



Health Risk Assessment of Heavy Metals in Selected Sachet Water Brands Following Sunlight Exposure in Enugu Metropolis, Enugu State, South-East Nigeria

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ABSTRACT

Heavy metals in drinking water may pose health concerns when exposure is prolonged, even when individual concentrations remain below regulatory limits. This study evaluated potential adult and child exposure to selected heavy metals in sachet water before and after sunlight exposure. Selected sachet-water brands were maintained under control conditions of 22–25°C and test samples exposed to sunlight at approximately 35 – 40°C for 7, 14 and 21 days respectively. Zinc, chromium, copper, iron and manganese concentrations were determined by Atomic Absorption Spectrophotometry. Average Daily Dose (ADD), Hazard Quotient (HQ), Hazard Index (HI) and chromium-related carcinogenic risk (CR) were estimated separately for adults and children. Children consistently recorded higher estimated ADD and HQ values than adults. For ESW21, adult HI increased from 0.2674 in the unexposed condition to 0.3818 after 21 days, whereas child HI increased from 0.6239 to 0.8913. ESW18 child HI increased from 0.9054 to 1.1527, while ESW1 increased from 0.9290 to 1.2025. ESW15 recorded child HI values above unity throughout the exposure period, ranging from 1.0522 to 1.0958. ESW9 and ESW5 remained below unity throughout the assessed periods. Chromium-related carcinogenic-risk estimates increased with exposure duration for several samples, and child estimates were consistently higher than adult estimates. The results indicate that exposure-related risk was more pronounced among children under the assumptions used. Although baseline heavy-metal concentrations were generally below the applicable regulatory limits, the risk assessment identified scenarios in which cumulative non-carcinogenic hazard exceeded unity for children. The findings emphasize the importance of considering exposure duration, storage conditions and population vulnerability when evaluating packaged drinking-water safety.

Keywords: heavy metals; sachet water; hazard quotient; hazard index; carcinogenic risk; chromium; children; sunlight exposure; Enugu.

1. INTRODUCTION

Heavy metals in drinking water are of public-health importance because some metals can produce adverse effects following prolonged exposure. Conventional assessment based solely on comparison of measured concentrations with regulatory limits may not fully describe risk because actual health risk depends on concentration, intake rate, body weight and duration of exposure (USEPA, 2005). Risk assessment methods such as ADD, HQ, HI and CR provide a quantitative framework for evaluating potential exposure. HQ compares estimated exposure with an appropriate reference dose, while HI represents the cumulative contribution of multiple contaminants (Dada, 2009). Children may receive higher contaminant doses relative to body weight than adults. Consequently, separate adult and child exposure estimates are important when assessing drinking-water risks, Campbell and Reece (2009). The present study evaluated heavy metal exposure and potential health risks associated with sachet water consumption under control and sunlight exposure conditions (Daramola, *et al.*, 2019).



2. MATERIALS AND METHODS

2.1 Experimental design

Selected sachet-water brands representing different packaging materials were analyzed before exposure and after 7, 14 and 21 days of sunlight exposure respectively for nine hours (8am-5pm) daily at approximately 35–40°C. Controls were maintained at approximately 22–25°C. At the end of each exposure window, samples were taken from the exposed and unexposed sachet water brands for heavy metal determination and human health risk assessment of toxic metals for an adult and a child using average daily dose (ADD), hazard index (HI), hazard quotient (HQ) and carcinogenic risk (CR).

2.2 Heavy-metal determination

Zn, Cr, Cu, Fe and Mn were determined using Atomic Absorption Spectrophotometry.

2.3 Average Daily Dose

ADD was calculated using the equation:

$$ADD = \frac{C_{\text{water}} \times IR \times EF \times ED}{BW \times AT}$$

Where ADD = average daily dose of potential toxic metals exposure (mg/kg/day), C_{water} = concentration of potential toxic metals in water (mg/L), IR = water ingestion rate of adults: 2L/day, children: 1L/day, EF = exposure frequency: 365 days/year, ED = duration of adult exposure: 30 years for carcinogenic effects in adults/6yrs for children, BW = body weight of humans: 70kg (adults)/15kg for children, AT = average time of exposure: 365 days/year $\times$ 70 years for adults/6 $\times$ 365 days for children, (USEPA, 2005).

