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Quantitative Microbial Risk Assessment (QMRA) of major drinking water sources at household level incorporating boiling treatment effect

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Abstract

This study conducted a quantitative microbial risk assessment (QMRA), incorporating the effect of boiling of water, on major sources of drinking water for households in Afikpo North LGA, Ebonyi State, Nigeria. Water samples were collected from12 drinking water boreholes (n =36), a popular spring water (n= 36) and four popular brands of sachet water (n= 36).The samples were analysed in the laboratory for colonies of microorganisms, coliform organisms, *E. coli*, *Salmonella* spp and *Giardia lamblia*. Data were analysed for specific parameters of the study population (n =1150). The parameters include daily water consumption per person per day (L/person/day), the fraction of thepopulatonexposed to the contaminated drinking water source under consideration, the percentage ofthe population vulnerableto pathogenic infection among the exposed population,the pathogen strike rate in each water source, and the probability that water is boiled before drinking. Quantitative microbial risk assessment was performed for concentrations of *E. coli* (CFU/L), *Salmonella* spp (CFU/L), and *Giardia lamblia* (Cyst/L) in the water samples. From the findings, the risk of diarrhea is significantly highin all the drinking water sources examined. The risk of diarrhea ranged between0.090 and 0.190 for borehole water source, 0.004 and 0.032 for spring water source, 0.039 and 0.125 for sachet water sources. The implication is an urgent need to regualte the operation of water boreholes, protect spring water source, and enforce standards on the processes of production, distribution and storage of sachet water in Afikpo North LGA.

Keywords: QMRA; Drinking water; Boiling; Risk; Diarrhea

1. Introduction

Extensive studies have implicated contaminated drinking water as a major pathway for microbial hazards (active pathogens) that cause diarrhea and diarrhea-related water borne diseases such as dysentery, typhoid fever, and cholera [1-5]. Current estimates [6] put diarrhea as a leading cause of death for young children across the world and responsible for death of about 484,000 children annually. Controlling microbial risks in drinking water sources and improving access to clean water can reduce diarrhea by about 40% [7, 8]. Instructively, the water quality guidelines by the World Health Organization (WHO) emphasize a risk-based management approach for prevention or minimization of microbial hazards in the water supply process [9].

Hence, various quantitative microbial risk assessment (QMRA) models have been developed for drinking water sources across the world. QMRA enjoys a wide acceptance, especially in the developed countries, as a scientific means of estimating human exposure to unsafe drinking water and quantifying the health risks associated with consumption of contaminated drinking water. The outcome of QMRA provides objective basis for monitoring the concentration of pathogenic microorganisms and keeping the pathogen loads at safe levels along the processes of drinking water treatment and supply systems [10].

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Many, especially at the household level in the developing countries, do not recognize the risk of microbial contamination in some common sources of drinking water. However, extensive studies indicate that common sources of drinking water, such as the water borehole, spring and the sachet water, do produce unsafe water [11- 13]. Therefore, water supply systems at both the raw water and treatment levels require period assessment. This practice will enable proactive detection and control of imbedded microbial pathogens that may pose health risk to consumers in drinking water sources.

Most of the current QMRA were applied along municipal systems, outside the household level. However, in many developing countries municipal drinking water treatment systems are lacking [14]. Appropriate application of QMRA at household drinking water sources therefore needs to take into consideration the drinking water treatment processes and water supply sources that are available at the household levels where the municipal system does not exist. In this study, QMRA was conducted on drinking water supply system at household level in Afikpo North Local Government Area (LGA), Ebonyi State, Nigeria.

Lack of access to municipally or centrally treated drinking water constrains many households in Afikpo North LGA to obtain drinking water through private arrangements from sources such as surface water (rivers, streams and ponds), springs, water wells, water boreholes and vended water, including packaged (sachet) water. A previous study observed a high prevalence of waterborne diseases among the household communities in Afikpo North LGA. Amatobi and Adenaike [15] found that the prevalence rates of typhoid fever, hepatitis A, dysentery and diarrhea in Afikpo North Local Government Area were 20%, 1.52%, 7.27%, and 14.55% respectively.

The aim of this study is to conduct a quantitative microbial risk assessment (QMRA), incorporating the effect of boiling of water, on major sources of drinking water for households in Afikpo North LGA, Ebonyi State, Nigeria The study was designed to conduct QMRA on the three major drinking water sources namely boreholes, sachet water, and spring water. Data from appropriate QMRA of the major drinking water sources of household communities will provide objective site-specific data, which can assist authorities, stakeholders and individual water operators and water consumers to take right decisions regarding safe drinking water supply in Afikpo North LGA. This study is envisaged to facilitate proper understanding, creation of awareness and taking preventive and proactive actions towards maintaining safe drinking water quality thereby reducing the prevalence of waterborne diseases and protecting public health.

2. Material and methods

2.1. The study area

Afikpo North LGA is located in Ebonyi State, Southeastern Nigeria, on latitude 6°Nand longitude 8°E. The study area covers approximately 164 square kilometers in land area. The current population of Afikpo North LGA is about 259000, projecting (with 3% national growth rate) from Nigeria's last census of 2006 [16]. The LGA hosts three major growing urban cities of Ebonyi State, which are Afikpo (the LGA headquarters), Unwana (the site of Akanu Ibiam Federal Polytechnic) and Amasiri (a growing commercial transit town). The study area has no municipal or centralized drinking water supply system and so drinking water supply in Afikpo North LGA is largely a private affair. A previous study reveals that the three major sources of drinking water in the study area are water boreholes, sachet water and spring water. A formal epidemiological or waterborne diseases prevalence data for Afikpo North LGA are currently not available for Afikpo North LGA. However, a previous study [15] reinforced by the current researchers' experience reveal a high prevalence of waterborne gastro-intestinal diseases such as diarrhea, typhoid fever and dysentery in the study area.

