Scientific Research Publishing

American Journal of Analytical Chemistry, 2022, 13, 314-330
https://www.scirp.org/journal/ajac
ISSN Online: 2156-8278
ISSN Print: 2156-8251

Trace Metal Leaching from Cookware Locally Fabricated from Scrap Metal: A Case Study of Ntungamo District, Uganda

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How to cite this paper: Habimaana, S., Gumisiriza, H. and Birungi, G. (2022) Trace Metal Leaching from Cookware Locally Fabricated from Scrap Metal: A Case Study of Ntungamo District, Uganda. *American Journal of Analytical Chemistry*, **13**, 314-330.
https://doi.org/10.4236/ajac.2022.139022

Received: August 2, 2022
Accepted: September 24, 2022
Published: September 27, 2022

Abstract

Heavy metal exposure remains a significant public health problem, particularly in sub-Saharan Africa where use of artisanal cookware made from recycled metallic materials is still common. In this study, the effect of cookware composition, cleaning material, heating duration and temperature on metal migration from different cookware, including artisanal pans was investigated. Trace element concentrations were determined with Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). Locally fabricated cookware leached the highest levels of metals, where the levels of Pb ($9.00 \pm 0.80 \times 10^{-2}$ mg/l), Al ($11.40 \pm 0.02 \times 10^{-2}$ mg/l), Cd ($5.80 \pm 0.30 \times 10^{-2}$ mg/l), Cr ($6.60 \pm 0.03 \times 10^{-2}$ mg/l) and Ni ($3.00 \pm 0.01 \times 10^{-2}$ mg/l) were above the WHO permissible limits of heavy metals for drinking water. Steel wire was the most aggressive cleaning material to the cookware surfaces, followed by sand and then ash. For cookware heated at 100˚C and above, an exponential relationship between temperature and the migration of Al, Pb and Cd was observed. The findings revealed heavy metal exposure from cookware usage, which poses potential health risks to the population. There is need for policies and civic education to minimize this exposure.

Keywords

Local Fabrication, Cookware, Metal Leaching, Scrap Metal, Uganda

1. Introduction

Cookware comprises of cooking vessels, such as saucepans and frying pans that can conduct heat during the cooking process [1]. Globally, metals and alloys are commonly used for the production of cookware, owing to their high thermal conductivity and thermostability [2]. The most used metals include Al, Cu, Fe, Sn, Cr and Ni, however, other toxic trace elements, like As, Pb, and Cd, can be included either as contaminants or impurities in the manufacturing process [2] [3]. For instance, stainless cookware is made from an alloy which is mainly iron containing chromium, nickel, and some manganese and these saucepans are commonly used for kitchen cookware [4]. The composition of stainless steel varies from 50% to 88% Fe, 11% to 30% Cr, and 0% to 31% Ni [5]. Aluminum cookware is formed from sheets of aluminum metal, and due to its softness, it may be alloyed with magnesium, copper, or bronze to increase its strength [6]. This implies that the population which uses metallic cookware in everyday life in household activities, especially boiling water and cooking food stuffs may be at risk of metal exposure.

Studies have demonstrated that when metallic cookware comes in contact with food, migration of trace elements into food occurs [7] [8] [9] which poses a significant impact on human health. Although trace levels of some metals, such as Cr, Fe, Cu are vital for normal body functioning, excessive intake of such metals can be very harmful to health [10]. These elements cause organ toxicity and are also carcinogenic [2]. When ingested, Cd, Ni, and Pb predominantly affect the kidney, while As can cause multi-organ failure [11] [12]. A recent study revealed that ingestion of mercury, lead, arsenic and cadmium resulted in more than one million cases of ill health and more than 56,000 deaths, of which, over half (54%) were due to lead, 22% and 20% from methylmercury and arsenic respectively and 1% from cadmium [8]. The contamination of food with metals has been worsened by the use of locally fabricated cookware items manufactured from scrap metal by local artisans [7].

The use of scrap metal waste as a source of artisanal production of cookware has continued to increase by over 40% from the start of the aluminium industry in 1920 [7]. Scrap metal has been used as a primary source of aluminium in 43 countries of the world by the year 2000, with the United States producing about 35% of the primary aluminium recovered from scrap metal waste [13]. Scrap is made up of discarded metal waste of car parts and old aluminium saucepans which make the largest composition of the scrap metal used in the artisanal fabrication process of cookware [14]. These fabricated cookware types are abundantly used in Asia [15] [16] and throughout Africa [8] [17] [18].

In sub-Saharan Africa, aluminium pots replaced earthenware vessels [19] and proliferated as a normal piece of everyday cooking equipment [20], which has exposed the population to aluminium poisoning [7] [9]. As a result, previous studies focused on food contamination by metal leaching from the commonly used aluminium cookware in South Africa [8], Nigeria [7] [21] [22], Benin, Cameroon, Mali and Nigeria [17], Cameroon, Senegal, Central African Republic [18], leaving other metallic cookware less studied. However, there is limited data on comparison of metal leaching from the various metallic cookware materials. This suggests that there is urgent need to evaluate possibilities of metal exposure from different types of cookware commonly used by the African population, including the locally fabricated cookware.

