04	5.96E-03	1.39E-03	2.06E-03	1.54E-04	2.57E-04	1.39E-03
GS	1.98E-04	3.31E-04	1.32E-03	7.28E-04	7.28E-04	2.65E-04	9.92E-05	1.09E-02
W	2.14E-04	6.21E-04	1.40E-03	2.33E-04	1.01E-03	No Data	1.55E-04	3.05E-03
Carcinogenic average daily intake (CADI)								
Alcoholic drink	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Nickel	Zinc
HG	1.42E-05	1.56E-04	6.52E-04	7.09E-05	4.18E-04	5.67E-05	4.25E-05	3.62E-04
IRW	5.36E-05	1.82E-04	5.68E-04	8.03E-04	4.71E-04	5.14E-04	3.21E-05	3.18E-03
H	1.15E-04	5.76E-04	3.07E-04	9.34E-04	6.40E-04	5.12E-05	1.15E-04	1.75E-03
IDG	5.76E-05	3.35E-04	7.02E-04	6.29E-05	2.31E-04	1.05E-05	5.24E-06	6.55E-04
LDG	4.66E-05	1.02E-04	3.97E-03	6.36E-05	3.31E-04	2.12E-05	8.48E-06	3.86E-04
PW	1.76E-04	3.97E-04	2.56E-03	5.95E-04	8.82E-04	6.61E-05	1.10E-04	5.95E-04
GS	8.51E-05	1.42E-04	5.67E-04	3.12E-04	3.12E-04	1.13E-04	4.25E-05	4.68E-03
W	9.15E-05	2.66E-04	5.99E-04	9.99E-05	4.33E-04	No Data	6.66E-05	1.31E-03

No data analytical data unavailable

**Fig. 3** Hazard Index of alcoholic beverages

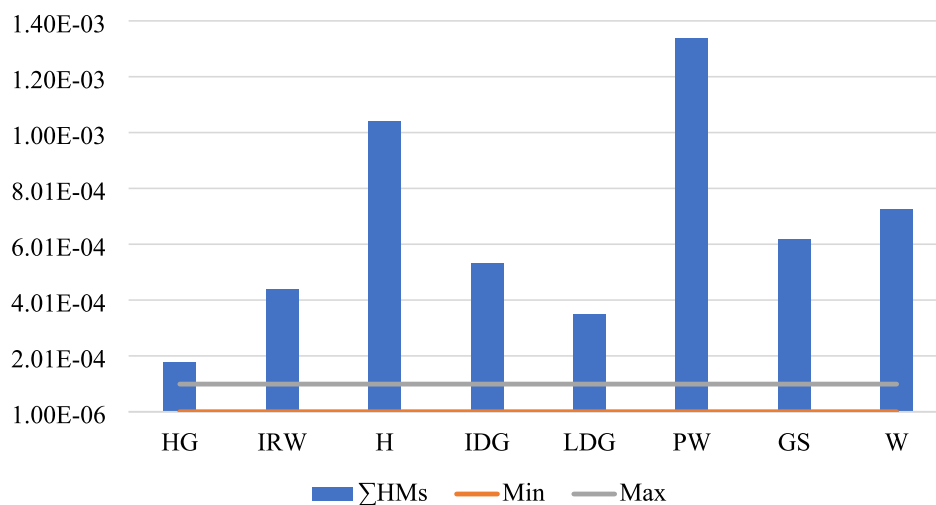
will impact 1 in 1000 population. Heavy metals have the potential to cause cancer risk. For example, in a study conducted by Middleton et al. [96], the authors averred that alcohol intake above 2 bottles has the potential to cause prostate cancer in males. In addition, excessive alcohol intake can cause the initiation of diverse cancer types such as breast, lungs, nasopharynx, pancreatic, kidney, stomach, and liver cirrhosis [97–100].