Since drinking water is one of the major pathways for transmission of gastro-intestinal infections, there is a need for a formal quantitative microbial risk assessment of major drinking water sources in Afikpo North Local Government Area of Ebonyi State Nigeria. Fig, 1 consists of maps of Nigeria, Ebonyi State and Afikpo North LGA locating the study area and the sampling points.

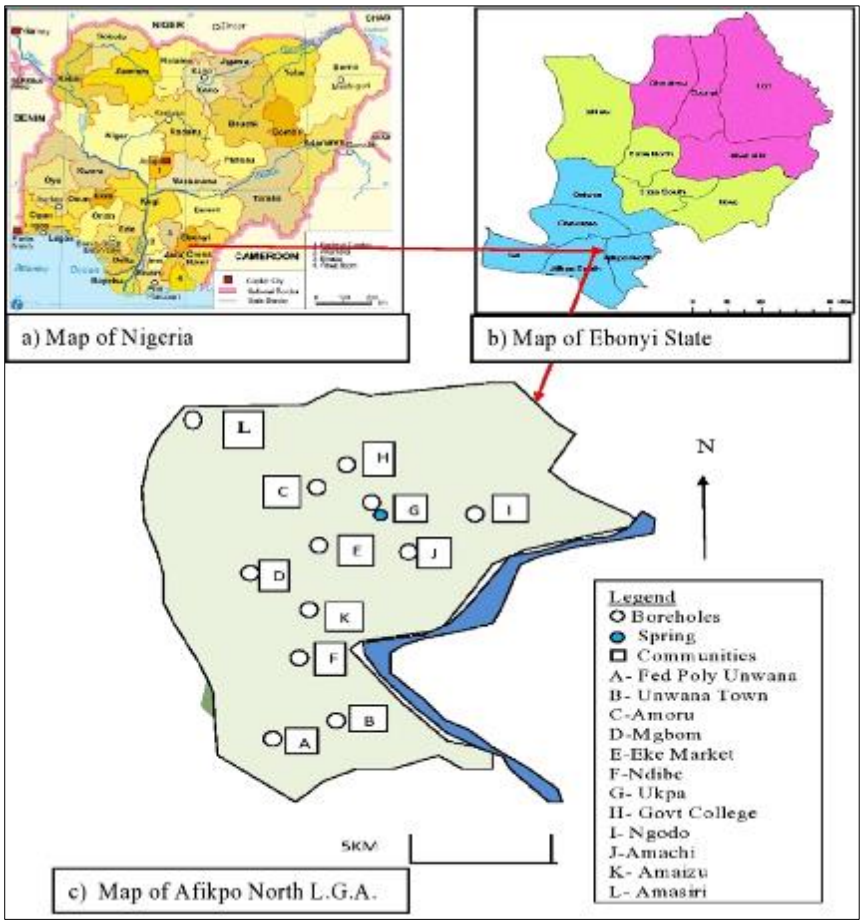

Figure 1 Maps of Nigeria, Ebonyi State and Afikpo North Local Government Area, locating the sampling points

2.2. Sample collection

Water samples were collected from 12 drinking water boreholes, a popular spring water source ("Why Worry" spring at McGregor hill Ukpa), and from four brands of vended sachet water in the study area. These three water sources provide daily drinking water for about 90% of people living in the selected communities [15]. The communities include Akanu Ibiam Federal Polytechnic Unwana premises, Unwana Town, Amuro, Mgbom, Eke Market Environ, Ndibe, Ukpa, Government College Environ, Ngodo, Amachi, Amaizu and Amasiri. For boreholes, water samples were collected from twelve (12) most patronized commercial drinking water sources across communities in the study area. The selected boreholes were sampled three (3) times each (in three weeks), making 36 samples in all. The water samples from the boreholes were collected into 1.5 L polyethylene terephthalate [PET] bottles that were pre-soaked with 20% HNO_3 solution for 12 hours and rinsed with de-ionized water prior to collection of samples. Thirty-six (36) water samples were also collected (in 36 days) from the spring using 1.5 PET bottles prepared in similar manner as in the sampling of water boreholes. In addition, water samples were collected from each off our (4) common brands of sachet water that are sold in the study area and each brand was randomly sampled 9 times (in nine days)making a total of 36 samples. In all, 108 drinking water samples were collected. In each case, the PET bottles that were filled with sampled water were stored in an ice-chest, imbedded with ice packs, and taken to laboratory within 24 hours of collection for analyses.

2.3. Laboratory tests

In the current study, *E. coli* and *Salmonella* spp were selected as indicators of bacteria while *Giadia lamblia* was selected to represent protozoa. Viruses were not included in the scope of microorganisms for QMRA in this study due to the low rate of survival of viruses outside their natural water environment and the constraints of feasibility in laboratory analysis. For purpose of comparison of the water quality with the safe drinking water limits set by the WHO [17] and the Nigerian Standard for Drinking Water Quality [NSDWQ] [18], the colonies of microorganisms and coliform organisms were also determined in the water samples.

The water samples were analysed using standard laboratory procedures for concentrations of colonies of microorganisms, coliform organisms, *E. coli, Salmonella* spp and *Giardia lamblia* [19, 20]. The analyses were also used to reveal the pathogen strike rate (percentage of positive samples in the total sample).

2.4. Site visits for field (household) survey

Apart from visits to water source sites in the study area for collection of samples, households in the study area communities were also surveyed (using structured questionnaire) to determine some key input parameters for the QMRA. The parameters determined include per capita water consumption per day (L/person/day), percentage of people exposed to each of the major water sources in each community (or the exposed population), percentage of vulnerable population, and the probability that water from a specific source is boiled before drinking.

