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A Case for Adoption of Industry-Wide Application of Solar Disinfection of Packaged Drinking Water Before Distribution in Nigeria

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ABSTRACT: The study makes a case for adoption of an industry-wide application of solar disinfection (SODIS) in the disinfection of packaged water at the production stage. To do this, 60 samples, comprising 12 brands of bottled water and 18 brands of sachet-packaged water were randomly purchased from street vendors in Nsukka, Enugu State, Nigeria and investigated. One sample was hidden from sunlight while the other sample was exposed to a day of sunlight before the two samples were subjected to microbial analysis for the determination of total coliform (TC) using the method of multiple-tube fermentation technique (MPN). Results show that 63% of packaged water vended in Nsukka is not fit for consumption. The risk of contamination is about 44% higher in sachet water when compared with bottled water (relative risk = 1.44). Exposing packaged water to a day of sunlight reduces the risk of consuming contaminated water by about 97% (relative risk reduction value = 0.97). Advocacy of industry-wide application of SODIS may hold the key to ending widespread contamination of packaged water and the resulting life-threatening illnesses that have decimated the population of developing countries.

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Nigeria contributes more than 35% of global diarrhoea deaths mainly due to the consumption of microbially contaminated drinking water (WHO and UN-Water, 2014). Package water, in the form of bottled water and sachet water, is generally perceived as a safer alternative to other sources of drinking water, including municipal water supplies. At a slightly higher cost, it is readily available as a convenient and healthy drinking water source associated with affluence and good living. The consumption of packaged water is rapidly increasing in developing countries, especially where municipal water supply is of doubtful quality. It has become an integral part of water security towards the realization of the water target of the Sustainable Development Goals (SDGs) (Vedachalam *et al*., 2017). It is also a big part of relief emergencies in the event of a humanitarian crisis, especially in the camp of Internally Displaced Persons (IDPs) (IFRC, 2008). However, evidence questioning the microbial integrity of the street-vended packaged water continues to accumulate, especially in low- and middle-income countries. Unacceptable levels of microbial pathogens have been found in street-vended packaged water by independent studies around the globe (Ajala *et al*., 2020; Williams *et al*., 2015). Organisms that have been isolated include both enteric and pathogenic microorganisms implicated in fatal disease conditions and illnesses such as bacillary dysentery, gastroenteritis, diarrhoea, cryptosporidiosis, giardiasis, shigellosis, etc. (Akinde *et al*., 2011; Osei *et al*., 2013).

Interestingly, all the classically defined water-borne pathogens, including the majority of those isolated in packaged water, are known to be amenable to solar disinfection (SODIS) within 6 h of exposure to sunlight (McGuigan *et al*., 2012). SODIS procedure involves exposing water stored in transparent

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polyethylene terephthalate (PET) containers or polyethylene (PE) bags, the same materials used for packaging drinking water, for a period of about 6 h of strong sunlight after which the water is safe for consumption. The pathogens are destroyed by the combined action of infrared (IR) heat and ultraviolet (UV) components of solar radiation (Luzi *et al*., 2016; Meierhofer and Wegelin, 2002). SODIS is one of the methods recommended by the World Health Organisation (WHO) for point-of-use water treatment, especially where there are no other methods of obtaining safe drinking water. The SODIS method has an additional advantage as it can still be applied after the water has been packaged, provided the packaging material is transparent. Clinical trials and health impact assessment studies that investigated SODIS effectiveness in the field recorded significant reductions in diarrhoea episodes and infant mortality (Conroy *et al*., 2001; McGuigan *et al*., 2011; Waddington and Snilstveit, 2009). Concerns about the migration of genotoxins and other potentially harmful chemicals into SODIS water during exposure had been addressed through numerous control experiments (McGuigan *et al*., 1998; Mustafa *et al*., 2013; Schmid *et al*., 2008). A review of available evidence suggests that the health risk of consuming SODIS water is in the same order of magnitude as the risk of consuming PET-packaged beverages and water that has not been exposed to the sun (McGuigan *et al*., 2012). The aim of this study is to make a case for an industry-wide application of Solar Disinfection (SODIS) of packaged drinking water just before distribution in Nigeria.