Except for a few literature reports by Izah et al. [101] on concentration and potential health implications of beverages consumed in Nigeria, Iwegbue et al. [77] on a survey of metal profiles in some traditional alcoholic beverages in Nigeria, Orisakwe et al. [102] on the copper, selenium, and zinc content of canned and non-canned beverages in Nigeria, and Maduabuchi et al. [103] on iron, manganese, and nickel exposure from beverages in Nigeria and public health

**Table 8** Hazard index and risk total of heavy metals from consumption of alcoholic beverages

Alcoholic drink	Hazard Quotient (HQ)								Hazard Index
	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Nickel	Zinc	
HG	6.62E-02	1.21E-01	3.80E-02	2.36E-03	2.79E-01	9.45E-04	1.18E-04	2.81E-03	5.11E-01
IRW	2.50E-01	1.42E-01	3.31E-02	2.68E-02	3.14E-01	8.57E-03	8.93E-05	2.47E-02	7.99E-01
H	5.37E-01	4.48E-01	1.79E-02	3.11E-02	4.26E-01	8.53E-04	3.20E-04	1.36E-02	1.48E+00
IDG	2.69E-01	2.61E-01	4.10E-02	2.10E-03	1.54E-01	1.75E-04	1.46E-05	5.09E-03	7.32E-01
LDG	2.18E-01	7.91E-02	2.31E-01	2.12E-03	2.20E-01	3.53E-04	2.35E-05	3.00E-03	7.54E-01
PW	8.23E-01	3.09E-01	1.49E-01	1.98E-02	5.88E-01	1.10E-03	3.06E-04	4.63E-03	1.89E+00
GS	3.97E-01	1.10E-01	3.31E-02	1.04E-02	2.08E-01	1.89E-03	1.18E-04	3.64E-02	7.97E-01
W	4.27E-01	2.07E-01	3.50E-02	3.33E-03	2.88E-01	No Data	1.85E-04	1.02E-02	9.71E-01
Alcoholic drink	Cancer Risk (CR)								Risk – Total
	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Nickel	Zinc	
HG	8.93E-05	7.80E-05	No CSF	No CSF	3.56E-06	No CSF	8.51E-06	No CSF	1.79E-04
IRW	3.37E-04	9.10E-05	No CSF	No CSF	4.01E-06	No CSF	6.43E-06	No CSF	4.39E-04
H	7.25E-04	2.88E-04	No CSF	No CSF	5.44E-06	No CSF	2.30E-05	No CSF	1.04E-03
IDG	3.63E-04	1.68E-04	No CSF	No CSF	1.96E-06	No CSF	1.05E-06	No CSF	5.34E-04
LDG	2.94E-04	5.09E-05	No CSF	No CSF	2.81E-06	No CSF	1.70E-06	No CSF	3.49E-04
PW	1.11E-03	1.98E-04	No CSF	No CSF	7.49E-06	No CSF	2.20E-05	No CSF	1.34E-03
GS	5.36E-04	7.09E-05	No CSF	No CSF	2.65E-06	No CSF	8.51E-06	No CSF	6.18E-04
W	5.77E-04	1.33E-04	No CSF	No CSF	3.68E-06	No Data	1.33E-05	No CSF	7.27E-04

No CSF absence of cancer slope factor; No data analytical data unavailable

**Fig. 4** Risk total of alcoholic beverages

concern, this study is likely the first of its kind in terms of evaluating heavy metal contamination in alcoholic beverages consumed in Awka, South-East Nigeria. Furthermore, the health and environmental risks of these toxic metals have been detailed in this work, raising an important alarm for government regulatory agencies, industrial players, alcoholic beverage consumers, and other beverage industry stakeholders to have a broader understanding of action plans and process controls.

## 4 Conclusion

The heavy metal composition of alcoholic beverages in Awka, Nigeria is unknown from empirical reviews as this study assessed the concentrations of Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn metals. Interesting dissimilarities were seen as Cu and Zn were the predominant contaminants possible from process water, production tools, and

packaging devices that have the potential to cause intense taste, odour, colour, and flavouring, in addition to adverse health issues from consumption. The concentrations were subjected to contamination and pollution potential, which showed no form of contamination across the diverse alcoholic brands. The average daily intake was evaluated using a consumption rating of each alcoholic brand to determine the hazard index and risk total, as HL and PW were more dominant than other brands such as HL, IRW, IDG, LDG, GS, and W. Therefore, carcinogenic risk shows that all respondents are at risk of having probable cancer disease from a population of 1 in 1000 to 10,000 people. Consequently, industrial players and regulatory agencies are advised to constantly follow food and beverage guidelines as required from an ethical standpoint to safeguard the health and wellbeing of consumers of alcoholic beverages.