2.5. Dose response model

This study adoptedthecomprehensive susceptibilty dose-response model developed byAmatobi and Agunwamba[10]. Thecomprehensive susceptibilty model is stated as [10]:

$$P_I = \zeta[1 - (e^{-0.5\lambda V})],\ 0 < \zeta < 1 \text{.....(1)}$$

Where:P_I is the daily risk of infection; ζ is a comprehensive susceptibility parameter (which is characteristic of the exposed population and pathogen prevalence among the exposed population); λ, is the concentration of specific pathogenic organism in the water samples; V is the volume of water ingested by an individual per day.

The comprehensive susceptibility parameter is mathematically defined as [10]:

$$\zeta = 0.33\left(P_p + P_v + S_d\right) \text{..... (2)}$$

Where:P_p is the fraction of populaton of the study area exposed to the contaminated drinking water source under consideration;P_v is the percentage ofthe population vulnerableto pathogenic infection among the exposed population; and S_d is the pathogen strike rate.

The comprehensive susceptibilitymodel was modified by this study with incorporation of boiling treatment effect parameter (1-t). Thus, the modified formulation of the daily risk of infection is stated as:

$$P_I = (1 - t)\zeta[1 - (e^{-0.5\lambda V})],\ 0 < \zeta < 1 \text{.....(3)}$$

Equation (3) is the formulation used in this study to calculate the daily risk of pathogen infection from ingestion of contaminated drinking water.

Where t is the probability that a particular water source is boiled before drinking.

2.6. Application of the QMRA model

A point estimates for ζ, λ, V, and t were obtained using descriptive statistics. Risks of pathogen infection and diarrhea for the three major sources of drinking water (water boreholes, sachet water and spring water) in the study area were determined. Risk of disease multiplication factors (P_{ill} = K) were used to convert risk of pathogen infection to risk of diarrhea were obtained from literature: for *E. coli* O157:H7, P_{ill} = 0.25; for *Salmonella* spp, Pill = 0.45 and for *Giardia lamblia*, P_{ill} = 0.67 [10]. To address the uncertainty and variability in the exposure estimates, ten thousand Monte Carlo iterations were executed for concentration of pathogens identified in each water source. The simulations were performed using a programme written in Microsoft Office Excel 2007 spreadsheet. The pathogens used for simulation of daily risks of infection and diarrhea disease were *E. coli* (cfu/l), *Salmonella* spp (cfu/l) and *Giardia lamblia* (cyst/l). *E. coli* concentration was converted to *E. coli* O157; H7 by a factor of 0.08 [21, 10].

3. Results and discussion

3.1. Mean concentration of pathogens

Table 1 presents the mean concentration of pathogens in water samples collected from water boreholes, sachet water and spring water. The table contains guideline values recommended by NSDWQ [18] and WHO [17].

Table 1 Mean concentration of pathogens in water boreholes, sachet water and spring water samples

Water sources	**Colonies of Microorganisms (cfu/ml)**	**Coliform Organisms (cfu/100ml)**	***E-coli* (cfu/100ml)**	***Salmonella* spp (cfu/100ml)**	***Giardia lamblia* (cyst/100ml)**
Borehole: Mean(std. dev)	51 (12)	17 (5)	4.44(2.39)	1.22 (0.99)	0.44 (0.3)
Sachet water: Mean(std. dev)	14.53 (2.3)	4.73 (0.4)	0.88 (0.3)	0.57 (0.3)	0.4 (0.3)
spring water: Mean(std. dev)	7.94 (2.37)	0.36 (0.93)	0.08 (0,28)	0.03 (0.17)	0.06 (0.23)
NSDWQ[18]Limits	10	0	0	NS	NS
WHO[17]Limits	10	0	0	NS	NS

This result indicates that most of the borehole and sachet water sources currently available in Afikpo North LGA do not produce drinking water within the safe guideline values of the WHO [17] and the NSDWQ [18].

3.2. Pathogen strike rate

This result revealedthe frequency of detection of contaminats in the specific water sources. It measured the percentage of samples that tested positive for a particular pathogenic organism. Thus this outcome revealed how critical or vulnerable a particular drinking water source could be to microbial contamination. The outcome is presented in table 2.

Table 2 Pathogen strike rate

Water sources	**Pathogen strike rates**				
	Colonies of Microorganism	**Coliform Organism**	***E-coli***	***Salmonella* spp**	***Giardia lamblia***
Borehole	1	1	0.53	0.33	0.33
Sachet water	1	0.69	0.44	0.33	0.33
spring water	1	0.17	0.08	0.03	0.06

The result in table 2 corroborates with the one in table one showing high incidences of pathogens in borehole and sachets water samples.

3.3. Per capita water consumption

Per capita water consumption (L/person/day) was determined to be 1.52L/person per day in the study area. Per capita water consumption is an important component in the exposure analysis stage of quantitative microbial risk assessment. The product of the per capita water consumption and concentration of pathogenic organism in the drinking water gives the exposure dose. A knowledge of per capita water consumption can also be useful when estimatingdrinking water demand for a community. The result obtained is in consonace with a previous study by Amatobi and Agunwamba [10].

3.4. Vulnerable population

The vulnerable population was determined for the study area to be 18.38%.This is the fraction of people in the study area most susceptible to waterborne pathogen and waterborne diseases due to weak or compromised immune system. This group of people includes children under five, adults above 65, pregnant women and people suffering or undergoing treatment for immune depleting illnesses such as cancer, HIV/AIDS, etc. [10].

3.5. Distribution of drinking water population by source

Fig. 2 shows the distribution of population by consumption of drinking water from the common sources in the study area. Fig. 2 shows that 57% of the people in the study area rely on borehole water, while 19% reply on sachet water as sources of drinking water. These two sources constituting 76% of the population in this study are also currently the major sources of drinking water in many communities in Nigeria. Udoh et al [5] assert that 18% of urban households in Nigeria depend on sachet water as source of drinking water. A recent survey [22] suggests that the water borehole contributes over 40% of drinking water consumed in Nigeria.