The widespread artisanal production and use of artisanal cookware has been reported in Bangladesh [15], India [16] and the developing countries around the world [17]. Like most Sub-Saharan Africa households, about 73% of the rural population in Uganda use locally made cookware recycled from scrap metal [23], while very few rich urban dwellers use the factory-made pans, and variations in leaching of aluminium into human food from different types of African cookware in the districts of Arua, Rukungiri and Soroti in Uganda have been reported [19]. A survey in Ntungamo district reported 68% of the households to be using locally fabricated cookware, commonly referred to as "*endongoburaya*" [24].

The high demand for cookware has led to its increased production, often without any information about the manufacture or composition of the cookware pieces [25], hence possible exposure to substandard products [7]. In developing countries, much of this cookware is locally made, uncoated and not anodized [26] which makes them prone to corrosion. Producers of cookware depend on scrap metal waste and used aluminum products such as plates, motor parts, old metal pots, broken spoons, and cans, which are picked up from the streets [27]. This source of raw materials for the production of cookware could lead to human exposure to heavy metals through diet. A concern about possible absorption of aluminium (Al), cadmium (Cd), lead (Pb), nickel (Ni), copper (Cu), arsenic (As), and other heavy metals leaching into boiled water and food from cookware, as a result of corrosion of cookware materials has been reported [28]. These heavy metals have various deleterious effects in the biological system [7].

Boiling water before drinking is a common practice in several parts of the world, especially in developing countries with inadequate access to portable water [7]. This practice which is encouraged by WHO to prevent waterborne diseases [29], can be a plausible route of entry of heavy metals and other trace elements into drinking water and eventually into human systems with its associated adverse health effects. Furthermore, many homes use their cookware for several years without disposal despite obvious corrosion of the cooking pots perhaps due to lack of information or poverty. This behavior can further increase the leaching of heavy metals into boiled water and food. Also, the effect of cleaning methods on metal leaching from cookware has been reported [30]. For example, steel wire which is widely used was found to have scratching effect on the cookware, which may accelerate metal leaching [31]. Other common cookware cleaning methods include using ash, sand, scouring pad and sponge.

Cookware has been reported to be a likely source of heavy metal leaching into beverages, water, and food under diverse experimental conditions modified by varying the levels of citrate, chlorides, fluorides, pH, and acetate [32]. Studies have further confirmed that leaching of heavy metals is dependent on pH, temperature, age of the cookware, and the presence of complexing agents from the alloys used in making the cookware [26] [28] [33]. Cooking at high temperatures was also found to increase the rate of metal leaching [25]. Metal leaching from a cookware during cooking was reported to be five times higher at 100˚C than at ambient temperature [34]. Similarly, longer cooking durations were found to increase the levels of metal leaching from cookware [30]. However, there is paucity of data concerning the effect of cookware composition and cleaning materials on leaching of heavy metals from locally fabricated cookware, yet they are used by 88% of the Ugandan population [35]. In this study, the heavy metal constituents of the water boiled from different cookware used in Ntungamo district in Western Uganda were evaluated in order to establish the potential of locally fabricated cookware leaching trace metals into drinking water.

2. Methods

2.1. Study Area

The cookware samples were purchased from three markets located in Ntungamo district, Western Uganda: Kagarama market at E030.17012-0.83165 from where aluminium cookware were obtained, Karegyeya trading centre at E030.23490-0.88020 where locally fabricated cookware were obtained and Nyakazinga market at E030.13032-0.83401 from where stainless-steel cookware were obtained (**Figure 1**). Geographic location was determined using GPS Etrex 10, Garmin technology.

2.2. Instrumentation

Analyses were carried out using Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES, Perkin-Elmer, USA; ICP Optima 4300 DV), equipped with an auto-sampler (AS93 plus, PE) and with two peristaltic pumps (WSP3000 series) and regulated argon gas supply (**Table 1**).

These elements were selected basing on their prevalence in cookware studies reported elsewhere in the world [7] [8] [15] [16] [17] [18] [21] [22].

Table 1. Investigated elements and their respective wavelength set for their identification and quantification.