2.4 Hazard Quotient

$$HQ = \frac{ADD}{RfD}$$

Where HQ = hazard quotient via ingestion of potential toxic metals, ADD = Average daily dose, RfD = reference doses for ingestion of potential toxic metals (mg/kg/day).

The RfD_{ing} were 0.07, 0.14, 0.003, 0.001, 0.04, 0.3, 0.0035, 0.0003 and 0.02 mg/kg for Fe, Mn, Cr, Cd, Cu, Zn, Pb, As and Ni respectively (USEPA, 2005). HQ values >1 indicates an impending health danger (Adekunle, *et al.*, 2021). An HQ below 1 indicates that estimated exposure is below the reference dose under the specified assumptions, whereas an HQ above 1 indicates potential concern.

2.5 Hazard Index

The combined non-carcinogenic risk was calculated as:

$$HI = HQ_{\text{(Cr)}} + HQ_{\text{(Cu)}} + HQ_{\text{(Mn)}} + HQ_{\text{(Fe)}} + HQ_{\text{(Zn)}}.$$

Where HI = hazard index and $HQ > 1$ shall be taken as an impending health worry (Ballester and Sunyer, 2000; USEPA, 2005).

2.6 Carcinogenic risk

Chromium-related carcinogenic risk was calculated as:

$$CR = ADD \times CSF$$

Where CR = carcinogenic risk via ingestion of potential toxic metals, CSF = carcinogenic slope factor. The carcinogenic slope factors were Pb (0.0085 mg/kg/day), Cd (0.38 mg/kg/day), As (1.5 mg/kg/day), Cr (0.5 mg/kg/day), Backen, *et al.*, (2014). CR values above 10^{-6} to 10^{-4} indicate a possibility of having cancer over a 70 years lifetime, (USEPA, 2005).

3. RESULTS

3.1 Hazard Index

The principal HI results were:

Sample	Exposure	Adult HI	Child HI
ESW21	Control	0.2674	0.6239
ESW21	7 days	0.2759	0.6437
ESW21	14 days	0.3713	0.8667
ESW21	21 days	0.3818	0.8913
ESW18	Control	0.388	0.9054
ESW18	7 days	0.3893	0.9085
ESW18	14 days	0.4922	1.1486
ESW18	21 days	0.494	1.1527
ESW1	Control	0.398	0.929
ESW1	7 days	0.4085	0.9534
ESW1	14 days	0.5043	1.1768
ESW1	21 days	0.5152	1.2025
ESW15	Control	0.4509	1.0522
ESW15	7 days	0.4589	1.0711
ESW15	14 days	0.4609	1.0759
ESW15	21 days	0.4695	1.0958
ESW9	Control	0.1391	0.3248
ESW9	21 days	0.1507	0.3515
ESW5	Control	0.2148	0.5014
ESW5	21 days	0.2183	0.5092

3.2 Adult versus child exposure

The child HI values were consistently higher than adult values. This pattern reflects the lower body-weight of the child and therefore higher contaminant intake per unit body weight, (USEPA, 2005).

3.3 Carcinogenic risk

The chromium-related CR estimates increased with exposure duration for several samples.

For example, the reported values for ESW21 were:

Exposure	Adult CR	Child CR
Control	1.43×10^{-4}	3.33×10^{-4}
7 days	2.86×10^{-4}	6.67×10^{-4}
14 days	5.71×10^{-4}	1.33×10^{-3}
21 days	8.57×10^{-4}	2.00×10^{-3}

The analysis reported higher CR values for children than adults and increasing values for several samples with longer exposure, (USEPA, 2005).