MATERIALS AND METHODS

Study location: The experiments were conducted in Nsukka, Enugu State, the southeastern region of Nigeria. Nsukka is located within latitudes 6.86^o N and 6.83^o N of the Equator, and longitudes 7.36^o E and 7.42^o E of Greenwich Meridians. Topographically, Nsukka is located in a plateau, an escarpment region with ground elevations ranging from 280 m to 530 m above mean sea level with a mean of about 429 m. Recent meteorological data of Nsukka Urban show a maximum monthly rainfall of 231 mm/month with an atmospheric temperature range of 22 – 36 ^{o}C and a mean annual relative humidity of 77%. The region is known for its copious rainfall from June to October and an extended dry period lasting from November to March. During the dry season, the sunlight reaching Nsukka is significantly dimmed by the dust-laden airmass and aerosol pollution of the dusty northeasterly trade wind (Harmattan wind) that blows from southern Sahara to the Gulf of Guinea (Ugwuoke and Okeke, 2012). An earlier study (Nwankwo and Agunwamba, 2021) that investigated the pattern of seasonal variation of solar radiation and maximum air temperature confirmed the applicability of SODIS in Nsukka. Monthly averages of 5-hour midday radiation intensity and maximum air temperature indicated that only the rainy months of July and August do not meet the recommended daily average of 500 W/m^2 radiation intensity or 270 Wh/m^2 daily UV dose required for the effective application of SODIS (Nwankwo and Agunwamba, 2021).

Experimental procedure and analysis: Sixty samples, comprising 12 brands of bottled water (750 mL) and 18 brands of sachet-packaged water (600 mL) were used for the experiments. For each experiment, 2 samples of the same packaged water brand were randomly purchased from street vendors in Nsukka urban in Enugu state (Southeastern Nigeria). One sample was hidden from sunlight in a Pullman drawer, and the other sample was exposed to sunlight for a day before the two samples were subjected to microbial analysis at the Sanitary Engineering Laboratory, University of Nigeria, Nsukka for the determination of the total coliform (TC) based on the procedure described in the Standard Methods for the Examination of Water and Wastewater (APHA, 2017). The number of samples that tested positive and negative for total coliform were entered in a 2 × 2 contingency table for analysis and computation of relative risks (RR) of contamination. The nomenclature for a 2 × 2 contingency table is shown in Table 1.

Table 1 Nomenclature for a 2 × 2 contingency table

	No. of positive samples	No. of negative samples	N
Exposed	A	B	n_1
Dark control	C	D	n_2

The computational formula for relative risk (RR) is

$$RR = \frac{A/n_1}{C/n_2}$$

The log relative risk ($\log RR$) is then

$$\log RR = \text{In}\ (RR)$$

The variance of log relative risk can be approximate as given by Borenstein *et al*. (2009) as

$$V_{\log(RR)} = \frac{1}{A} - \frac{1}{n_1} + \frac{1}{C} - \frac{1}{n_2}$$

The standard error of log relative risk is given by

$$SE_{\log(RR)} = \sqrt{V_{\log(RR)}}$$

So that 95% confidence interval becomes

$$95\%\ \mathrm{CI} = exp\left(\mathrm{In}\ (RR) - 1.96 \times SE_{\log(RR)}\right) \text{ to } exp\left(\mathrm{In}\ (RR) + 1.96 \times SE_{\log(RR)}\right)$$

Note that zero cells may occur in a contingency table if there are no positive samples. One way of dealing with zero cells is by adding 0.5 to all cells in the contingency table (Pagano and Gauvreau, 2018). Nandram *et al*. (2015) discussed several methods of dealing with both structural and sampling zeros in contingency tables.