**Acknowledgements** The authors would like to express their gratitude to Nnamdi Azikiwe University for their support, as well as the technical team of the Central Laboratory, Nigerian Institute for Oceanography and Marine Research, Victoria Island, Lagos, particularly Mr. Idumah O. Macaulay.

**Author Contributions** VNO: research concept, chemical analysis, results analysis, statistics, preparation of the manuscript, DOO: research concept, results analysis, statistics, preparation of the manuscript, CVO: sampling, results analysis, laboratory work, preparation of the manuscript, ECU: research concept, preparation of the manuscript.

**Funding** This work was unfunded.

**Data Availability** Data can be available upon request from the authors.

## Declarations

**Conflict of interest** There are no conflicts of interest declared by the authors.

## References

- Buglass AJ (2011) Handbook of Alcoholic Beverages: Technical, Analytical and Nutritional Aspects. 2 Volume Set (John Wiley & Sons Ltd) pp 1208. Accessed 5 Nov 2021
- Collins SE, Kirouac M (2013) Encyclopaedia of Behavioural Medicine. NY Springer, New York, pp 61–65. <https://doi.org/10.1007/978-1-4419-1005-9>
- Sayette MA (2017). Behav Res Ther. <https://doi.org/10.1016/j.brat.2016.06.005>
- Rehm J (2011) J Natl Institut Alcohol Abuse Alcoholism 34:2 (PMID: 22330211; PMCID: PMC3307043)
- Griswold MG, Fullman N, Hawley C, Arian N, Zimsen SRM, Tymeson HD, Venkateswaran V, Tapp AD, Forouzanfar MH, Salama JS, Abate D, Abay SM, Abbafati C, Abdulkader RS, Abebe Z, Aboyans V, Abrar MM, Acharya P, Adetokumbo OO, Adhikari TB, Adsuar JC, Afarideh M, Agardh EE, Agarwal G, Aghayan SA, Agarwal S, Ahmed MB, Akibu M (2018) Lancet 392:1015–1035. [https://doi.org/10.1016/S0140-6736\(18\)31310-2](https://doi.org/10.1016/S0140-6736(18)31310-2)
- Worldwide alcohol consumption declines. International Wines and Spirit Records (IWSR), (2019). Retrieved 2019-06-04.
- Vaillant GE, Keller M (2021) Encyclopaedia Britannica,. <https://www.britannica.com/topic/alcohol-consumption>. Accessed 14 Apr 2022.
- Bagchi SN, Sharma A (2015) Textbook of food and beverage service, 3rd Edn Aman Publications
- Omokpariola DO, Omokpariola PL. Chemical sciences in the focus edited by Ponnadurai Ramasami. <https://doi.org/10.1515/9783110726145-002>.
- Onwukeme VI, Okechukwu VU (2021) IOSR J Environ Sci Toxicol Food Technol 15:4. <https://doi.org/10.5620/eaht.2021023>