3.4 Key findings: Sunlight Exposure

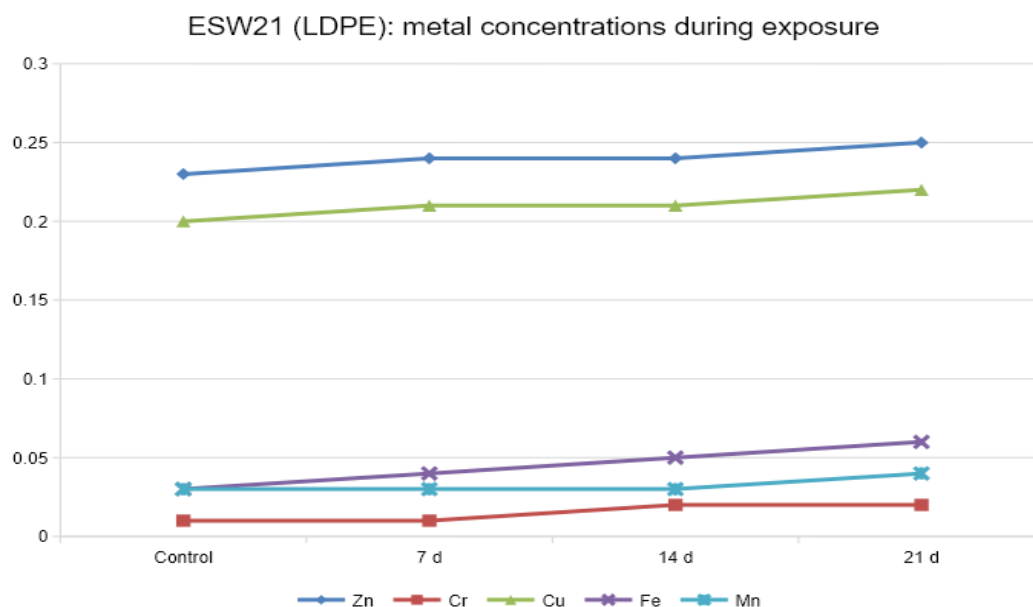


Figure 3.1 show several metals progressive or near progressive increases with exposure duration, although concentrations remained below the permissible limits. Result support the need to consider storage temperature and direct sunlight as post production quality factors.