The daily cumulative UV irradiance was estimated for the exposure days using a Digital UVA/UVB light meter (General Tools UV513AB, 280 – 400 nm). The LCD screen of the digital UV meter displays the rate of radiant energy per unit area in mW/cm^2 or $\mu W/cm^2$. The readings of the UV meter were taken using an Open Camera 1.48.3 App for android phones, which has features that allow shots to be taken repeatedly at a preset time interval. On the days of experiments, the camera would be primed and positioned to snap the LCD screen of the digital UV meter every 60 s from 9 a.m. to 5 p.m. The readings were used to estimate the daily UV profile, which was in turn used to evaluate the cumulative UV dose. All the experiments were conducted during the three months between July and September 2019.

RESULTS AND DISCUSSION

Tables 2 and 3 show the most probable number (MPN) per 100 mL for the different brands of sachet and bottled water used in the experiment for the exposed and dark-controlled samples together with the maximum 5-hour average of daily UV dose received on the days of exposure. Analysis of results from the dark-controlled samples showed that more than 63% of the packaged water vended in the streets of Nsukka do not meet the WHO standard and therefore not fit for consumption..

Table 2 Total Coliform population for exposed and control sachet water samples

Date	UV dose (Wh/m^2)	Sachet water brand Name	Dark-controlled sample (MPN/100 mL)	Exposed Sample (MPN/100 mL)
27/07/2019	166.0	Ecaison	17.0	<1.8
28/07/2019	196.0	De Occcasion	25.0	<1.8
29/07/2019	220.0	Rocktama	21.0	<1.8
02/08/2019	189.0	Akukris	41.0	<1.8
13/08/2019	208.0	Aqua Rapha	2.2	<1.8
18/08/2019	276.0	MC Family	<1.8	<1.8
20/08/2019	271.0	Mt Calvary	<1.8	<1.8
21/08/2019	253.0	Jives	3.6	<1.8
25/08/2019	241.0	Zeroth	<1.1	<1.8
26/08/2019	268.0	Addmore	3.6	<1.8
27/08/2019	324.0	Galaxy	23.0	<1.8
29/08/2019	344.0	Goddybrings	130.0	<1.8
01/09/2019	338.0	Blessed	94.0	<1.8
01/09/2019	193.0	Oscilla	17.0	<1.8
03/09/2019	206.0	Diou	<1.8	<1.8
04/09/2019	210.0	O’ gala	<1.8	<1.8
07/09/2019	192.0	De Lord	10.0	<1.8
09/09/2019	274.0	Sachet Water	24.0	<1.8

Table 3 Total Coliform population for exposed and control bottled water samples

Date	UV dose (Wh/m^2)	bottled water brand Name	Dark-controlled sample (MPN/100 mL)	Exposed Sample (MPN/100 mL)
11/09/2019	204.0	Ecaison	<1.8	<1.8
12/09/2019	306.0	MC Family	9.2	<1.8
14/09/2019	258.0	Noson	<1.8	<1.8
15/09/2019	270.0	Ragolis	<1.8	<1.8
16/09/2019	187.0	Lion	20.0	<1.8
18/09/2019	387.0	Eva	<1.8	<1.8
19/09/2019	173.0	Nestle	<1.8	<1.8
20/09/2019	260.0	Aquafina	4.5	<1.8
22/09/2019	293.0	Pellar	3.6	<1.8
24/09/2019	212.0	De-Lord	<1.8	<1.8
26/09/2019	237.0	Gavinco	6.0	<1.8
28/09/2019	198.0	Seborn	12.0	<1.8