- Iweala EEJ, Olugbuyiro JAO, Durodola BM, Fubara-Manuel DR, Okoli AO (2014) Research Journal of Environmental Toxicology. <https://doi.org/10.3923/rjet.2014.92.97>. <https://scialert.net/abstract/?doi=rjet.2014.92.97>
- Voica C, Magdas D (2015) Feher. J Chem. <https://doi.org/10.1155/2015/192032>
- Isa NM, Aris AZ, Lim WY, Sulaiman WNAW, Praveena SM (2014) Arab J Geosci 7:3
- Ashraf S, Abbas F, Ibrahim M, Rashid U, Khalid S, Ahmad HR, Hakeem KR, Majeed T (2015) J Geog Sci 25:2
- Li W, Wang M, Liu L, Yan Y (2015) Water 7(3):1109–1128. <https://doi.org/10.3390/w7031109>
- Thuong NT, Yoneda M, Shimada Y (2015) Environ Earth Sci 73:3925–3936. <https://doi.org/10.1007/s12665-014-3678-7>
- Varol M, Şen B (2012). Catena. <https://doi.org/10.1016/j.catena.2011.11.011>
- Zhao H, Xia B, Fan C, Zhao P, Shen S (2012) Sci Total Environ 417–418 (2012). <https://doi.org/10.1016/j.scitotenv.2011.12.047>
- Li Z, Ma Z, van der Kuijp TJ, Yuan Z, Huang L (2014). Sci Total Environ. <https://doi.org/10.1016/j.scitotenv.2013.08.090>
- Varol M (2019) Chemosphere 228:1–8. <https://doi.org/10.1016/j.chemosphere.2019.04.126>
- Chabukdhara M, Nema AK (2012) Chemosphere 87:8. <https://doi.org/10.1016/j.chemosphere.2012.01.055>
- Luo C, Liu C, Wang Y, Liu X, Li F, Zhang G, Li X (2011). J Hazard Mater. <https://doi.org/10.1016/j.jhazmat.2010.11.024>
- Sharma RK, Agrawal M, Marshall FM (2009) Food Chem Toxicol 47(3):583–591. <https://doi.org/10.1016/j.fct.2008.12.016>
- Shabbaj II, Alghamdi MA, Shamy M, Hassan SK, Alsharif MM, Khoder MI (2017) Int J Environ Res Public Health 15(1):36. <https://doi.org/10.3390/ijerph15010036>
- Okafor VN (2016) Hops and potential Nigerian substitutes: comparative studies in beer brewing. Lambert Academic Publishing-GmbH & Co. KG, Germany
- Okafor VN, Eboatu AN, Omuku PE (2016) Asian J Med Health Res 1:6
- Okafor VN, Tabugbo IB, Anyalebechi RI, Okafor UW, Obiefuna NJ (2020) Int Res J Pure Appl Chem 21:15
- Okafor VN, Umennadi PU, Odidika CC, Vinna DC (2021). J Chem Soc Nigeria. <https://doi.org/10.46602/jcsn.v46i4.646>
- Pohl P (2008) Food Addit Contam 25:6. <https://doi.org/10.1080/02652030701772323>
- Omokpariola DO, Omokpariola ECO, Okechukwu VU (2021) Bull Chem Soc Ethiop 35(2):461. <https://doi.org/10.4314/bcse.v35i2.18>
- Omokpariola ECO, Omokpariola DO (2021) World Scientific News. 154:89
- Okafor VN, Eboatu AN, Anyalebechi RI, Okafor UW (2016) J Adv Chem Sci 2:4
- Okafor VN (2016) Int J Adv Res 4:12. <https://doi.org/10.21474/IJAR01/2675>
- Jorge G, Ibanez JG, Alejandra CA, Maximiliano BM, Norberto CN (2008). J Food Compos Analysis. <https://doi.org/10.1016/j.jfca.2008.06.005>