3.5 Key Findings: Hazard Index (HI) and Carcinogenic Risk (CR)

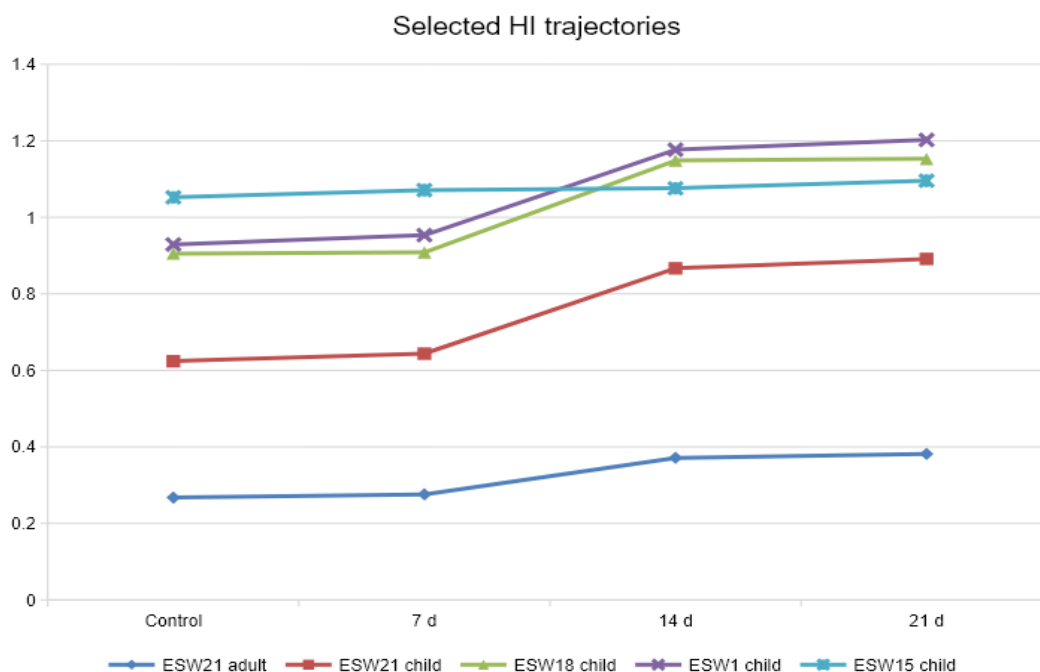


Figure 3.2 reported chromium-related CR increased with exposure duration in ESW21, ESW18 and ESW1, children had higher estimates than adults. ESW18 exceeded 1 after 14 and 21 days: ESW1 exceeded 1 after 13 and 21 days: ESW15 was already >1 in the unexposed condition and remained >1.



4. DISCUSSION

The risk assessment adds an important dimension to the concentration-based assessment of sachet water. Although baseline concentrations were generally below the applicable regulatory limits, the ADD and HQ results indicate that risk cannot be interpreted solely from concentration values (Addo, *et al.*, 2020). Children recorded higher ADD and HQ values than adults. This is attributable primarily to the relationship between contaminant intake and body weight in the exposure model (USEPA, 2005).

The HI results are particularly important. ESW21 remained below unity for both adults and children. In contrast, ESW18 and ESW1 exceeded unity for children after 14 and 21 days. ESW15 exceeded unity for children even under the control condition (Adefemi, *et al.*, 2008). An HI above unity is generally used as a screening indicator of potential non-carcinogenic concern under the specified assumptions. It does not establish that adverse health effects will occur in exposed individuals. Rather, it indicates that the estimated combined exposure warrants additional attention, Adelekan and Abegunde (2011).

The increase in some HI values with exposure duration is consistent with the observed changes in metal concentrations during elevated-temperature exposure. This supports the hypothesis that storage conditions can influence exposure estimates (Campbell, *et al.*, 2006). Chromium-related CR estimates also increased for several samples with prolonged exposure. Children recorded higher values than adults. These estimates should similarly be interpreted as model-based risk indicators rather than predictions of actual disease occurrence, Daniel and Daodu (2016). An important strength of this study is the simultaneous assessment of multiple metals. However, the risk estimates are dependent on assumptions concerning water intake, body weight, exposure frequency, exposure duration and toxicity reference values. Uncertainty in these parameters should therefore be considered when applying the estimates to the wider population (Dada, 2009).

5. CONCLUSION

The study demonstrates that potential health risk associated with sachet-water heavy metals is influenced not only by contaminant concentration but also by exposure duration and population characteristics. Children generally recorded higher ADD, HQ, HI and CR estimates than adults. Some child HI values exceeded unity, particularly for ESW18, ESW1 and ESW15. Chromium-related carcinogenic-risk estimates increased with exposure duration for several samples. Therefore, heavy-metal monitoring should be combined with exposure-based risk assessment when evaluating the safety of packaged drinking water.

RECOMMENDATIONS

1. Routine heavy-metal surveillance should be incorporated into sachet-water quality-control programmes.
2. Risk assessments should separately consider adults and children.
3. Sachet water should be protected from prolonged sunlight and elevated temperatures.
4. Long-term exposure studies should be conducted using larger sample sizes.
5. Future studies should include additional potential migrants from polyethylene packaging.
6. Probabilistic risk assessment should be considered to quantify uncertainty in exposure assumptions.

6. DECLARATION

Conflict of interest

The authors declare that there is no conflict of interest associated with this study.



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Author's contribution

The authors were responsible for the conceptualization of the study, sample characterization, interpretation of FTIR, DSC and mechanical-testing results, and preparation of the manuscript.

Data availability

The data underlying the findings are derived from the experimental characterization of sachet-water packaging materials. The relevant results are presented in the manuscript. Additional raw analytical data may be made available by the corresponding author upon reasonable request, subject to applicable institutional requirements.

Ethical statement

The study involved characterization of packaging materials and did not involve human participants or experimental animals in the reported analytical procedures.

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