Further analysis showed that bottled water may be safer than sachet water. About 72% of sachet water and 50 % of bottled water tested positive for total coliform. Although not significant, the risk of consuming contaminated packaged water was found to be higher in sachet water (relative risk, RR = 1.44, 95% CI 0.77 – 2.72). Therefore, the evidence from this study is not sufficient to state that sachet water is of less quality than bottled water. No total coliforms were detected in all the exposed samples, including samples exposed on days that did not receive the requisite UV dose of 270 Wh/m^2 in 5 hours necessary for complete inactivation of bacterial pathogens in SODIS. The relative risk reduction (RRR) value suggests that exposing packaged water to a day of sunlight can reduce the risk of consuming contaminated packaged water by about 97% (RRR = 0.97, 95% CI 0.593 – 0.998). Therefore, SODIS can be employed for water purification at the industrial level just before distribution. Thus, pathogens that escaped the treatment processes, or those introduced during filling and packaging can be eliminated. The only foreseeable barrier to the adoption of SODIS methods in the packaged water production industry is the popular mythology that exposing water to the sun makes water quality worse. Impartation of taste and risk of migration of potentially harmful chemicals from the polymeric materials are the major public concerns. This is because PET and PE, even without solar exposure, are generally a potential source of genotoxicity, especially additives like phthalates and antimony used as plasticizers and catalysts in the PET production process. These chemicals can cause cancer, disrupt the function of endocrine gland, increase adiposity and insulin resistance (Grün and Blumberg, 2009), and lead to a variety of adverse reproductive health conditions (Pan *et al*., 2006; Swan *et al*., 2005). Polyethylene (PE) contains fewer additives and is generally less prone to generate photoproducts when compared to PET (Gutiérrez- Alfaro *et al*., 2017). Low-density polyethylene (LDPE) is known to retain its stability under severe temperature conditions even in the absence of heat stabilizers (Hahladakis *et al*., 2018). Phthalates were not detected in sachet water stored at 65 ºC for 8 hours (Young and Tarawou, 2016). GC-MS analysis on SODIS water using bags detected only 2,4-ditert-butylphenol, albeit in a concentration range (1 – 4 µg/L) that passes the drinking water standard of the United States Environmental Protection Agency, from a possible migration of 2,4-ditert-butylphenol, 4-tert-butylphenol, 4-ethylphenol, and 2,6-di-tert-butyl-p-benzoquinone (Danwittayakul *et al*., 2017). The most abundant phthalates that are found in PET-bottled water are di (2-ethylhexyl) phthalate (DEHP), diisobutyl phthalate, dibutyl phthalate, and diethyl phthalate (DEP) (Montuori *et al*., 2008; Sax, 2010). Other compounds that could leach into PET-packaged water include aldehydes, terephthalic acid, dimethyl terephthalate, and ethylene glycol. Aldehydes are responsible for the fruity off-taste and odour in PET-packaged water (Lugwisha *et al*., 2016), which can be detected by consumers when the concentration of acetaldehyde reaches 0.02 mg/L (Welle, 2018). Terephthalic acid and dimethyl terephthalate are known to be genotoxic, but they are not soluble in water, and their chances of migrating into water are minimal (McGuigan *et al*., 1999). Ethylene glycol is more likely to leach into the water, as it is more water-soluble. These compounds generally become more unstable and soluble with increasing temperature and storage time (Farhoodi *et al*., 2008; Mihucz and Záray, 2016). For example, significant concentrations of antimony were only reported in cases involving long storage times and/or water temperatures of >60 ºC (Luzi *et al*., 2016). This range of temperatures was not attained year-round under normal SODIS conditions, even in the Tropics (Nwankwo and Agunwamba, 2021).