Element	Wave length (nm)
Aluminium (Al)	396.153
Arsenic (As)	193.696
Cadmium (Pd)	228.802
Chromium (Cr)	267.716
Copper (Cu)	327.393
Iron (Fe)	238.204
Lead (Pb)	220.353
Manganese (Mn)	257.610
Mercury (Hg)	253.652
Nickel (Ni)	231.604

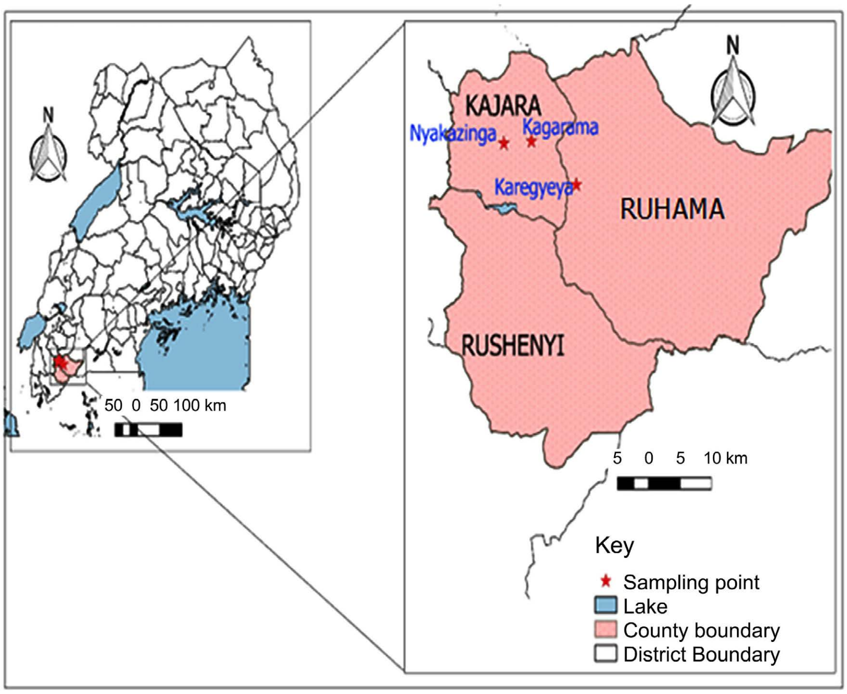


Figure 1. Location of the study area in Western Uganda, showing the sampling sites (Source: Generated from shape files using ARC-GIS software).

2.3. Reagents

All reagents were of analytical grade. Nitric acid (Merck), sulphuric acid (Merck) and Whatman 0.45 μm membrane filter paper were used. The calibration of the ICP-OES device was completed with five concentrations in the range of 0 - 10 ppm. For this we used a multi-element standard solution of 1 g/L (atomic spectrometry standard, Perkin-Elmer, USA).

2.4. Sample Preparation

The inner walls of the locally fabricated, aluminium and stainless-steel cookware were separately cleaned using steel wire, ash, sand, scouring pad and sponge. This was done by scrubbing the inner walls of a cookware with deionised water and soap using a cleaning material such as steel wire, and then rinsing the cookware twice with deionised water. Deionised water was used in cleaning and rinsing to avoid possible metal deposits from water used. Deionised water (1 litre) was poured in each of the rinsed saucepans, heated until the water boiled and rolled for one minute. Into another set of cleaned and rinsed cookware, deionised water (1 litre) was heated using a water bath (Model: Grant OLS200) at 50˚C for 30 minutes, 1 hour, 2 hours, 3 hours and 4 hours, according to a method described by Kamerud *et al.* [36]. For the third set of cookware, water was heated using an oven set at temperatures of 30˚C, 50˚C, 100˚C, 150˚C and 200˚C for 1 hour following a method by Bassioni *et al.* [37]. The cookware was placed in an oven, with a tolerance of 0.8˚C and 1.9˚C at 0˚C - 100 and 100˚C - 200˚C respectively, to reach and maintain a particular temperature.

The boiled water samples were then filtered through Whatman 0.45 µm membrane filter paper. The filtrate (50 ml) was digested using concentrated nitric acid (5 ml) and concentrated sulphuric acid (5 ml). The digested sample was allowed to cool to room temperature and then filtered through Whatman's 0.45 µm filter paper. The final volume was adjusted to 50 ml with double distilled water following the method by Cobbina *et al.* [38]. The digested water samples (50 ml each) were packed into a 60 ml PET bottle to allow space for possible thermal expansion. The composite sample (45 ml) was obtained by measuring 1ml from each of the digested water samples. Deionised water (not boiled in any cookware) was used as a negative control.

The concentration of all elements as shown in **Table 1** (aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury and nickel) was monitored with ICP-OES. Each analysis was performed in triplicate and the average value was calculated.

3. Results and Discussion

3.1. The Effect of Cleaning Material on Leaching of Heavy Metals into Boiled Water

Generally, the concentration of trace elements into boiled water was highest in the cookware cleaned using steel wire > sand > ash > scouring pad > sponge, according to the reducing abrasion effect of the cookware surfaces (**Table 2**). The presence of Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Hg and Ni was detected in boiled water samples, but not detected in the deionized water control sample. The presence of heavy metals in boiled water samples confirms the leaching of heavy metals from the cookware into the water during the heating process, and therefore equally during cooking.

