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Cooking Pots: A Source of Heavy Metal Contamination of Food and Water

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Introduction: Certain kitchen utensils used for food preparation can present significant risk because they are manufactured with materials such as aluminum, stainless steel and enamel that can be hazardous or contaminate food when heated.
Aim: The aim of this study was to determine the microbial and heavy metals found in leachates from some cooking utensils subjected to heating.
Methodology: A total of four aluminum and stainless steel cooking pots were used and seven hundred and fifty (750) millilitres of tap water was boiled for 15 minutes to 30 minutes in each of the pots at boiling point of 100°C. The analyses of the water samples for bacteria were carried out using the conventional standard procedures of isolating and identifying bacteria. The physicochemical parameters were quantified with the APHA method whereas the Atomic Absorption Spectrophotometer (AAS) was used for the determination of heavy metals.
Results: The results showed that *Pseudomonas* spp and *Staphylococcus* spp were isolated from some of the water samples that were not boiled while the boiled water showed no bacteria growth. The physicochemical parameters of the water samples before boiling were pH 5.36 to 7.41, temperature 30.7°C to 31.0°C, turbidity 0.04 to 1.41NTU, total dissolve solids 50.0 to 114.9 mg/l and others, while the presence of heavy metals such as Lead (Pb), Zinc (Zn), Iron (Fe), Cadmium (Cd) and Chromium (Cr) were detected in leachates from the pots subjected to heating. The values obtained were higher in leachates from pots that were heated for longer period. The oldest pot of thirty (30) years had a value of 0.0175±0.0007 mg/l to 0.0275±0.0021 mg/l for Zn while the value for Cd was 0.1110±0.0014 to 0.1245±0.0007 mg/l and the values for the newest pot was 0.0505±0.0021 to 0.0775±0.0035 mg/l for Pb and 0.0455±0.0248 mg/l to 0.0515±0.0191 mg/l for Cr.

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Conclusion: Cadmium values in all the pots exceeded the control and World Health Organization (WHO) recommended values. It may be concluded that heavy metals leached out into water and food from some pots when heated for longer periods and this may become one source of exposure of heavy metals into the human body that may bioaccumulate to create health problems.

Keywords: Bioaccumulation; hazardous; leachates; metals; bacteria.

1. INTRODUCTION

Most people are aware of air pollution, water pollution and the dangers of household chemicals. Studies are now showing that certain cookwares can also be polluting our bodies. The exposure of any material to heat with high temperature causes such material to expand, melt or burn depending on its nature, as the heat breaks the binding bonds between the elements. There is a toxicological risk when the pots are constantly reused because increasing their use degrades the pots cover especially the enamel covering the vessel due to heating, acidity and the friction between the food and the vessel walls, which consequently causes a greater concentration of heavy metals to leach. The greater use of the pots leads to more leaching of heavy metals into food and water [1]. Studies have shown that handcrafted glass-clay containers are a health risk because they can be contaminated by heavy metals, which can be transferred to food, thus reaching the human body to potentially cause illness. The presence of metals in food can be caused by different sources, such as direct contamination during production, metal-rich soil, air, contaminated water, or from the use of pesticides or fertilizers. Food can also be contaminated during transportation, industrial processing, or during storage [2,3,4]. The domestic preparation of food as a potential source of heavy-metal contamination has been given little importance. However, there are reports that indicate that certain kitchen utensils used for food preparation can present a significant risk because they are manufactured with materials that can be hazardous or contaminated by toxic metals [5,6, 7]. Metals are substances with high electrical conductivity, malleability, and luster, which voluntarily lose their electrons to form cations, and are found naturally in the earth's crust with varying compositions among different localities, resulting in spatial variations of surrounding concentrations. The metal distribution in the atmosphere is monitored by the properties of the given metal and by various environmental factors [8]. Heavy metals are generally referred to as those metals which possess a specific density of more than 5 g/cm3 and adversely affect the environment and living organisms [9]. There are other sources of heavy metals and their harmful effects on the environment and living organisms. These metals are quintessential to maintain various biochemical and physiological functions in living organisms when in very low concentrations, however they become noxious when they exceed threshold concentrations. Although it is acknowledged that heavy metals have many adverse health effects and last for a long period of time, heavy metal exposure continues and is increasing in many parts of the world. Heavy metals are significant environmental pollutants and their toxicity is a problem of increasing significance for ecological, evolutionary, nutritional and environmental reasons [10,11]. The most commonly found heavy metals in waste water include arsenic, cadmium, chromium, copper, lead, nickel, and zinc, all of which pose risks to human health and the environment [12]. Heavy metals enter the surroundings by natural means and through human activities, and the various sources include soil erosion, natural weathering of the earth's crust, mining, industrial effluents, urban runoff, sewage discharge, insect or disease control agents applied to crops, and many others [13]. In this work evaluation of leached Lead, Iron, Zinc, Cadmium, and Chromium from different types of pots into boiling water and the presence of associated bacteria was carried out.