With solar exposure and the attendant increase in water temperature, the rate of migration of these polymer-based compounds will invariably increase. However, it has been demonstrated through laboratory and field studies using applied analytical methods that some of the photoproducts such as aldehydes and phthalates generated during solar exposure of PET can only be detected at the outer surface of the bottles (Wegelin *et al*., 2001). There were no signs of possible migration of additives or photoproducts from PET to water. Only about the first 35 µm depth of the exposed surface would go through photochemical oxidation, the core and the inner surface usually remain unaffected (Sang *et al*., 2020). Ubomba-Jaswa *et al*. (2010) did not detect genotoxicity in SODIS water exposed to sunlight under normal SODIS conditions (emptying and refilling before another exposure) but detected genotoxicity in PETs continuously stored under sunlight for 2 months (without emptying and refilling). However, similar levels of genotoxicity were also found in the dark control samples, suggesting that it is unlikely that the occurrence of genotoxic compounds in SODIS water is related to solar exposure. Schmid *et al*. (2008) demonstrated that the concentration of plasticisers, di (2-ethylhexyl) adipate (DEHA) (0.046 µg/L) and DEHP (0.71 µg/L), after 17 hours of exposing PET to direct sunlight is in the range found in commercial bottled water. Another study by Mustafa *et al*. (2013) found a maximum DEHP concentration of 0.38 µg/L under SODIS conditions, which is well below the WHO's recommended limit of 8 µg/L (WHO, 2022). These results are consistent with the general findings that chemical micropollutants ingested from drinking water and their total dietary contribution can be considered a minor issue when compared with the health risks from microbial contamination (van Dijk-Looijaard and van Genderen, 2000; van Leeuwen, 2000).

Conclusions: The study has provided evidence of widespread contamination of packaged water vended in the streets of Nsukka. Sachet water is generally more likely to be contaminated with microbial pathogens than bottled water. Solar disinfection offers a cheap and viable water disinfection solution that could be applied at the final stage of packaged water production processes just before distribution. What is remaining is to dismantle the deep-seated psychological barrier that exposing water to the sun makes its quality worse.

REFERENCES

Ajala, OJ; Ighalo JO; Adeniyi, AG; Ogunniyi, S; Adeyanju, CA (2020). Contamination issues in sachet and bottled water in Nigeria: a mini-review. *Sustain. Water Res. Manage*. 6(6): 112.

Akinde, SB; Nwachukwu, MI; Ogamba, AS (2011). Storage effects on the quality of sachet water produced within Port Harcourt Metropolis, Nigeria. *Jordan J. Biol. Sci*. 147(621): 1–8.

APHA (2017). Standard Methods for the Examination of Water and Wastewater (B. B. Rodger, D. E. Andrew, & W. R. Eugene (eds.); 23rd ed.). American Public Health Association (APHA). https://doi.org/10.2105/SMWW.2882.192

Borenstein, M; Hedges, LV; Higgins, JPT; Rothstein, HR (2009). Introduction to Meta-Analysis. John Wiley & Sons, Ltd.

Conroy, RM; Meegan, ME; Joyce, T; McGuigan, KG; Barnes, J (2001). Solar disinfection of drinking water protects against cholera in children under 6 years of age. *Arch. Disease in Childhood*. 85(4): 293–295.

Danwittayakul, S; Songngam, S; Fhulua, T; Muangkasem, P; Sukkasi, S (2017). Safety and durability of low-density polyethylene bags in solar water disinfection applications. *Environ. Technol.* 38(16): 1987–1996.

Farhoodi, M; Emam-Djomeh, Z; Ehsani, MR; Oromiehie, A (2008). Effect of environmental conditions on the migration of di (2-ethylhexyl) phthalate from PET bottles into yogurt drinks: influence of time, temperature, and food simulant. *Arabian J Sci Eng*. 33(2): 279–287.

Grün, F; Blumberg, B (2009). Endocrine disrupters as obesogens. *Molecular and Cellular Endocrinology*. 304(1): 19–29.

Gutiérrez- Alfaro, S; Acevedo, A; Figueredo, M; Saladin, M; Manzano, MA (2017). Accelerating the process of solar disinfection (SODIS) by using polymer bags. *J. Chem. Technol. Biotech.* 92(2): 298–304.