The levels of Al, Cd, Cr, Pb, and Ni in water samples boiled from different cookware cleaned using steel wire were higher than the WHO maximum permissible limits for drinking water, except for aluminium in stainless steel cookware (**Table 2**). These high levels were probably due to the high abrasive effect of steel wire on the cookware surface, which exposes the metal fabric of the cookware to accelerate metal leaching [31] much more than other cleaning materials under study. In addition, steel wire leaves its residues into the cookware after rinsing and this contaminates water with metals that make up the composition of steel wire [39]. Therefore, the use of steel wire during cookware cleaning poses a high risk to the population. This can be minimized by using the less abrasive cleaning materials such as sponge or scouring pad.

The high levels of Al, Cd, Cr, Pb, and Ni (**Table 2**) in all boiled water shows a potential to expose the population to heavy metals which if accumulated in their bodies would have life threatening health effects. For instance, lead and cadmium exposure is associated with brain damage and lowers IQ levels especially in children [40]. Also, lead exposure has been reported to account for more than 853,000 deaths per year globally [41]. Similarly, cadmium has been reported to

Table 2. Mean metal concentrations (mg/l) in water boiled from different cookware types cleaned using different materials.

Cookware Type	Cleaning Material	Mean Concentration ± SD (mg/l) (n = 45)						
		Pb × 10^{-2}	Al × 10^{-2}	Cd × 10^{-2}	Fe × 10^{-2}	Cr × 10^{-2}	Ni × 10^{-2}	Mn × 10^{-2}
Locally Fabricated cookware (*Endongoburaya*)	Steel wire	9.00 ± 0.80	11.40 ± 0.02	5.80 ± 0.30	0.80 ± 0.07	6.60 ± 0.03	3.00 ± 0.01	5.50 ± 0.11
	Sand	4.00 ± 0.30	6.10 ± 0.09	0.41 ± 0.01	0.70 ± 0.40	1.00 ± 0.02	1.00 ± 0.03	1.20 ± 0.03
	Ash	3.00 ± 0.10	2.60 ± 0.05	0.40 ± 0.10	0.50 ± 0.30	1.00 ± 0.05	1.30 ± 0.02	1.10 ± 0.02
	Scouring pad	7.00 ± 0.60	5.90 ± 0.23	0.40 ± 0.20	0.20 ± 0.20	0.50 ± 0.02	1.70 ± 0.11	2.00 ± 0.01
	Sponge	1.00 ± 0.20	2.30 ± 0.13	0.20 ± 0.10	Nd	0.20 ± 0.01	Nd	nd
Aluminium cookware	Steel wire	7.0 ± 0.60	58.30 ± 0.62	1.20 ± 0.20	6.00 ± 0.30	2.00 ± 0.60	2.10 ± 0.19	3.70 ± 0.60
	Sand	3.0 ± 2.00	54.00 ± 0.03	0.30 ± 0.04	1.60 ± 0.41	1.10 ± 0.20	1.00 ± 0.15	0.07 ± 0.03
	Ash	5.0 ± 1.00	28.90 ± 0.41	0.10 ± 0.03	0.10 ± 0.02	0.30 ± 0.02	1.30 ± 0.21	nd
	Scouring pad	1.0 ± 0.50	3.40 ± 0.03	0.10 ± 0.02	Nd	0.10 ± 0.02	0.20 ± 0.03	Nd
	Sponge	0.6 ± 0.10	2.10 ± 0.04	nd	nd	nd	Nd	Nd
Stainless-steel cookware	Steel wire	2.80 ± 0.50	7.40 ± 0.40	0.50 ± 0.10	11.00 ± 0.20	1.50 ± 0.30	4.80 ± 0.80	3.00 ± 0.06
	Sand	2.00 ± 0.70	3.30 ± 0.41	0.40 ± 0.20	3.00 ± 0.09	1.20 ± 0.13	0.60 ± 0.30	0.70 ± 0.03
	Ash	0.60 ± 0.40	3.90 ± 1.20	0.40 ± 0.10	1.80 ± 0.10	1.00 ± 0.80	Nd	Nd
	Scouring Pad	nd	2.60 ± 0.40	nd	Nd	nd	Nd	Nd
	Sponge	nd	0.20 ± 0.10	nd	Nd	nd	Nd	Nd
WHO		**1.00**	**10.00**	**0.30**	**10.00**	**5.00**	**2.00**	**40.00**

nd, not detected; WHO, World Health Organisation Permissible limits for drinking water.

be neurotoxic, carcinogenic and causes kidney and heart damage [42]. Aluminum is also suspected to contribute to neurodegenerative diseases [43]. This implies that continuous exposure to heavy metals is of great health risk.

Water boiled from cookware cleaned using a sponge contained the least metal levels and, in most cases, the heavy metals were not detected. Where detected, the heavy metal levels were still lower than the WHO permissible limits of heavy metals as indicated in **Table 2**. The low levels were attributed to the least abrasive effect of sponge on the cookware surface, implying least cookware fabric exposure due to cleaning. However, the presence of some heavy metals in water boiled from cookware cleaned using sponge suggests that, irrespective of the cleaning material, cookware can still leach some heavy metals. Though cleaning using sponge causes leaching of metals within WHO permissible limits for drinking water, daily exposure through food and water is still a great health threat since heavy metals have the ability to bioaccumulate within the body [44].