2. MATERIALS AND METHODS

This study was carried out in Port Harcourt, the capital of Rivers State, in the Niger Delta region of Nigeria (Fig. 1). It has a multi-race population of over 5 million people from all walks of life. The natives are mainly farmers, fishermen and industrious traders. The land area covers over 369Km^2 and water area covers about 9 Km^2 with a population density of 2700-12000/Km^2. Port Harcourt, the capital of Rivers State, has tropical climate with lengthy wet season and very short dry seasons. Only the months of December and January truly qualify as dry season months in the city. The dry and dusty northeasterly trade wind (harmattan), which blows from the Sahara over West Africa into the Gulf of Guinea that climatically influences many cities in West Africa is less pronounced in Port Harcourt as its heaviest precipitation occurs in September with an average of 367 mm of rain.

2.1 Sample Collection

Two selected stain-less steel enamel pots were sourced from different residential areas of Port Harcourt. The water samples used for the work were collected from different areas such as Trans-Amadi, Etche and Mile IV in Rivers State and Umuahia in Abia State. The Trans –Amadi water sample served as control because it is always treated before use. Old and new pots made of aluminum, electric cookers, stop-watch, distilled water and other water samples were collected and transported to the laboratory.

2.2 Sample Preparation

2.2.1 Procedure

Each pot, new, old and very old made of stainless steel, aluminum and enamel were washed with distilled water and soap and rinsed properly with sterile distilled water for at least five times. Thereafter, 750 mls of each of the water sample was added to each pot and heated to boiling point of 100°C on gas cookers for a start and allowed to further boil for 15 minutes and 30 minutes time intervals respectively. Water samples for analyses were collected after 15 minutes and 30 minutes boiling with the use of sterile pipettes and, 20 ml of the cooled boiled water was transferred into two different sterile universal bottles of 25 ml capacity each for transportation under ice pack for heavy metals analysis to the Laboratories. The boiled water samples were properly labeled and sent to the Department of Fisheries, University of Agriculture, Umudike, Abia State for estimation of heavy metals, while the water samples for microbiological assay were sent to Medical Microbiology Laboratory Unit of the University of Port Harcourt Teaching Hospital, Port Harcourt and the samples for physiochemical parameters analyses were sent to Institute of Pollution Studies (IPS), Rivers State University, Nkpolu Oroworukwo, Port Harcourt. The Trans-Amadi water sample was used as a control because it receives better pretreatment before use, and its physiochemical analysis and microbiological assay were also determined.