Hahladakis, JN; Velis, CA; Weber, R; Iacovidou, E; Purnell, P (2018). An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. *J. Hazard. Mat*. 344: 179–199.

IFRC (2008). Household water treatment and safe storage in emergencies. In Household water treatment and safe storage. Household water treatment and safe storage. www.who.int/household_water/research/technologies_intro/en/ (accessed February 02, 2020).

Lugwisha, E; Mahugija, JAM; Mwankuna, C (2016). Levels of formaldehyde and acetaldehyde in selected bottled drinking water sold in urban areas in Tanzania. *Tanzania J. Sci.* 42(1): 1–14.

Luzi, S; Tobler, M; Suter, F; Meierhofer, R. (2016). *SODIS* Manual: Guidance on Solar Water Disinfection. https://www.sodis.ch/ (accessed February 02, 2020).

McGuigan, KG; Conroy, RM; Mosler, HJ; du Preez, M; Ubomba-Jaswa, E; Fernandez-Ibañez, P (2012). Solar water disinfection (SODIS): A review from bench-top to roof-top. *J. Hazard. Mat*. 235–236: 29–46.

McGuigan, KG; Joyce, TM; Conroy, RM (1999). Solar disinfection: Use of sunlight to decontaminate drinking water in developing countries. *J. Med. Microb.* 48(9): 785–787.

McGuigan, KG; Joyce, TM; Conroy, RM; Gillespie, JB; Elmore-Meegan, M (1998). Solar disinfection of drinking water contained in transparent plastic bottles: Characterizing the bacterial inactivation process. *J. Appl. Microb.* 84(6): 1138–1148.

McGuigan, KG; Samaiyar, P; Du Preez, M; Conroy, RM (2011). High compliance randomized controlled field trial of solar disinfection of drinking water and its impact on childhood diarrhea in rural Cambodia. *Environ. Sci. Technol.* 45(18): 7862–7867.

Meierhofer, R; Wegelin, M (2002). Solar Water Disinfection: A Guide for the Application of SODIS. In SANDEC (Water & Sanitation in Developing Countries).

Mihucz, VG; Záray, G (2016). Occurrence of antimony and phthalate esters in polyethylene terephthalate bottled drinking water. *Appl. Spectroscopy Rev*. 51(3): 183–209.

Montuori, P; Jover, E; Morgantini, M; Bayona, JM; Triassi, M (2008). Assessing human exposure to phthalic acid and phthalate esters from mineral water stored in polyethylene terephthalate and glass bottles. *Food Additives & Contaminants: Part A*. 25(4): 511–518.

Mustafa, A; Scholz, M; Khan, S; Ghaffar, A (2013). Application of solar disinfection for treatment of contaminated public water supply in a developing country: Field observations. *J. Water and Health*. 11(1): 135–145.

Nandram, B; Bhatta, D; Bhadra, D (2015). A likelihood ratio test of quasi-independence for sparse two-way contingency tables. *J. Stat. Comp. Sim.* 85(2): 284–304.

Nwankwo, EJ; Agunwamba, JC (2021). Effect of reactor characteristics on the seasonal effectiveness of solar disinfection: a factorial study. *Water SA*. 47(1): 113–122.

Osei, AS; Newman, MJ; Mingle, JAA; Ayeh-Kumi, PF; Kwasi, MO (2013). Microbiological quality of packaged water sold in Accra, Ghana. *Food Control*. 31(1); 172–175.

Pagano, M; Gauvreau, K (2018). Principles of biostatistics (2nd ed.). Taylor & Francis Group.

Pan, G; Hanaoka, T; Yoshimura, M; Zhang, S; Wang, P; Tsukino, H; Inoue, K; Nakazawa, H; Tsugane, S;
Takahashi, K (2006). Decreased serum free testosterone in workers exposed to high levels of di-n-butyl phthalate (DBP) and di-2-ethylhexyl phthalate (DEHP): a cross-sectional study in China. *Environ. Health Perspect*. 114(11): 1643–1648.