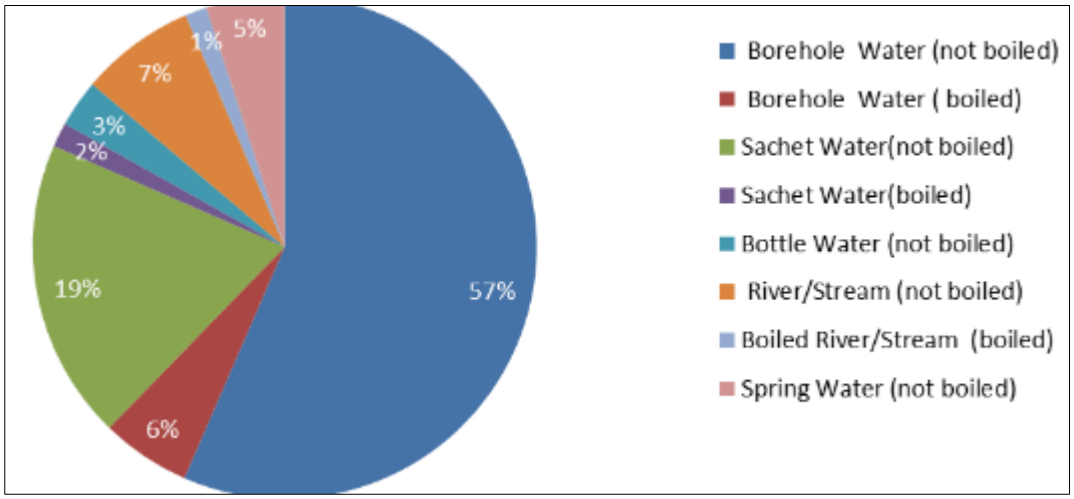

Figure 2 Distribution of drinking water population by sources in the study area

3.6. Boiling treatment effect

Table 3 presents the proportions of the population that boil water from specific sources before drinking. This proportion represents the probability that consumers could boil water from a specific source before direct consumption. The proportion generates the boil effect (1-t , section2.5) on the risk of pathogen infection .The result suggests that boiling water before drinking is not a popular behaviour in the study area. Only 9% of respondents indicated that they boil water before drinking.

Table 3 Proportion of boiling water before direct consumption of specific water sources

Drinking water source	Not boiled	Boiled	Total	Proportion of boiled water before direct consumption (t)	Boiling Effect† 1-t
Borehole	650	66	716	0.09	0.91
Sachet water	222	18	240	0.08	0.93
Bottle water	35	0	35	0.00	1.00
River water	85	16	101	0.16	0.84
Spring water	58	0	58	0.00	1.00
Total	1050	100	1150	0.09	0.91

† A value of 1 signifies no effect; a value of 0 signifies absolute effect (approximately total decimation of microorganisms)

3.7. Risk Characterization

3.7.1. Infection and diarrhea risks of different water sources

Tables 4a – c present the risks of pathogen infections based on 10,000 Monte Carlo simulations for water borehole, spring and sachet water sources respectively.

Table 4a Mean values of risks of pathogen infection predicted (based on 10,000 Monte Carlo simulations) for concentration of pathogens in borehole water samples

Pathogen	Predicted risk values on borehole water					
	Mean	**Std. Dev.**	**Mode**	**Median**	**95th Percentile**	**5th Percentile**
E-coli O157:H7 (cfu/l)	0.35	0.08	0.39	0.39	0.39	0.14
Salmonella spp (cfu/l)	0.29	0.10	0.33	0.33	0.33	0.00
Giardia lamblia(cyst/l)	0.29	0.09	0.33	0.33	0.33	0.00

Table 4b Mean values of risks of pathogen infection predicted (based on 10,000 Monte Carlo simulations) for concentration of pathogens in spring water samples

Pathogen	Predicted risk values					
	Mean	**Std. Dev.**	**Mode**	**Median**	**95th Percentile**	**5th Percentile**
E-coli O157:H7 (cfu/l)	0.015	0.018	0.000	0.008	0.052	0.000
Salmonella spp (cfu/l)	0.036	0.036	0.000	0.027	0.086	0.000
Giardia lamblia (cyst/l)	0.046	0.042	0.000	0.052	0.097	0.000

Table 4c Mean values of risks of pathogen infection predicted (based on 10,000 Monte Carlo simulations) for concentration of pathogens in sachet water samples

Pathogen	**Predicted risk values**					
	Mean	**Std, Dev.**	**Mode**	**Median**	**95th Percentile**	**5th Percentile**
E-coli O157:H7 (cfu/l)	0.153	0.046	0.170	0.159	0.218	0.068
Salmonella spp (cfu/l)	0.151	0.044	0.220	0.164	0.217	0.023
Giardia lamblia (cyst/l)	0.185	0.068	0.220	0.216	0.217	0.000

The results in table 4a-c show that mean daily risks of infection by *E. coli* O1567:H7 for consuming contaminated water was highest in borehole water sources (0.35 ± 0.08), followed by sachet water sources (0.153 ± 0.046) and the least was spring water source (0.015 ± 0.018). Risks of infection of *Salmonella* spp and *Giardia lamblia* followed the same pattern with the case of *E. coli* O1567:H7 in the three water sources. For *Salmonella* spp, the mean risks were (0.29 ± 0.10), (0.151 ± 0.044) and (0.036 ± 0.036) for borehole, sachet water and spring water sources respectively. The risk values obtained exceed even the acceptable annual risk of infection for drinking water, which is conventionally put at 1 in 10,000 [23]. The scenario of high risk of waterborne pathogen infection from drinking water source has also been observed by other studies in Nigeria [24, 25]. In developing countries, drinking water supply is typically a private arrangement and water supply process is usually not regulated. As a result, quality of water supply is usually compromised due to poor operational environment.