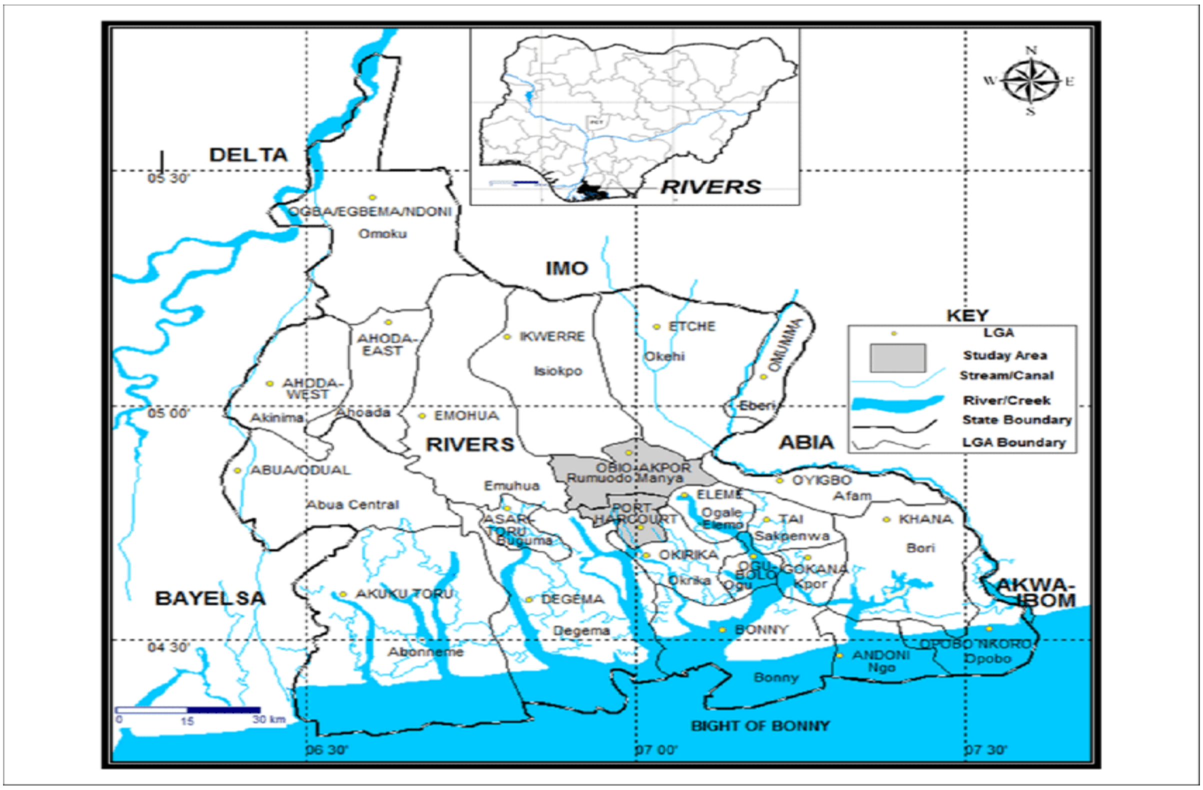

Fig. 1. Map of Rivers State showing the position of Port Harcourt City

2.2.2 Preparation of culture plates and broth

The media used were Nutrient and MacConkey agars that were prepared according to the manufacturer's specification of weighing out 28g and 50g respectively as the required amount of each powder and dissolved in one litre each of distilled water while Salmonella - Shigella, Thiosulphate Citrate Bile Salt and Sucrose (TCBS) and Eosin Methylene blue agar were also prepared using the manufacturer's recommended instruction. The MacConkey broth was prepared by weighing out 40g of the powder and dissolved in one litre of distilled water and mixed properly. And using a sterile pipette nine (9.0ml) milliliters of the broth were transferred into clean and dried test tubes arranged in the rack with inverted Durham tubes. The media and broth were autoclaved and sterilized at 121°C at 15psi for 15minutes. The media were brought out and allowed to cool to 45°C and 20 ml poured into each sterile culture plate for the agar and then allowed to set.

2.2.3 Isolation and enumeration of bacteria in water samples before boiling

The water samples were serially diluted by pipetting one (1.0ml) milliliter of the water and adding it to nine (9.0ml) milliliters of sterile distilled water thereby making a one in ten (1:10) dilution. A zero-point one (0.1ml) milliliter of each diluted water sample was pipetted and dropped on the dried culture plates Nutrient and MacConkey agar. The dropped aliquot was then spread with a sterile spreader that was dipped into an absolute alcohol solution and flamed in a bunsen burner flame for sterilization. The plates were then incubated at 37°C for 24 hours. The results of each plate were read by counting the number of bacteria which served as total heterotrophic bacteria count and the morphological and cultural characteristics of the bacteria growth were noted and recorded as well as the total and faecal coliform. Then, each isolated colony was sub-cultured and characterized with the use of Gram staining and biochemical tests like catalase, coagulase, indole, citrate, Motility test, urease, oxidase test, and carbohydrate assimilation tests [14]. This procedure was repeated for all the isolates in samples boiled for 15minutes and 30minutes period respectively.

2.2.4 Isolation of bacteria in water samples after boiling

The culture plates used were labeled clearly for proper identification of the samples. The water samples were not diluted because they were clear and not turbid. The spread plate technique was used to culture the water samples on the different media used which were Nutrient Agar, MacConkey, Salmonella- Shigella agar, Thiosulphate Citrate Bile Salt and Sucrose agar (TCBS), Eosin Methylene blue agar. An aliquot of 0.1ml of each sample was pipetted and placed on each of the plates after which the sterile spreader was used to spread each of the inoculum in the plates [14]. They were then incubated at 37^{O}C for 24 hours in an incubator.