3.2. The Effect of Cookware Composition on Leaching of Heavy Metals into Boiled Water

Generally, boiled water from locally fabricated cookware contained the highest concentrations of heavy metals followed by aluminium cookware and finally stainless-steel cookware (**Table 2**). All the boiled water samples from locally fabricated cookware cleaned using steel wire contained all the studied metals with levels higher than the WHO permissible limits for drinking water, except for Fe and Mn. The levels of Pb and Cd were higher than WHO permissible limits in all water samples, except where sponge was used to clean the cookware. These findings suggest that the use of locally fabricated cookware exposes boiled water and food to metal contamination effect is exacerbated by harsh cleaning materials. The source of these heavy metals is likely to be metal scrap which is the raw material used to fabricate the cookware by local artisanal activity [45], in which the component metals are inadequately alloyed and not anodized [16]. Thus, such cookware cannot resist corrosion by water, salt and other environmental agents, and by a wide range of other chemical and physical agents [16]. Therefore, there is need to improve on procedures for artisanal fabrication of cookware to meet minimum standards for manufacturing of cookware.

Water boiled in locally fabricated cookware contained highest levels of aluminium ($11.40 \pm 0.02 \times 10^{-2}$ mg/ml) followed by lead ($9.00 \pm 0.80 \times 10^{-2}$ mg/ml) and then cadmium ($5.80 \pm 0.30 \times 10^{-2}$ mg/ml), all far above WHO permissible limits of heavy metals (**Table 2**). The high concentrations of aluminium are attributed to the fact that most of the scrap materials used to fabricate cookware are mainly from used aluminum products such as plates, motor parts, old aluminum pots, broken spoons and cans that have been discarded [7] [13]. The findings agree with Weidenhamer *et al.* [26] who found out that locally fabricated saucepans posed exposure hazards of lead, aluminium and cadmium. The current study also reported very high levels of aluminium, lead and cadmium than WHO permissible limits from locally fabricated cookware. Therefore, the extensive use of locally fabricated cookware puts the users at a health risk associated with heavy metal exposure. This calls for efforts to standardize the local artisanal activity involving cookware manufacture to minimize the harm from daily heavy metal exposure, since the local communities use cookware at least once daily during cooking and/or boiling drinking water.

The aluminium cookware studied leached high levels of aluminium followed by lead and the cadmium in the boiled water samples where steel wire and sand were used for cleaning. This agrees with previous studies which have reported the leaching of cadmium, lead and aluminium from aluminium cookware [7] [8]. Aluminium is not an essential element to man; it is considered to be one of the most toxic elements in the human body. When, aluminium is ingested, it causes brain disorders, bone and blood disorders, and has been linked with ailments like Alzheimer's disease and other neurological conditions such as Parkinson's disease [43]. Therefore, food contamination with leached aluminium still remains highly undesirable, and its cumulative effect might eventually lead to a less productive population [19]. During aluminium cookware manufacture, coating and anodization processes are used to render the cookware surfaces relatively non-reactive, lowering the rate of metal leaching into foodstuffs. Consequently, aluminium cookware, produced using standardized processes, is widely used by households around the world and deemed safe [8]. Therefore, very high levels of heavy metal concentration in water boiled from locally fabricated cookware may indicate manufacturing defects, which calls for production monitoring by relevant quality assurance enforcement teams.

Stainless-steel cookware exhibited the least heavy metal leaching into boiled water. Boiled water samples where steel wire was used for cleaning contained higher levels of Pb, Fe and Ni, while when sand was used, only higher levels Pb were found to be higher than the recommended WHO permissible limits of heavy metals. This implies that stainless-steel poses the least health risk pertaining heavy metal exposure, followed by aluminium cookware. On the other hand, locally fabricated cookware poses a great health risk and continuous use may be harmful. Unfortunately, most ordinary people in Africa and particularly in Uganda, may not be mindful of the nature of the containers their food is prepared in [19]. In settings of poverty, such as in many parts of Africa, locally fabricated cookware crafted from waste metal have high appeal [8]. They are relatively cheap, and their heating times are shorter, leading to decreased use of fuels such as charcoal and wood, which in most areas are becoming increasingly scarce. Artisanal aluminium cookware is light and thus easy to carry around, especially by children and women, who most frequently bear the burden of cooking and collection of wood fuel. Artisanal aluminium pots are also fairly strong, durable and can retain heat [8]. All these factors have favored extensive use of locally fabricated cookware, leaving the masses to continuous exposure to heavy metals with the associated health risks. This therefore necessitates community sensitization about the dangers involving cookware usage.