3.7.2. Distribution of diarrhea risks based on presence of specific pathogens in the water sources

Figs. 4– 6 present the distribution of the risks of diarrhea for the investigated pathogens, based on 10,000 Monte Carlo simulations for water borehole, spring and sachet water sources respectively. As also stated, consumers of water from these two sources consist 76% of the population of the study area. This may be the reason the incident of diarrhea diseases in the study area is as high as 9.3% [10].

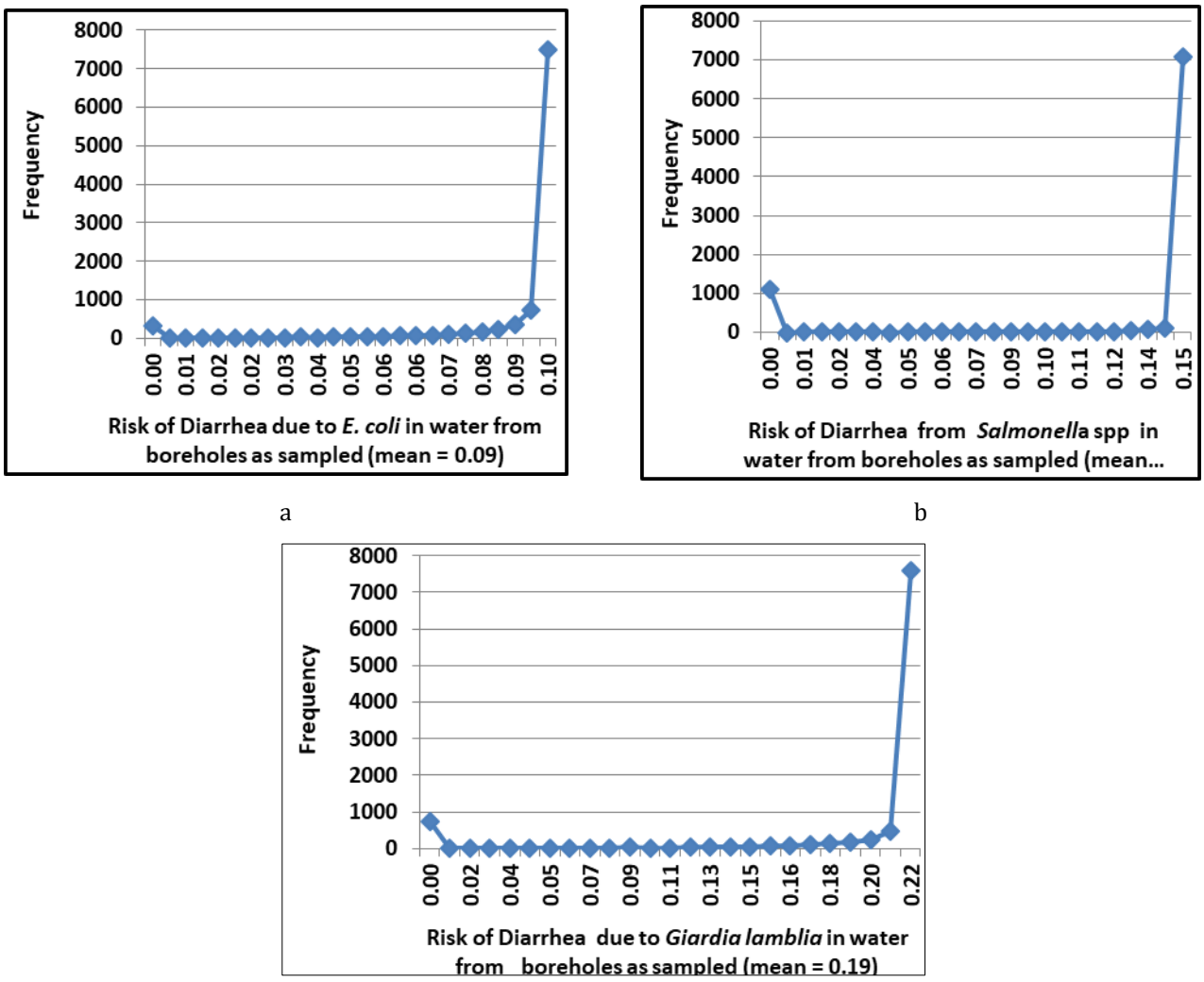

Figure 4 Risk of diarrhea distribution (based on 10,000 Monte Carlo simulations) from consumption of water from boreholes in the study area by specific pathogens: a – *E. coli*; b – *Salmonella* spp; and c – *Giardia lamblia*

The risk of diarrhea from exposure to water in the studied boreholes is not normally distributed among the population. The highest risk exposures arising from *E. coli* (Fig.4a), *Salmonella* spp, and *Giardia lamblia* (Fig. 4c) also have the highest frequency, with the modal risks ranging between 7000 – 8000 people for every 10,000 population. The mean risk of diarrhea ranges between 0.09 and 0.19.This is a high-risk scenario; also suggesting that borehole water in the study area is unsafe for direct human population. High risk of diarrhea results from high levels of pathogen contamination beyond tolerable limit in the borehole water sources. The sinking and operation of boreholes are not currently regulated in most States in Nigeria. The consequence is that many boreholes in Nigeria are installed and operated indiscriminately making many of them to be prone to pollution and microbial contamination from the environment [26].