3. RESULTS

The analyzed result of the heavy metals in leachates from Pot 1 a Salad Master pot is presented in Table 1 and Fig. 2. The values for each metal Lead (Pb), Zinc (Zn), Iron (Fe), Cadmium (Cd) and Chromium (Cr) are as shown. The value for Pb ranged from 0.0050 ± 0.0014mg/l for 15 minutes boiling to 0.0070±0.0000mg/l for 30 minutes boiling with a control value of 0.0265 ± 0.0021mg/l, Zn value ranged from 0.0020 ±0.0000mg/l at 15 minutes to 0.0035 ± 0.0007mg/l for 30minutes and a control value of 0.0050 ± 0.0000mg/l, Fe value was 0.0165 ± 0.0021mg/l for both 15 and 30 minutes boiling respectively with a control value of 0.0145 ± 0.0007mg/l while the Cd value ranged from 0.0520 ± 0.0000mg/l to 0.0740 ± 0.0014mg/l for both 15 and 30 minutes respectively and a control value of 0.0170 ± 0.0000mg/l and the Cr value ranged from 0.0190 ± 0.0000mg/l for 15 minutes to0.0255 ± 0.0007mg/l for 15 and 30 minutes respectively with a control value of 0.0055 ± 0.0007mg/l. The World Health Organization (WHO) Standards (WHO, 2002) [15] for each heavy metal are also presented in the Table 1.

The level of heavy metals in leachates in pot 2 are as shown in Table 2 and the Fig. 3, these show the plot of three different varieties of pots. The different pots are namely stain-less steel Master Chef pot already in use (a bigger pot), identified as pot 2(0), New stain-less steel Master Chef pot (big) and labeled as pot 2(1) and a stain-less steel Master Chef pot 2 (1) (biggest size). The values of each of the heavy metals that was analyzed were recorded for both the leachate, control and WHO standards [15].

The Pb value for control was 0.0265 ± 0.0021/mg/l while pot 2(0) ranged from 0.0045 ± 0.0007 for 15 minutes to 0.0085 ± 0.0007 mg/l, for 30 minutes, pot 2(1) values are

0.005 ± 0.0007mg/l for 15 minutes to 0.0085 ± 0.0007mg/l for 30 minutes while pot 2(11) ranged from 0.0085 ± 0.0007mg/l for 15 minutes to 0.0110 ± 0.0007mg/l for 30 minutes.

The obtained Zn values for control was 0.0050 ± 0.000mg/l, while pot 2(0) ranged from 0.0065 ± 0.0007mg/l at 15 minutes to 0.00060±0.0000mg/l for 30 minutes, pot 2(1) values were 0.0065±0.002/mg/l for 15 minutes to 0.0060 ± 0,0000mg/l for 30 minutes and pot 2(11) value was 0.0060 ± 0.000mg/l for 15 minutes to 0.0070±0.0014 mg/l for 30 minutes.

The value for Fe control was 0.0145 ±0.0007mg/l, pot 2(0) ranged from 0.0140 ± 0.000mg/l for 15 minutes to 0.0180 ± 0.00140 mg/l for 30 minutes, pot 2(1), value ranged from 0.0130±0.0000 for 15 minutes to 0.145±0.0007 mg/dl for 30 minutes and pot 2(11) values were 0.0120±0.0000 for 15 minutes to 0.0150±0.0000 mg/l for 30 minutes.

Table 1. Descriptive statistics of heavy metal analysis of pot 1

Parameters (mg/L)	Control	15 minutes	30 minutes	WHO Standard Concentration (mg/L)
Pb	0.0265[a]±0.0021	0.0050[b]±0.0014	0.0070[b]±0.0000	0.13
Zn	0.0050[a]±0.0000	0.0020[c]±0.0000	0.0035[b]±0.0007	0.8
Fe	0.0145[a]±0.0007	0.0165[a]±0.0021	0.0165[a]±0.0021	1.0
Cd	0.0170[c]±0.0000	0.0520[b]±0.0000	0.0740[a]±0.0014	0.003
Cr	0.0055[c]±0.0007	0.0190[b]±0.0000	0.0255[a]±0.0007	0.1