3.3. The Effect of Heating Duration on Leaching of Heavy Metals into Boiled Water

There was general increase in leaching of metals into water with increase in heating duration, with water heated in locally fabricated cookware showing the highest concentrations of heavy metals (**Table 3**). This is probably because heating a cookware for more than 2 hours creates a mechanical strain on the surface of the saucepan which later causes pitting [30]. Pitting initiates leaching through creation of anodic sites and cathodic sites at various points on the cookware surface where metal contents start etching out of the cookware material [46]. Also, longer cooking duration allows more total kinetic energy of the metal contents which increase their rate and duration of migration into boiling water.

Locally fabricated cookware leached the highest concentrations of metals with increase in cooking duration, which could be attributed to lack of standard operating procedures in their fabrication especially, the ratios of metal alloys that mix up during melting of the scrap [47]. These metals are more prone to leaching since they are not sandwiched by other protective layers that would reduce their exposure [16].

Table 3. Mean metal concentrations (mg/l) in water heated from different cookware types for different durations.

Cookware Type	Heating Duration (Hours)	Mean Concentration ± SD (mg/l) (n = 45)						
		Pb × 10^{-2}	Al × 10^{-2}	Cd × 10^{-2}	Fe × 10^{-2}	Cr × 10^{-2}	Ni × 10^{-2}	Mn × 10^{-2}
Locally Fabricated cookware	4	7.00 ± 0.30	83.20 ± 0.42	0.70 ± 0.09	2.40 ± 0.10	16.70 ± 0.230	1.10 ± 0.30	2.20 ± 0.70
	3	5.00 ± 0.35	77.20 ± 0.89	0.40 ± 0.30	2.20 ± 0.40	16.10 ± 0.190	0.60 ± 0.10	0.20 ± 0.10
	2	2.00 ± 0.13	44.00 ± 2.39	0.40 ± 0.10	1.30 ± 0.70	3.00 ± 0.016	Nd	nd
	1	nd	32.10 ± 0.70	nd	0.10 ± 0.02	1.10 ± 0.040	Nd	nd
	½	nd	23.00 ± 0.06	nd	Nd	1.00 ± 0.047	Nd	nd
Aluminium cookware	4	3.02 ± 0.24	9.20 ± 0.24	0.20 ± 0.10	3.20 ± 0.50	27.00 ± 0.17	0.80 ± 0.14	1.20 ± 0.70
	3	0.92 ± 0.40	5.40 ± 0.09	0.10 ± 0.06	2.80 ± 0.32	18.30 ± 1.29	0.30 ± 0.10	0.70 ± 0.30
	2	0.10 ± 0.03	1.10 ± 0.08	0.10 ± 0.03	1.70 ± 1.20	1.70 ± 0.01	Nd	0.40 ± 0.20
	1	nd	1.80 ± 0.09	nd	0.10 ± 0.09	1.10 ± 0.01	Nd	Nd
	½	nd	0.20 ± 0.01	nd	Nd	0.30 ± 0.01	Nd	nd
Stainless steel cookware	4	2.00 ± 0.11	6.30 ± 0.15	1.80 ± 0.18	5.10 ± 1.20	3.00 ± 0.06	0.10 ± 0.04	6.90 ± 3.90
	3	1.30 ± 0.28	0.20 ± 0.01	0.40 ± 0.31	0.80 ± 0.50	2.10 ± 0.09	0.10 ± 0.02	0.70 ± 0.43
	2	1.00 ± 0.19	nd	0.10 ± 0.02	0.50 ± 0.20	2.00 ± 0.03	Nd	Nd
	1	0.10 ± 0.03	nd	nd	Nd	Nd	Nd	Nd
	½	nd	nd	nd	Nd	Nd	Nd	Nd
WHO		**1.00**	**10.00**	**0.30**	**10.00**	**5.00**	**2.00**	**40.00**

nd, not detected; WHO, World Health Organisation Permissible limits for drinking water.

All the water samples from stainless-steel cookware had metal concentrations below WHO permissible limits of heavy metals for drinking water, except lead (2.00 ± 0.11 × 10^{-2} mg/l) at 4 hours heating duration (Table 3). The low metal concentrations are due the use of approved standard operating procedures in terms of ratios of alloy components and melting uniformity of materials during the manufacture of stainless-steel cookware. The protective layers on the inner and outer walls of the stainless-steel cookware make it resistant to corrosion and other effects of long hours of exposure to high temperatures [45]. This also enables stainless-steel cookware to withstand excessive heating and prevent pitting.

3.4. Effect of Temperature on Leaching of Metals from Different Cookware Types

There was a general increase in leaching of metals into water with increase in temperature, with water heated in locally fabricated cookware showing the highest concentrations of heavy metals (Table 4).