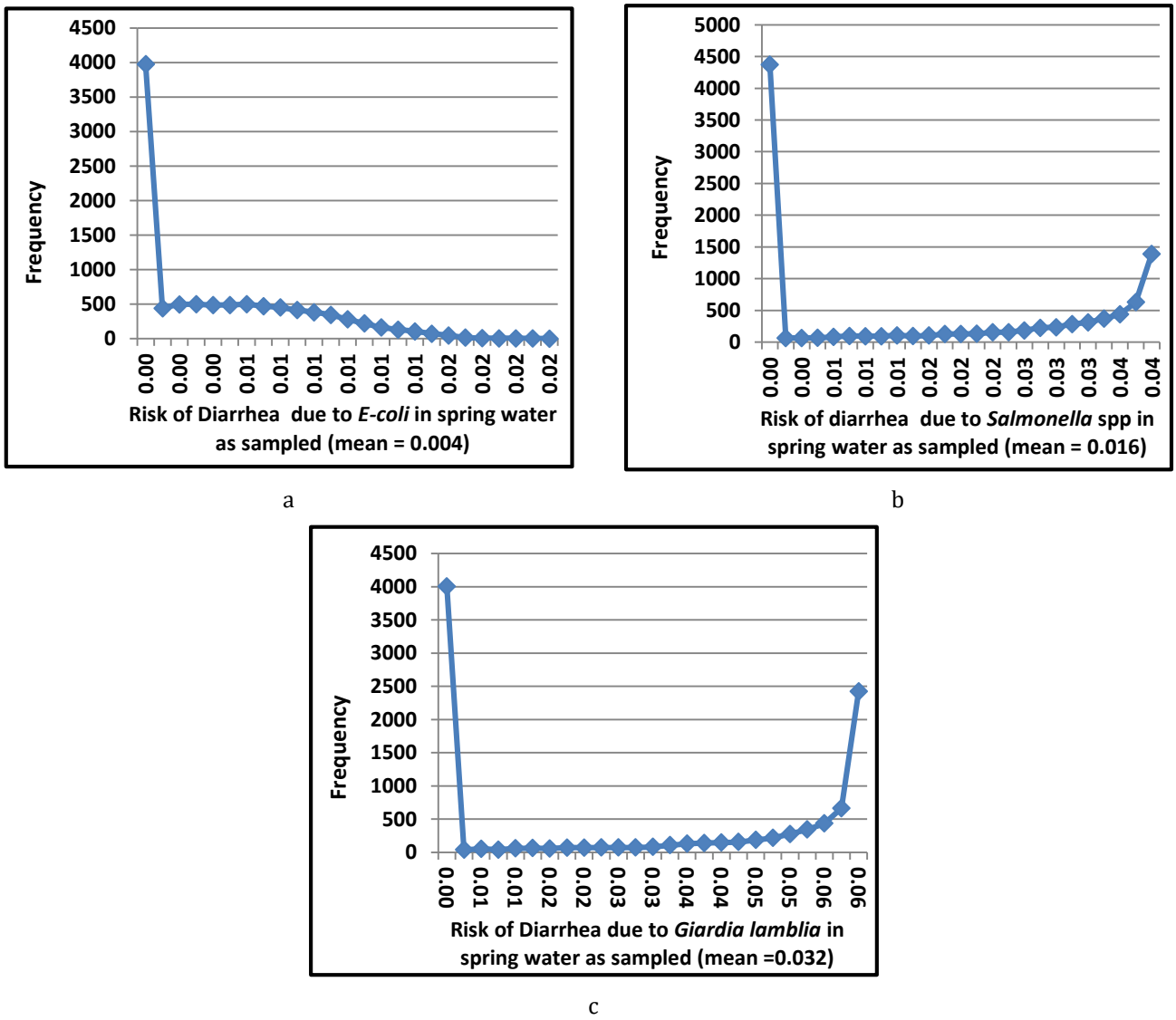

Figure 5 Risk of diarrhea distribution (based on 10,000 Monte Carlo simulations) from consumption of water from spring water in the study area by specific pathogens: a – *E .coli*, b – *Salmonella spp*, and c – *Giardia lamblia*

Diarrhea risk exposures to the spring water source in the study area are also not normally distributed (Figs. 5a – c). Unlike the case in boreholes, the lowest risk exposures have the lowest frequencies, with the modal risk of diarrhea being approximately zero from the three reference pathogen sources. This suggests a low risk situation. Indeed, the diarrhea risk determined from the spring water source is lowest of the three major sources of drinking water investigated. Most of the spring water samples reported zero risk. However, the mean daily risk of diarrhea from exposure to spring water is still significantly high, ranging between 0.004 and 0.032. It means that the annual risk of infection observed in the current study is much greater than the recommended annual risk of infection of 10^{-4} per person [23].