35. Nędzarek A, Krzysztof F, Formicki K, Kowalska-Goralska M, Dobrzanski Z (2022). *J Food Compos Anal*. <https://doi.org/10.1016/j.jfca.2022.104525>
36. Song D, Zhuang D, Jiang D, Fu J, Wang Q (2015). *Int J Environ Res Public Health*. <https://doi.org/10.3390/ijerph120707100>
37. FAO/WHO. Summary and Conclusions of the 61st Meeting of the Joint FAO/WHO Expert Committee on Food Additives. Available online: <ftp://ftp.fao.org/esn/jecfa/jecfa61sc.pdf> (accessed on 4 Dec 2015).
38. EPA. Integrated Risk Information System. Available online: <http://www.epa.gov/iris/rfd.htm> (accessed on 4 Dec 2015).
39. EPA. Risk Assessment Guidance for Superfund (Part E, Part F); EPA: Washington, DC, USA, 2011.
40. I. Al-Saleh, M. Nester, E. DeVol, N. Shinwari, S. Al-Shahria, *Int. J. Occup. Environ. Health*, 5 (1999). <https://doi.org/10.1179/oe.1999.5.2.107>. PMID: 10330510.
41. EPA (1986) Guidelines for the health risk assessment of chemical mixtures. *Fed Regist* 51:34014–34025
42. Cao S, Duan X, Zhao X, Wang B, Ma J, Fan D, Sun C, He B, Wei F, Jiang G (2015). *Environ Pollut*. <https://doi.org/10.1016/j.envpol.2015.02.010> (PMID: 25686884)
43. EPA. Risk assessment guidance for superfund: Volume I. Human health evaluation manual (Part A). U.S.; EPA: Washington, DC, USA, 1989.
44. IARC, in IARC monographs on the evaluation of the carcinogenic risk of chemicals to humans. (International Agency for Research on Cancer: Monograph No. 58, Lyon, 1993).
45. Zheng X, Han B, Thavamani P, Duan L, Naidu LR (2015). *Environ Earth Sci*. <https://doi.org/10.1007/s12665-015-4287-9>
46. Vetrimurugan E, Brindha K, Elango L, Osman MN (2017). *Appl Water Sci*. <https://doi.org/10.1007/s13201-016-0472-6>
47. Edokpayi JN, Enitan AM, Mutileni N, Odiyo JO (2018) *Chem Central J* 12:2. <https://doi.org/10.1186/s13065-017-0369-y>
48. Boateng TK, Opoku F, Akoto O (2019) *Appl Water Sci* 9:33. <https://doi.org/10.1007/s13201-019-0915-y>
49. Okafor VN, Omokpariola DO, Igbokwe EC, C.M. Theodore CM, Chukwu NG (2022) *Int J Env Anal Chem* <https://doi.org/10.1080/03067319.2022.2038587>
50. Onoyima CC, Okibe FG, Ogah E, Dallatu YA (2021) *J Res Fores Wildlife Environ* 13(4):205–214
51. Wickham H, François R, Henry L, Müller K (2021). <https://CRAN.R-project.org/package=dplyr>. Assessed 31 Dec 2021
52. Francois R, Eddelbuettel D, Bates D (2012) *RcppArmadillo: Rcpp integration for Armadillo templated linear algebra library-R package version 0.3*
53. Eurachem (1998) The fitness for purpose of analytical method: a laboratory guide to method validation and related topics. [www.eurachem.org/guides/pdf/valid.pdf](http://www.eurachem.org/guides/pdf/valid.pdf). Accessed 27 July 2020
54. Christian GD (2003) *Analytical chemistry*, 6th edn. Wiley, New York, p 128
55. Addis W, Abebaw A (2017). *Cogent Chem*. <https://doi.org/10.1080/23312009.2017.1419422>
56. Tan M, Sudjadi A, Astuti R, Rohman A (2018) *J Appl Pharm Sci*. 8(2):44–48. <https://doi.org/10.7324/JAPS.2018.8206>
57. World Health Organization (WHO). Content sheet 7–1: overview of quality control for quantitative tests, pp 1–13. [www.who.int/ihr/training/laboratory\\_quality/7\\_b\\_content\\_quant\\_qc.pdf?ua=1](http://www.who.int/ihr/training/laboratory_quality/7_b_content_quant_qc.pdf?ua=1). Assessed 30 July 2020
58. Deka AK, Handique P, Deka DC (2021) *Toxicology Reports* 8(2021):1220–1225. <https://doi.org/10.1016/j.toxrep.2021.06.013>
59. OIV. Compendium of international methods of wine and must analysis. 1st ed. Organization Internationale de la Vigne et du VIN (OIV), 2 C, OIV, Paris 2007 – 2008, 2008, 1–3.