Note: Mean scores with the same superscript across the rows are not significantly different
Key: Zn = Zinc, Pb = Lead, Fe =Iron, Cd = Cadmium, Cr = Chromium, P1 = Salad Master pot

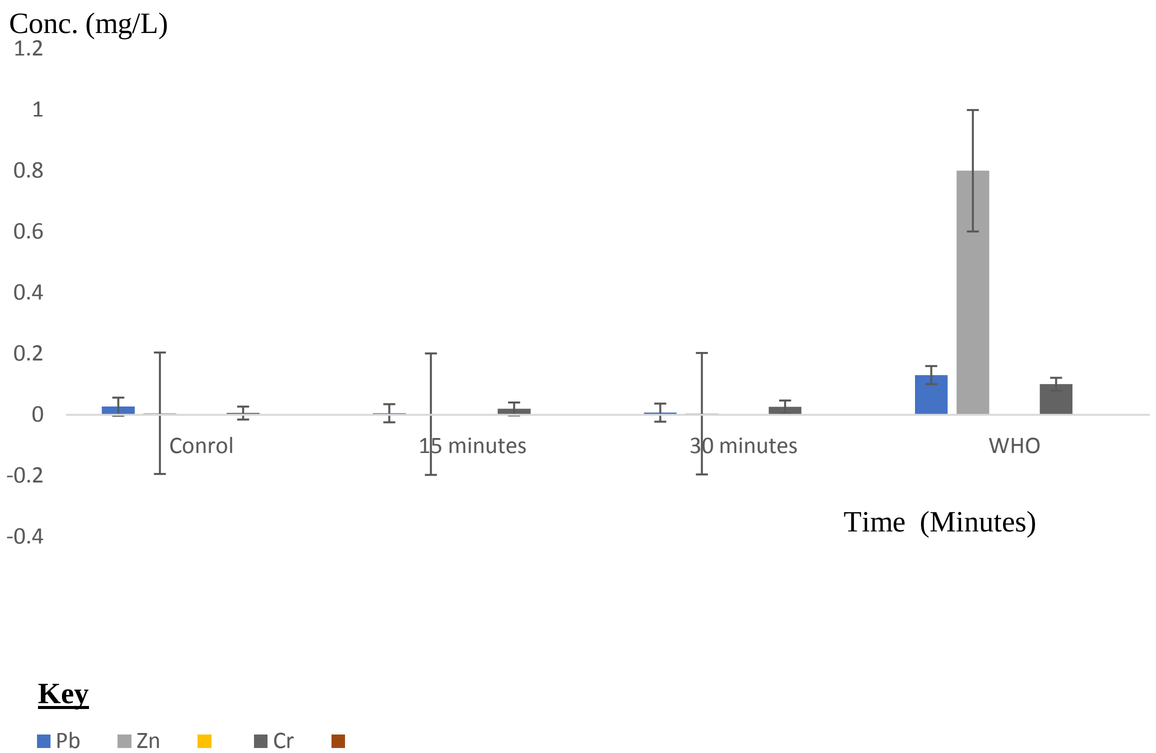

Fig. 2. Plot of Comparison of Heavy Metals in Leachates in Pot 1 at Different Timing with Control and WHO Standard

Table 2. Descriptive statistics of heavy metal analysis from three (3) different Pots labeled as (Pot 2 0, I, and II)

Parameters (mg/l)	Control	Pot 2(0)– 15	Pot 2(0) - 30	Pot 2(I) - 15	Pot 2(1) – 30	Pot 2 (II) -15	Pot 2 (II) -30
Pb	0.0265^{a}±0.0021	0.0045^{c}±0.0007	0.0085^{b}±0.0007	0.0125^{c}±0.0007	0.0085^{c}±0.0007	0.0085^{c}±0.0007	0.0110^{bc}±0.000
Zn	0.0050^{a}±0.0000	0.0065^{a}±0.0007	0.0060^{a}±0.0000	0.0065^{a}±0.0021	0.0060^{a}±0.0000	0.0060^{a}±0.000	0.0070^{a}±0.0014
Fe	0.0145^{bc}±0.0007	0.0140^{bc}±0.0000	0.0180^{a}±0.0014	0.0130^{cd}±0.0000	0.0145^{bc}±0.0007	0.0120^{d}±0.0000	0.0150^{b}±0.0000
Cd	0.0170^{e}±0.0000	0.0840^{c}±0.0014	0.1130^{a}±0.0028	0.0715^{d}±0.0035	0.0805^{c}±0.0007	0.0965^{b}±0.0021	0.0725^{d}±0.0007
Cr	0.0055^{e}±0.0007	0.0310^{a}±0.0014	0.0075^{de}±0.0007	0.01250^{bc}±0.0021	0.0150^{b}±0.00014	0.0090^{d}±0.0000	0.0120^{c}±0.0000