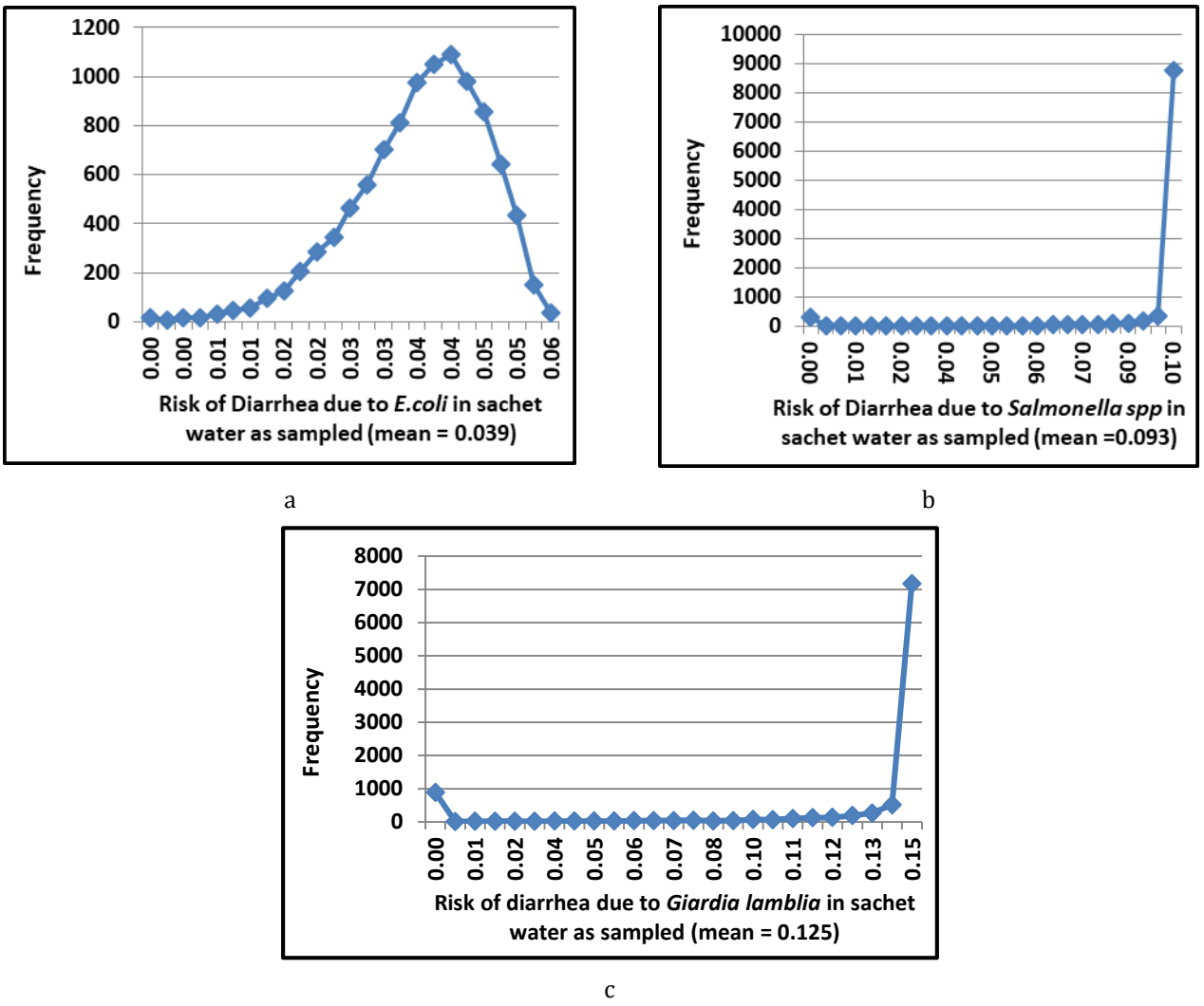

Figure 6 Risk of diarrhea distribution (based on 10,000 Monte Carlo simulations) from consumption of water from sachet water in the study area by specific pathogens: a – *E. coli*, b – *Salmonella* spp, and c – *Giardia lamblia*

The distribution of diarrhea disease risks in the sachet water samples (Fig.6) also indicate a high-risk scenario, with daily risk of diarrhea disease ranging between 0.039 and 0.125.Apart from improper treatment [27], sachet water can be contaminated through poor packaging [28] or poor storage (Ojekunle et al., 2015).

4. Conclusion

Consumers of untreated water from boreholes, spring and sachet water sources in Afikpo North LGA of Ebonyi State, Nigeria are at high risk of diarrhea. The practice of boiling water before direct consumption is minimal in the study area and at the current level does not significantly reduce the risk posed by microbial pathogens in water. Concentration of pathogens in samples taken from these major drinking water sources in the study area were above safe drinking water guideline values of the WHO [17] and NSDWQ [18]. Spring water samples are however close to meeting the guideline values. The following are the recommendations.

- There is a need for intensive public enlightenment by appropriate public health authorities on the necessity for boiling or any other cost-effective treatment of raw water before drinking to curb high prevalence of diarrhea related diseases in Afikpo North LGA.
- The sinking and operation of drinking water boreholes should be regulated and monitored to ensure that portable water or clean drinking water are continually produced.
- The appropriate public health authorities should continually monitor the processes involved in the production, distribution and storage of package water in Afikpo North LGA.

- There is need to protect the spring water at Afikpo (Why Worry Spring Water) from intrusion of runoff and animal droppings.
- Further studies could look into cost-effective drinking water treatment technologies at household level that may be appropriate for Afikpo North LGA.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

References

[1] Ramírez-Castillo, F. Y., Loera-Muro, A., Jacques, M. et al. (2015).Waterborne pathogens: detection methods and challenges. Pathogens, 4(2):307-34. https://doi.org/10.3390/pathogens4020307.

[2] Hongwei, S., Jinjin, Z. Yinghui, L. et al. (2016). The 12 Gastrointestinal Pathogens Spectrum of Acute Infectious Diarrhea in a Sentinel Hospital, Shenzhen, China. Frontiers in Microbiology, 7. https://doi.org/10.3389/fmicb.2016.01926.

[3] Abuzerr, S., Nasseri, S., Yunesian, M., et al. (2019).Microbiological quality of drinking water and prevalence of waterborne diseases in the Gaza Strip, Palestine: A narrative review. Journal of Geoscience and Environment Protection, 7, 122-138. https://doi.org/10.4236/gep.2019.74008.

[4] Ahmed, J.et al., (2020).Quantitative microbial risk assessment of drinking water quality to predict the risk of waterborne diseases in primary-school children. Int. J. Environ. Res. Public Health 17 (2774), 1-16.https://doi.org/10.3390/ijerph17082774/.

[5] Udoh, A., Lawal, B. K.,Akpan, M. et al. (2021).Microbial contamination of packaged drinking water in Nigeria.Trop Med Int Health. 26, 1378–1400. https://doi.org/10.1111/tmi.13672.

[6] UNICEF. (2022). Diarrhoea. United Nations Children's Fund.https://data.unicef.org/topic/child-health/diarrhoeal-disease/.