Locally fabricated cookware leached high levels of Al (13.70 ± 0.01 × 10^{-2} mg/ml) and Cd (0.50 ± 0.10 × 10^{-2} mg/ml) at 50˚C and Pb (2.00 ± 0.50 × 10^{-2} mg/ml) at 100˚C. This implies that even at low temperatures, there is a risk of metal exposure. This could be attributed the manufacturing defects [26] and the

Table 4. Mean metal concentrations (mg/l) in water heated from different cookware types at different temperatures.

Cookware Type	Temp. (˚C)	Mean Concentration ± SD (mg/l) (n = 45)						
		Pb × 10^{-2}	Al × 10^{-2}	Cd × 10^{-2}	Fe × 10^{-2}	Cr × 10^{-2}	Ni × 10^{-2}	Mn × 10^{-2}
Locally Fabricated cookware (*Endongoburaya*)	200	6.10 ± 0.20	339.00 ± 0.80	3.90 ± 0.30	3.20 ± 0.11	1.30 ± 0.30	0.60 ± 0.10	3.00 ± 0.17
	150	5.00 ± 1.40	102.10 ± 1.30	3.10 ± 0.60	2.50 ± 0.24	0.80 ± 0.50	0.40 ± 0.30	1.00 ± 0.40
	100	2.00 ± 0.50	24.60 ± 0.36	1.00 ± 0.80	1.40 ± 0.60	0.60 ± 0.20	Nd	0.70 ± 0.22
	50	0.50 ± 0.10	13.70 ± 0.01	0.50 ± 0.10	Nd	nd	Nd	Nd
	30	nd	8.90 ± 0.04	nd	Nd	nd	Nd	nd
Aluminium cookware	200	4.00 ± 0.30	72.90 ± 0.08	0.40 ± 0.10	0.60 ± 0.20	13.20 ± 0.34	1.20 ± 0.70	2.30 ± 0.43
	150	3.00 ± 0.10	52.20 ± 0.88	0.40 ± 0.06	0.50 ± 0.22	3.10 ± 0.05	Nd	1.70 ± 0.90
	100	1.00 ± 0.40	4.40 ± 0.07	nd	Nd	nd	Nd	1.30 ± 0.10
	50	nd	1.20 ± 0.03	nd	Nd	nd	Nd	Nd
	30	nd	nd	nd	Nd	nd	Nd	Nd
Stainless-steel cookware	200	0.70 ± 0.04	4.20 ± 0.70	0.40 ± 0.30	9.00 ± 1.10	1.80 ± 0.54	0.50 ± 0.01	0.70 ± 0.30
	150	nd	1.90 ± 0.30	nd	0.50 ± 0.30	0.80 ± 0.20	Nd	0.70 ± 0.10
	100	nd	0.10 ± 0.06	nd	nd	0.60 ± 0.50	Nd	Nd
	50	nd	nd	nd	nd	nd	Nd	Nd
	30	nd	nd	nd	nd	nd	Nd	Nd
WHO		**1.00**	**10.00**	**0.30**	**10.00**	**5.00**	**2.00**	**40.00**

nd, not detected; WHO, World Health Organisation Permissible limits for drinking water.

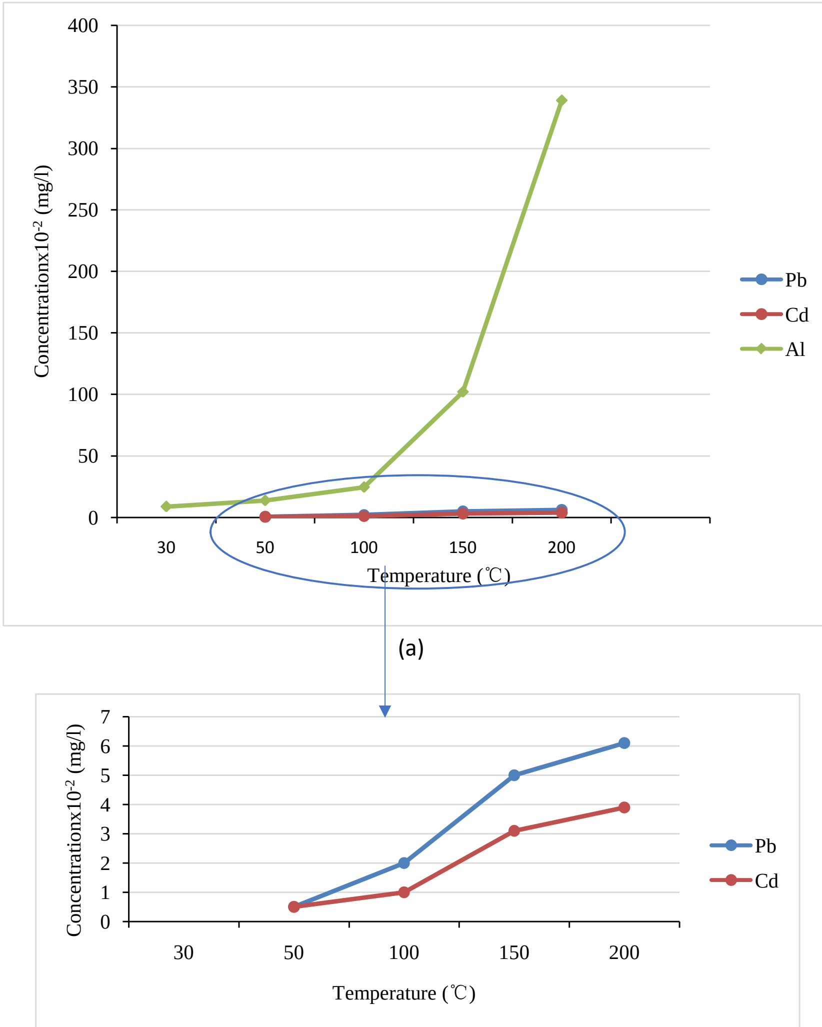
scrap metals which are used as raw materials [48]. At 150˚C and 200˚C, aluminium cookware leached Pb (4.00 ± 0.30 × 10^{-2} mg/ml), Al (72.90 ± 0.08 × 10^{-2} mg/ml) and Cr (13.20 ± 0.34 × 10^{-2} mg/ml) with concentration above WHO permissible limits (**Table 4**). This is probably because, Al and Cr are the major components of an aluminium saucepan and that is why they leached with such high concentration values [49], while Pb can be included either as contaminant or impurity in the manufacturing process [2] [3]. All the water samples from stainless-steel cookware contained metal concentrations below the WHO permissible limits of heavy metals. The ability of stainless-steel cookware to withstand heating at elevated temperatures renders them safe.