Note: Mean scores with the same superscript across the rows are not significantly different
WHO Standard Concentration (mg/l): Pb – 0.13, Zn – 0.8, Fe – 1.0, Cd – 0.003, Cr – 0.1
Key: Zn = Zinc, Pb = Lead, Fe = Iron, Cd = Cadmium, Cr = Chromium
Pot 2 (0) = Stainless Steel Master Chef Pot (Bigger in Use)
Pot 2 (I) = Stainless Steel Master Chef Pot (Big New)
Pot 2 (II)= Stainless Steel Master Chef Pot (Biggest in use)

The obtained results for pot 2(0) control are 0.0170±0.000 mg/dl for 15 minutes whereas pot 2(1) values are 0.0715±0.0035 mg/dl for 15 minutes to 0.0805±0.0007mg/l for 30 minutes and the P2(11) values are 0.0965±0.0021/mg/l for 15 minutes to 0.0725±0.0007mg/l for 30 minutes.

The Cr result for control is 0.0055±0.0007mg/l. The value for pot 2(1) ranged from 0.0330±0.0014mg/l for 15 minutes boiling, pot 2(1) ranged from 0.0310±0.0014mg/l for 15 minutes boiling to 0.0075±0.0007mg/l for 30 minutes boiling, pot 2(1) values ranged from 0.0125±0.00021mg/l for 15 minutes boiling to 0.0150±0.00014mg/l for 30 minutes boiling, while pot 2(11) had values of 0.0090±0.0000mg/l for 15 minutes boiling to 0.0120±0.0000mg/l for 30 minutes boiling.

The Table 3 shows some of the determined physicochemical parameters. The obtained values for pH ranged from 5.36 – 7.41, temperature ranged from 30.7°C – 31.0°C, turbidity 0.04 – 1.41NTU and total dissolved 50.0 – 114.9 mg/l.

