



# Evaluation of the impact of flood on groundwater quality in hand-dug wells in Monrovia, Liberia

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## Abstract

Globally, acceleration in population growth and changes in land-use patterns have increased human vulnerability to floods. In Monrovia, the capital city of Liberia, flooding remains unabated due to the heavy downpour of rain, poor drainages and the construction of buildings in waterways. In 2018, a major flood event occurred causing several residents of Monrovia to lose their personal belongings and even rendering some homeless. Besides damages to private properties and infrastructure, there are fears that the flood may have affected water resources in the area. This study, therefore, sought to assess the impact of flooding on water quality within a total of twelve (12) hand-dug wells in four communities in the Cape Mesurado peninsula of Liberia. Using the United States Environmental Protection Agency (USEPA) Standard Methods, a suite of physico-chemical (turbidity, pH, lead, nitrate, nitrite, phosphate, cadmium, copper and zinc) and microbial (*E. coli* and Fecal coliform) parameters were evaluated during both dry and wet seasons. To adequately assess the impacts of flooding on groundwater quality, water samples were collected from three flood-prone communities (Clara Town, Vai Town, West point) and one control community (Chocolate city) with results compared against WHO standards. A two-tailed Student *T* test was employed to point out significant differences between the results of dry and wet seasons. An increasing trend was observed in pollution levels from dry to wet season and all of the water samples analyzed fell short of the appropriate World Health Organization (WHO) standards for safe drinking water; suggesting that water samples from these sources are unfit for human consumption. Significant differences were observed between dry and wet seasons concerning turbidity, nitrate, nitrite, copper, lead, cadmium, *E. coli* and Facal coliform with no significant variation in pH, Phosphate and Zinc. Based on the findings of the research, it can be concluded that flood adversely affected water quality in the study communities with an even more pronounced consequence in the flood-prone communities of Clara Town, Vai Town, and West Point. It is recommended that the public be warned against consuming water from all of the test sources and proactive measures are adopted in the flood-prone communities to avoid contamination from municipal solid wastes and other refuse before flooding. The authors recommend that more studies of this nature be periodically expanded to other flood-prone communities across Monrovia to regularly monitor water quality and flood impacts on the socio-economic livelihood of the population.

**Keywords** Flood · Groundwater quality · Hand-dug wells · Monrovia · Liberia

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## Introduction

The last few years have witnessed a tremendous increase in the frequency of natural disasters, resulting in loss of life, damage to property and destruction of the environment (Living with Risk 2002). The number of people at risk has been growing each year and the majority are in developing countries with extreme poverty levels making them more vulnerable to disasters like mass wasting, volcanoes, and floods (Living with Risk 2002).

Floods are defined as the creation of open water, resulting from river capacities being exceeded due to increased runoff from heavy precipitation. Flood hazard is measured by the probability occurrence of their damaging values, conceived generally as flood risk, or by their impact on society, conceived usually as the loss of lives and material damage to society (Burrell et al. 2007).

The causes of floods can be broadly categorized into physical, (such as climatic forces), and human influences (such as vegetation clearing and urban development). Prolonged rainfall events are the most common cause of flooding worldwide and such events are usually associated with several days, weeks or months of continuous rainfall (Nott 2006).

Floods, as a natural phenomenon, form part of earth's bio-physical processes which can become devastating due to anthropogenic activities such as land-cover clearing, intervention in natural drainage lines, deforestation and building perpetually on wetlands in the buffer zones of riverbank ecosystem. In some cases, a flood occurs when dams fail thereby releasing a large and uncontrolled volume of water (Hanaa et al. 2000).

Floods may have some inherent benefits ranging from contribution to succession, productivity, and interaction of major biota in river basins, to the facilitation of nutrient transfer between rivers and adjacent flood plains. Floods can also provide for increased hydropower production and can benefit food production by adding nutrients to agricultural land, providing irrigation water, flooding rice paddies, and replenishing aquaculture ponds. Several studies have detailed the importance of flooding to ecological the health of riparian landscapes (Junk et al. 1989; Prowse et al. 2002; Takeuchi 2002).

Despite these excellent benefits, floods also have inherent negative impacts. In the last two decades, floods have become more frequent in developing countries with increasing severity resulting in loss of lives, injuries, homelessness, and damage to infrastructure and environment as well as impacting other critical sectors such as education and agriculture (Haque 2016).