There was exponential increase in metal migration with increase in temperature (**Figure 2**). The influence of temperature for a given reaction is based on Arrhenius law, with a simple formula;

$$K = A_e^{-Ea/RT} \qquad (1)$$

This means that the reaction rate constant (K), depends on the temperature (T) and the activation energy (Ea).

An increase in temperature or a decrease in activation energy of the system will provide a greater number of particles for which collision ends in a reaction. Also, high temperature causes the metal particles that compose the cookware to



(b)

Figure 2. Metal leaching from locally fabricated cookware in function of temperature for: (a) Aluminium, lead and cadmium; (b) lead and cadmium.

gain more kinetic energy. Consequently, leaching will increase exponentially as a function of temperature, which agrees with the current findings (**Figure 2**). There was an exponential increase in levels of metals from a temperature of 100˚C. The findings agree with Jariyaboon *et al.* [50] who reported metal leaching to be extremely higher at temperatures above 100˚C. Dissolution as a chemical process can also be described by this formula and therefore thermally dependent [51]. It can thus be concluded that an increase in temperature also signifies a lift in migration values. Therefore, there is need to minimize use of locally fabricated cookware while cooking at higher temperatures, since it is the most affected.

Generally, exposure to heavy metals is common among African communities. Although many of these metals are known toxicants, to date, monitoring of this exposure is limited, especially in developing countries such as Uganda that are undergoing rapid industrialization [52]. An assessment of the possible sources of metal exposure is the most critical step in evaluating the public health burden of metal exposure and in guiding its eradication. The toxicity of small amounts of lead and cadmium released into the food chain is generally known [25]. Other trace elements are also of particular interest due to their chronic exposure of consumers and potential long-term health effects [8] [16] [17] [19]. The set of migration values registered in this study indeed confirm the belief that in addition to lead and cadmium, other trace elements coming from cookware are a potential health risk. When compared to the permissible daily intake set by the WHO, a significant amount of the maximum daily values are in fact exceeded (**Tables 2-4**). The release of large amounts of Al, Cd, Cr, Pb, Fe and Ni can pose a threat to public health. Regular use of certain of these cookware, especially locally fabricated and aluminium cookware can cause heavy metal poisoning.

4. Conclusion

All metallic cookware studied leach metal contents when cleaned using abrasive materials. Locally fabricated saucepans leached the highest levels of metal content. Lead and cadmium dominantly leached from locally fabricated saucepans with their highest concentrations far above the WHO permissible limits, which poses a very serious health risk to the population. When cleaned using steel wire, sand or ash and heating at temperatures of 100˚C and above, aluminium cookware may also pose a great health risk, which partly could be due to quality control matters. This calls for societal awareness on the levels to which cookware, especially the locally fabricated, leach metal content. The use of steel wire, sand and ash which is a common practice needs to be minimized since it exposes the public to lead, thus lead poisoning. An exponential relationship between the metal migration and the temperature was observed for locally fabricated cookware. There is need for policy formulation to regulate artisanal activities to avoid entry substandard products into the population. The communities within the study area need to be sensitized on the choice and proper use of cookware.

Acknowledgements

The authors acknowledge the Department of Chemistry at Mbarara University of Science and Technology for the technical guidance offered. We would like to appreciate Ms. Kemigisha Charlotte for the moral support and the local communities around Ntungamo District for their willingness and openness during this study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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