Sang, T; Wallis, CJ; Hill, G; Britovsek, GJP (2020). Polyethylene terephthalate degradation under natural and accelerated weathering conditions. *European Polymer J.* 136: 109873. https://doi.org/10.1016/j.eurpolymj.2020.109873

Sax, L (2010). Polyethylene terephthalate may yield endocrine disruptors. *Environ. Health Perspect*. 118(4): 445–448.

Schmid, P; Kohler, M; Meierhofer, R; Luzi, S; Wegelin, M (2008). Does the reuse of PET bottles during solar water disinfection pose a health risk due to the migration of plasticisers and other chemicals into the water? *Water Res*. 42(20): 5054–5060.

Swan, SH; Main, KM; Liu, F; Stewart, SL; Kruse, RL; Calafat, AM; Mao, CS; Redmon, JB; Ternand, CL;
Sullivan, S (2005). Decrease in anogenital distance among male infants with prenatal phthalate exposure. *Environ Health Perspect*. 113(8): 1056–1061.

Ubomba-Jaswa, E; Fernández-Ibáñez, P; McGuigan, KG (2010). A preliminary Ames fluctuation assay assessment of the genotoxicity of drinking water that has been solar disinfected in polyethylene terephthalate (PET) bottles. *J. Water and Health*. 8(4): 712–719.

Ugwuoke, P; Okeke, C (2012). Statistical Assessment of Average Global and Diffuse Solar Radiation on Horizontal Surfaces in Tropical Climate. *Inter. J. Renewable Energy*. 2(2); 269–273.

van Dijk-Looijaard, AM; van Genderen, J (2000). Levels of exposure from drinking water. *Food. Chem. Toxic.* 38: S37–S42.

van Leeuwen, FXR (2000). Safe drinking water: the toxicologist's approach. *Food and Chemical Toxicology*. 38: S51–S58.

Vedachalam, S; MacDonald, LH; Omoluabi, E; OlaOlorun, F; Otupiri, E; Schwab, KJ (2017). The role of packaged water in meeting global targets on improved water access. *J.Water., Sanit. Hygiene. Develop*. 7(3): 369–377.

Waddington, H; Snilstveit, B (2009). Effectiveness and sustainability of water, sanitation, and hygiene interventions in combating diarrhoea. *J. Develop Effectiveness*. 1(3), 295–335.

Wegelin, M; Canonica, S; Alder, C; Marazuela, D; Suter, MJF; Bucheli, TD; Haefliger, OP; Zenobi, R;

McGuigan, KG; Kelly, MT; Ibrahim, P; Larroque, M (2001). Does sunlight change the material and content of polyethylene terephthalate (pet) bottles? *J. Water Supply: Res. Technol. AQUA*. 50(3): 125–135.

Welle, F. (2018). *The facts about PET*. https://www.petcore-europe.org/images/news/pdf/factsheet_the_facts_about_pet_dr_frank_welle_2018.pdf (accessed February 02, 2020).

WHO (2022). Guidelines for drinking- water quality: fourth edition incorporating the first and second addenda (4th ed + 1). World Health Organization.

WHO; UN-Water (2014). UN-water global analysis and assessment of sanitation and drinking-water (GLAAS) 2014 report: investing in water and sanitation: increasing access, reducing inequalities. In World Health Organization.

Williams, AR; Bain, RES; Fisher, MB; Cronk, R; Kelly, ER; Bartram, J (2015). A systematic review and meta-analysis of fecal contamination and inadequate treatment of packaged water. *PLoS One*. 10(10): e0140899.

Young, E; Tarawou, T (2016). The Effect of Temperature on the Migration of Phthalate Plasticizers from Plastic Sachet into Water. *Int. J. Sci. Res. Chem.* 1(1): 32–34.