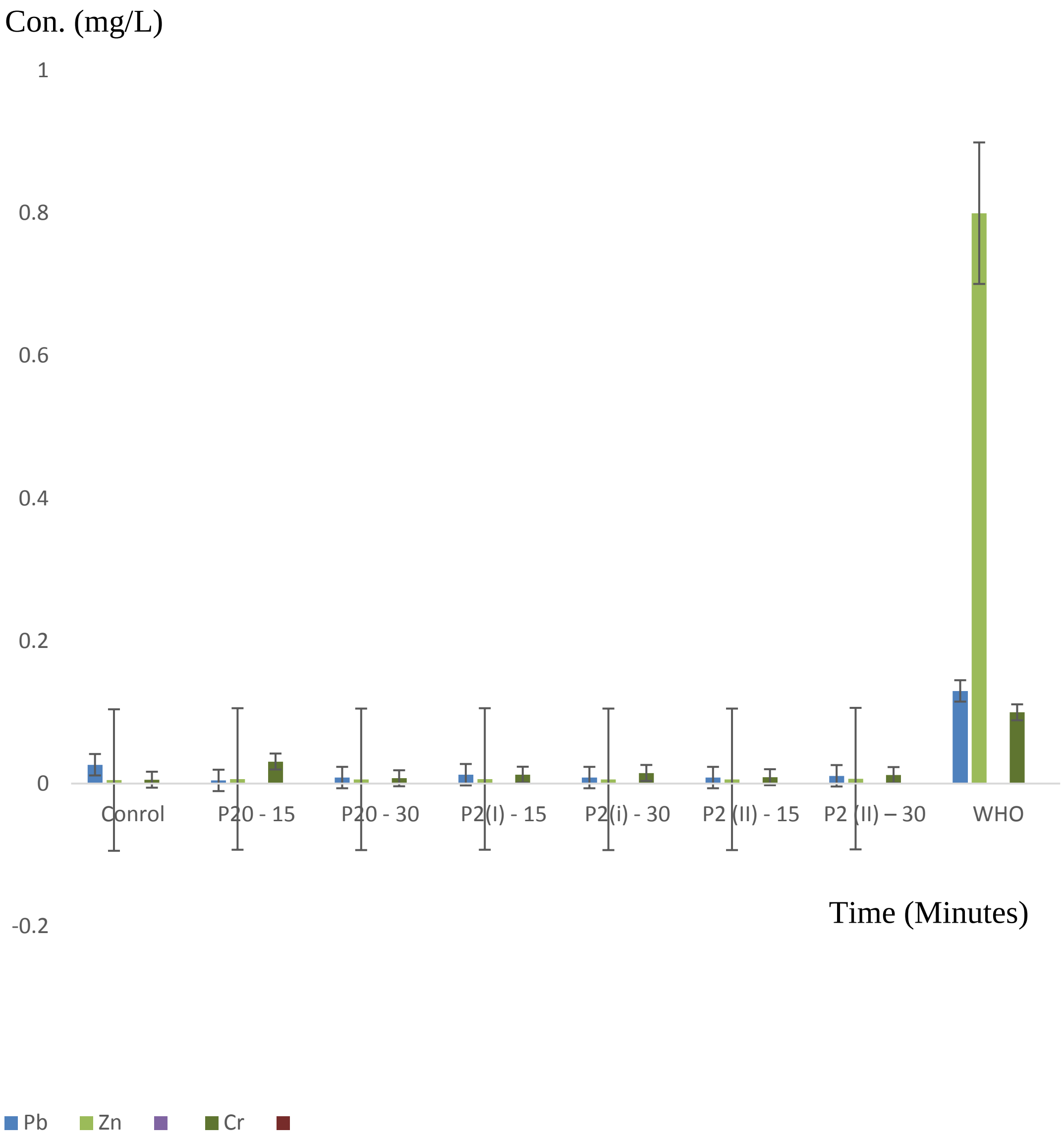

Fig. 3. Plot of Comparison of Heavy Metals in Leachates in Different Types of Pot 2 and Control with their Timing and WHO Standard

Table 3. Some physicochemical parameters of the water (H_2O) samples

Parameters	Mile IV H_2O	Etche H_2O	Umuahia H_2O	Trans-Amadi H_2O	WHO Std
pH	5.36	5.55	5.56	7.41	6.5-8.5
Electrical Conductivity(µs/cm)	68.0	95.9	85.4	164.4	1000
Salinity (%$_{o)}$	0.03	0.05	0.05	0.08	
Turbidity (NTU)	0.10	0.05	0.04	1.41	5
Temperature (°C)	30.7	30.8	31.0	31.0	25
Total Dissolved Solids (mg/l)	50.0	65.1	71.1	114.9	500

4. DISCUSSION

Heavy metals come into our surroundings by natural means and through human activities and the various sources are soil erosion, natural weathering of the earth's crust, mining, industrial effluents, urban runoffs, sewage discharge, insect or disease control agents applied to crops and many others [13].

There are possibilities of heavy metals moving out from cooking pots (cookware) into foods and water when the cookware is subjected to heating. This is because heating treatments in the production process of food has been known to be a source of chemical contamination of foods [16]. The use of high temperature for cooking paired with external factors potentially leads to the formation of toxic compounds that impact on food safety and quality [16]. In this study, water samples were used because contaminating substances present in water can easily be detected, since the pots would be heated, if there is release of metals, they (the metals) can easily be determined in the water. The determination of physicochemical parameters of the water samples used in this study were essential to know the water quality. The determined parameters were pH, temperature, salinity, electrical conductivity, total dissolved solids as presented in Table 3. The levels of the physicochemical parameters in the water samples were carried out to ensure that the water samples were not polluted and that their quality meet the recommended standards of water quality for drinking and can support life. These parameters were determined to rule out the possibility that some of them could be present in the water from leakages [17]. The obtained values of the parameters were all below the World Health Organization recommended values except the pH and temperature of all the water that were higher than the recommended value of 6.5 -8.5 and 25^{O}C respectively. The reason of these higher values could be as a result of the tropical nature of where the samples were collected. The obtained values for Cadmium (Cd) in Pot 1a Salad Master pot shown in Table 1 ranged from 0.0520^{b}±0.0000mg/l after 15 minutes boiling to 0.0740^{a}±0.0014mg/l after 30 minutes boiling and control value of 0.0170 ±0.0000mg/l. These values have revealed the presence of Cd in pots that have been subjected to heating and the values are higher than the recommended World Health Organization value of 0.003mg/l. The results from the three different types of the Master Chef Stainless Steel Pots 2(0, I and II) also show that the level of Cadmium was high in all of them as their values were higher than the World Health Organization recommended standards as can be seen in Table 2. These could be sources through which we take in Cadmium unknowingly and its accumulation could potent serious health hazard.