[7] Darvesh, N., Das, J.K., Vaivada, T. et al.(2017).Water, sanitation and hygiene interventions for acute childhood diarrhea: a systematic review to provide estimates for the Lives Saved Tool. BMC Public Health 17 (Suppl 4), 776 . https://doi.org/10.1186/s12889-017-4746-1.

[8] Soboksa, N. E., Gari, S. R., Hailu, A. B. and Alemu.B. M.(2020).Association between microbial water quality, sanitation and hygiene practices and childhood diarrhea in Kersa and Omo Nada districts of Jimma Zone, Ethiopia. PLoS One, 15(2), e0229303. https://doi.org/10.1371/journal.pone.0229303.

[9] WHO. (2017).Guidelines for drinking-water quality,4th ed. incorporating the first addendum.Geneva, World Health Organization.

[10] Amatobi, D. A. and Agunwamba, J. C. (2022). Improved quantitative microbial risk assessment (QMRA) for drinking water sources in developing countries. Applied Water Science, 12, 49.https://doi.org/10.1007/s13201-022-01569-8.

[11] Dzodzomenyo,M., Fink, G., Dotse-Gborgbortsi, W. et al. (2018).Sachet water quality and product registration: a cross-sectional study in Accra, Ghana. J Water Health, 16 (4), 646–656.https://doi.org/10.2166/wh.2018.055.

[12] Gwimbi, P., George, M. and Ramphalile, M.(2019).Bacterial contamination of drinking water sources in rural villages of Mohale Basin, Lesotho: Exposures through neighborhood sanitation and hygiene practices. Environ Health Prev Med 24, 33. https://doi.org/10.1186/s12199-019-0790-z.

[13] Boadi, N. O., Saah,S.A.Baa-Poku,F., Mensah, E.A. and Addo, M. (2020).Safety of borehole water as an alternative drinking water source. Scientific African, 10, e00657. https://doi.org/10.1016/j.sciaf.2020.e00657.

[14] Edokpayi, J. N., Rogawski, E. T., Kahler, D. M. et al. (2018).Challenges to sustainable safe drinking water: a case study of water quality and use across seasons in rural communities in Limpopo Province, South Africa. Water, 10, 159. https://doi.org/10.3390/w10020159.

[15] Amatobi, D. A. and Adenaike, O. A. (2021). Assessment of water sources, prevalence of waterborne diseases and socio-demographic categories for better focusing of intervention efforts in household drinking water supplies. Proceedings of the 3rd School of Engineering Technology (SET) Conference, Akanu Ibiam Federal Polytechnic Unwana, Nigeria.

[16] National Bureau of Statistics. (2013). Annual Abstract of Statistics, 2011.http://istmat.info/files/uploads/53129/annual_abstract_of_statistics_2011.pdf.

[17] World Health Organization. (2017). Guidelines for drinking-waterquality, 4th ed. incorporating the first addendum. Geneva, World Health Organization. Retrieved from: https://www.who.int/water_sanitation_health/dwq/gdwqvol32ed.pd.

[18] NSDWQ. (2015). Nigerian standard for drinking water quality. Nigerian Industrial Standard. https://africacheck.org/wp-content/uploads/2018/06/Nigerian-Standard-for-Drinking- Water-Quality-NIS-554-2015.pdf.

[19] Cheesebrough, M. (2000). District laboratory practice in tropical countries, Part 2. Cam-bridge: Cambridge University Press.

[20] Bichi, M. H. and Amatobi, D. A.(2013). Assessment of the quality of water supplied by water vendors to households in Sabon-gari area of Kano, northern Nigeria. The International Journal of Engineering and Science (IJES), 2(7), 09-17.

[21] Machdar, E., van der Steen, N. P., Raschid-Sally, L. & Lens, P.N.L. (2013). Application of quantitative microbial risk assessment to analyze the public health risk from poor drinking water quality in a low-income area in Accra, Ghana.Science of the Total Environment,449 (2013), 134–142.

[22] Sasu, D. D. (2022). Main source of water in Nigeria 2020, by area. https://www.statista.com/statistics/1269086/main-source-of-water-in-nigeria-by-area/.

[23] WHO. (2016). Quantitative microbial risk assessment: Application for water safety management. World Health Organization. Geneva

[24] Onyekachi, J. O., Ifeanyi, O. A., Anunobi, T. J. and Fabian, C.O. (2020).Risk assessment of waterborne infections in Enugu State, Nigeria: Implications of household water choices, knowledge, and practices. [J]. AIMS Public Health,7(3), 634-649. https://doi.org/10.3934/publichealth.2020050.

[25] Simon-Oke, I. A., Afolabi, O. .J. and Obimakinde, E.T. (2020).Parasitic contamination of water sources in Akure, Ondo State, Nigeria. JoBAZ, 81, 50. https://doi.org/10.1186/s41936-020-00187-7.

[26] Okhuebor, .S.O. and Izevbuwa, O. E. (2020). The quality and effect of borehole water proliferation in Benin City, Nigeria and its public health significance. Adv Microb Res 4: 013.

[27] Omalu, I.C. J., Eze, G. C., Olayem, I.K. et al. (2010).Contamination of sachet water in Nigeria: assessment and health impact. Online J Health Allied Scs. 9(4), 15. http://www.ojhas.org/issue36/2010-4-15.htm.

[28] Ajala, O. J., Ighalo, J.O., Adeniyi, A.G. et al.(2020). Contamination issues in sachet and bottled water in Nigeria: a mini-review. Sustain. Water Resour. Manag.6, 112. https://doi.org/10.1007/s40899-020-00478-5.

[29] Ojekunle, Z. O., Ojekunle, V. O., Eruola, A. O.et al. (2015). The Effects of Storage on Sachet Water Quality in Ogun State, Nigeria. J. Appl. Sci. Environ. Manage.19 (2),183 – 189. http://dx.doi.org/10.4314/jasem.v19i2.3.