60. World Health Organization. Guidelines for drinking-water quality: 4th ed. World Health Organization (WHO) incorporating the first addendum. Geneva. 2017. <https://apps.who.int/iris/rest/bitstreams/1080656/retrieve>.
61. Richard G, Youkparigha FO, Aigberua AO, Izah SC, Braide B (2021). *J Biotechnol Res*. <https://doi.org/10.32861/jbr.73.34.38>
62. Charehsaz M, Helvacioğlu S, Etinkaya SC, Demir R, Erdem O, Aydin A (2021). *Hum Exp Toxicol*. <https://doi.org/10.1177/0960327121993215>
63. Van-Wyk TN, Van Jaarsveld F, Caleb OJ, Afr S (2021). *J Enol Vitic*. <https://doi.org/10.21548/42-1-4238>
64. Liao Z, Chen Y, Ma J, Islam MS, Weng L, Li Y (2019). *Int J Environ Res Public Health*. <https://doi.org/10.3390/ijerph16152805>
65. Okaru AO, Lachenmeier DW (2021). *Nutrients*. <https://doi.org/10.3390/nu13113785>
66. Ayannuga AA, Oyekunle JA, Ijomone OM, Ibeachusim BI (2015). *Environ Pollut*. <https://doi.org/10.1164/j.css.20190402.11>
67. Iwegbue CMA, Overah LC, Bassey FI, Martincigh BS (2014). *J Inst Brew*. <https://doi.org/10.1007/s11694-014-9221-4>
68. Woldemariam DM, Chandravanshi BS (2011). *Bull Chem Soc Ethio*. <https://doi.org/10.4314/bcse.v25i2.65852>
69. Okareh OT, Oyelakin TM, Ariyo O (2018). *Beverages*. <https://doi.org/10.3390/BEVERAGES4030060>
70. Osei CB, Tortoe C, Kyereh E, Adjei-Mensah R, Johnson P-NT, Aryeaa D (2021). *Scientific African*. <https://doi.org/10.1016/j.sciaf.2021.e00813>
71. Tampah-Naah AM, Amoah ST (2015). *BMC Public Health*. <https://doi.org/10.1186/s12889-015-1651-3>
72. Tegegne WA (2015) *J Cereals Oilseeds* 6:2. <https://doi.org/10.5897/JCO15.0138>
73. Duodu GO, Amartey EO, Asumadu-Sakyi AB, Adjei CA, Quashie FK, Nsiah-Akoto I, Ayanu G (2012). *Food Public Health*. <https://doi.org/10.5923/j.fph.20120201.01>
74. Amidžić KD, Klarić I, Velić D, Dragojević IV (2011) *Czech J Food Sci* 29(2011):260–267. <https://doi.org/10.17221/132/2009-CJFS>
75. Abdel-Rahman GN, Ahmed MBM, Sabry BA, Ali SSM (2019) *Toxicol Rep* 6:210–214. <https://doi.org/10.1016/j.toxrep.2019.02.010>
76. Odangowei IO, Okiemute O, Chiemeziem ON, Oghenetega E (2020) *Int J Res Sci Innov* 7(4):176–179
77. Iwegbue CMA, Anwuli LO, Francisca IB (2014) *Food Sci Nutr* 2:724
78. Özcan M, Harmankaya M, Gezgin S (2011) *Environ Monit Assess* 184(1):313–20. <https://doi.org/10.1007/s10661-011-1969-y>
79. Ogidi OI, Enenebeaku UE, Okara E, Elumelu SA (2021). *J Toxicol Risk Assess*. <https://doi.org/10.23937/2572-4061.1510039>
80. Gazuwa SY, Dabak JD, Olomu SA, Abdullahi BH (2017). *Int J Biochem Res Rev*. <https://doi.org/10.23937/2572-4061.1510039>
81. Gonzalez A, Peters U, Lampe JW, White E (2009). *Nutr Cancer*. <https://doi.org/10.1080/01635580802419749>
82. Bondreau REA, Carmody G, Cheatham JJ (1999) <https://doi.org/10.26879/99014paleo-electronica.org/content/2-2-pareto>
83. Vu CT, Lin C, Shern C-C, Yeh C, Le VG, Tran HT (2017). *Ecol Ind*. <https://doi.org/10.1016/j.ecolind.2017.06.008>
84. Yan N, Liu WB, Xie HT, Gao LR, Han Y, Wang MJ, Li HF (2016) *J Environ Sci-China* 39:45
85. Ojaniyi OF, Okoye PAC, Omokpariola DO (2021). *Asian J Appl Chem Res*. <https://doi.org/10.9734/AJACR/2021/v9i130205>
86. National Agency for Food & Drug Administration & Control (NAFDAC). Food Safety & Applied Nutrition (FSAN) Directorate. Guidelines for inspection & requirements for pre-packaged food manufacturing/packing facilities in Nigeria. Doc. Ref. No: FSAN-GDL-002-01. 2018, 1-11. Available from: <http://www.nafdac.gov.ng/wp-content/uploads/Files/Resources/Guidelines/>