5. CONCLUSION

The obtained results from this work have shown and suggested that some metals used in making cooking wares could be the source through which the food and water we eat and drink are contaminated as the cooking pots are subjected to frequent heating that could break the bonds that holds the metals together and this might become a source of metal contaminant of food.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Valadez-Vega C, Zúñiga-Pérez C, Quintanar-Gómez S, Morales-González J, A. Madrigal-Santillán E, Villagómez-Ibarra J, R. Sumaya-Martínez MT, Juan Diego García-Paredes. Lead, Cadmium and Cobalt (Pb, Cd, and Co) Leaching of

Glass-Clay Containers by pH Effect of Food. International Journal of Molecular Sciences. 2011;12:2336-2350.
2. Gulson BL, Mizon KJ, Korsch MJ, Howarth D. Non-orebody sources are significant contributors to blood lead of some children with low to moderate lead exposure in a major lead mining community. Science of Total Environment. 1996;181:223–230.
3. Garcia M, Quintero R, López-Munguia A. Biotecnología Alimentaria; Goldberg, I., Ed.; Chapman & Hall: Limusa, Mexico. 2000;48–64.
4. Mariné AF. Influencia del Medio Ambiente en Las Relaciones Entre la Alimentación y Salud; Departamento de Nutrición y Bromatología, Universidad de Barcelona: Barcelona, Spain. 2000;354–377.
5. Wallace DM, Kalman DA, Bird TD. Hazardous lead release from glazed dinnerware: A cautionary note. Science Total Environmental. 1985;44:289–292.
6. Landa ER, Councell TB. Leaching of uranium from glass and ceramic food ware and decorative items. Health Physician. 1992;63:343–348.
7. Hight SC. Determination of lead and cadmium in ceramicware leach solutions by graphite furnace atomic absorption spectroscopy: Method development and inter-laboratory trial. J. AOAC Int. 2001; 84:861–872.
8. Khlifi R, Hamza-Chaffai A. Head and neck cancer due to heavy metal exposure via tobacco smoking and professional exposure: A review. Toxicological Application in Pharmacology. 2010;248: 71-88.
9. Jarup L. Hazards of heavy metal contamination. British Medical Bulletin. 2003;68(1):167–182.
10. Nagajyoti PC, Lee KD, Sreekanth TVM. Heavy metals, occurrence and toxicity for plants: A review. Environmental Chemistry Letters. 2010;8(3):199-216.
11. Jaishankar M, Mathew BB, Shah MS, Gowda KRS. Biosorption of few heavy metal ions using agricultural wastes. Journal of Environment Pollution and Human Health. 2014;2(1):1-6.
12. Lambert M, Leven BA, Green RM. New methods of cleaning up heavy in soils and water. Environmental Science and Technology briefs for citizens of Kansas State University, Manhattan, KS. 2000; 61(47):876-988.
13. Morais S, Costa FG, Pereira ML. Heavy metals and Human health, Environmental Health- Emerging issues and practice Jacques Oosthuizen, InterOpen; 2012. DOI: 10.5772/29869. Available:https://www.interopen.com/ books/environmental health-emerging-issues- and practice/heavy-metals-and human-health
14. Cheesbrough M. District Laboratory Practice in Tropical Countries, Part II, Low Priced Edition, Cambridge University Press, Cambridge. 2000;105-130.
15. World Health Organization (WHO). Reducing risks. Promoting healthy life. Geneva, Switzerland 2nd Edition. 2002; 5-10.
16. Nerín C, Aznar M, Carrizo D. Food contamination during foo process. Trends in Food Science and Technology. 2016;48: 63–68.
17. Alepu OE, Segun GA, Ikhumhen HO. Borehole water quality assessment in Bekwarra, Nigeria. Advanced Recycling Waste Management. 2016;2(1): 115-116.

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