- [FOOD\\_GUILDINES/Guildines-for-Inspection-and-Requirements-for-Packaged-Water-Facility-in-Nigeria.pdf](#). Accessed 20 Jan 2021
87. Dobaradaran S, Fard ES, Tekle-Röttering A, Keshtkar M, Karbasdehi VN, Abtahi M, Gholamnia R, Saeedi R (2020). *Environ Res*. <https://doi.org/10.1016/j.envres.2019.109062>
  88. Omokpariola DO, Nduka JK, Kelle HI, Mgbemena MN, Iduseri EO (2021). *Sci Rep Preprint*. <https://doi.org/10.2120/rs.3.rs-967523/v1>
  89. IPCS (2009) Environmental health criteria 239: principles for modelling dose-response for the risk assessment of chemicals; World Health Organization: Geneva, Switzerland
  90. Pflaum T, Hausler T, Baumung C, Ackermann S, Kuballa T, Rehm J, Lachenmeier DW (2016). *Arch Toxicol*. <https://doi.org/10.1007/s00204-016-1770-3>
  91. Okaru AO, Rehm J, Sommerfeld K, Kuballa T, Walch SG, Lachenmeier DW (2019) The Threat to quality of alcoholic beverages by unrecorded consumption in Alcoholic Beverages. Woodhead Publishing, Cambridge, pp 1–34
  92. Lachenmeier DW, Przybylski MC, Rehm J (2012). *Int J Cancer*. <https://doi.org/10.1002/ijc.27553>
  93. Lachenmeier DW, Gill JS, Chick J, Rehm J (2015). *Food Chem Toxicol*. <https://doi.org/10.1016/j.fct.2015.05.006>
  94. Lachenmeier DW, Rehm J (2015). *Sci Rep*. <https://doi.org/10.1038/srep08126>
  95. Okechukwu VU, Omokpariola DO, Onwukeme VI, Nweke EN, Omokpariola PL (2021). *Env Anal Health Toxicol*. <https://doi.org/10.5620/eaht.2021023>
  96. Middleton FK, Chikritzhs T, Stockwell T, Bostrom A, Pascal R (2009) *Mol Nutr Food Res* 53:2
  97. Genchi G, Sinicropi MS, Lauria G, Carocci A, Catalano A (2020) *Int J Environ Res Public Health* 17:11. <https://doi.org/10.3390/ijerph17113782>
  98. Omokpariola DO (2022) *Environ Analysis Health Toxicol* 37(3):e2022019. <https://doi.org/10.5620/eaht.2022019>
  99. Omokpariola PL, Omokpariola DO (2021) *ACS Chem Health Safety* 28(6):457–467. <https://doi.org/10.1021/acs.chas.1c00045>
  100. Ojaniyi OF, Okoye PAC, Omokpariola DO (2021) *Asian J Appl Chem Res* 9(1):64–81. <https://doi.org/10.9734/AJACR/2021/v9i130205>
  101. Izah SC, Inyang IR, Angaye TCN, Okowa IP (2017) *Toxics* 5(1):1. <https://doi.org/10.3390/toxics5010001>
  102. Orisakwe OE, Oragwu CI, Maduabuchi JMU, Nzegwu CN, Nduka JKC (2009) *Afr J Environ Sci Technol* 3(1):042–049. <https://doi.org/10.5897/AJEST08.153ISSN1991-637X>
  103. Maduabuchi JM, Nzegwu CN, Adigba EO, Chikelue IO, Agbo FN, Agbata CA, Ani GC, Orisakwe OE (2008) *J Health Sci* 54(2):335–338. <https://doi.org/10.1248/jhs.54.335>

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.