During major flooding, socio-economic and other activities are disrupted, extensive damages occur, and lives are

lost. These consequences characterized the human experience of flooding (Prowse et al. 2002).

Liberia has had its fair share of floods with adverse impacts. In recent years, heavy rains have resulted into recurrent flash floods and waterlogging in the valley and low lying areas such as Monrovia and other parts of Margibi County causing varying impacts on many sectors namely infrastructure, agriculture, education, health, water, sanitation and habitation (International Federation of Red Cross and Red Crescent Societies 2016).

It has been estimated by the Intergovernmental Panel on Climate Change (IPCC 2007) that a 1 m rise in sea level would put an estimated 230,000 people at risk and cause a loss of 2150 square kilometers of land and infrastructure, which is valued at US \$250 million in Liberia. The IPCC also asserted that an increase in flooding due to sea-level rise will also put Liberians at greater risk to epidemics of malaria, cholera, and diarrheal diseases, and increases in the incidences of Lassa fever, schistosomiasis, lymphatic filariasis, yellow fever, hepatitis A, and intestinal worms.

Floods and their impacts on waterways, society, and the economy have been extensively examined and documented on a global scale (Hanaa et al. 2000; Nott 2006; Saeed and Attaullah 2013); however, floods' impact on ground-water quality in Liberia is not well documented. It is from this background that this study sought to examine the key impacts of flood events on the quality of water in hand-dug wells in the greater Monrovia area to highlight key strategies to manage the adverse impacts of floods on ground water quality.

## Materials and methods

This study was conducted in four major communities in Greater Monrovia, Liberia. Monrovia lies along the Cape Mesurado peninsula, between the Atlantic Ocean and the Mesurado River, whose mouth forms a large natural harbor. Greater Monrovia extends north of Cape Mesurado into Montserrado County where the St. Paul River forms the city's northern boundary. This city experienced a growth in population from approximately 400,000 people in 1998 to nearly 1 million in 2008 (LISGIS 2008). Monrovia has a tropical monsoon climate and average annual precipitation of 5100 mm, with a dry season from November to April and a rainy (wet) season from May to October (Pettersson 2014).

The geology in the greater Monrovia area is characterized by the Paynesville Sandston series of Paleozoic–Mesozoic age (upper weathered zone and deeper, more competent zones), diabase bedrock in the eastern parts of the city, and unconsolidated sandy formations in coastal areas. Groundwater levels in Monrovia are shallow, ranging from less than 1 m in coastal areas to a few meters below ground

further inland. Hand-dug wells in communities are shallow (up to 10-m depths) and completed 1–2 m below the top of the water table. Boreholes (drilled wells) are in the 5–100 m depth range. The Liberia Water and Sewer Company (LWSC) is the major supplier of treated surface water, abstracted from the St. Paul River at the White Plains intake, through a piped network. The four communities sampled during the study include Clara Town, Chocolate City, Vai Town, and West Point.

The study relied on the analyses of water samples collected from hand-dug wells across the four study communities in Monrovia. Two sets of samples were collected from three hand-dug wells in each of the four communities in the month of March for the dry season and the month of July for the wet season. The essence for this was to compare the results from the two seasons to establish the impact of floods on water quality in those communities based on seasonal variations (Fig. 1).

Water samples collected from hand-dug wells were obtained using 500 ml sample bottles. Each bottle was washed with 2% nitric acid and then rinsed three times with distilled water. The bottles were then preserved in a clean sealed container. During the sampling procedure, the bottles

were filled leaving no air space and then sealed to prevent any leakage. Each container was marked with the name and date of sampling. The collected samples were then placed in a cool jug and immediately transported to the Environmental Protection Agency Laboratory in Sinkor, Liberia. The method used for the analysis of each parameter is outlined in Table 1.

### Results and discussion

This study assessed the impact of the flood on water quality within a total of twelve (12) hand-dug wells in four communities in the Cape Mesurado peninsula of Liberia. The study considered a suite of Physico-chemical (Turbidity, pH, Lead, Nitrate, Nitrite, Phosphate, Cadmium, Copper and Zinc) and microbial (E-coli and Fecal coliform) parameters to evaluate the quality of water during both dry and wet seasons. To adequately assess the impacts of the flood on groundwater quality, water samples were collected from three flood-prone communities (Clara Town, Vai Town, West point) and one control community (Chocolate City) with results compared against WHO standards. The results of the analyses are

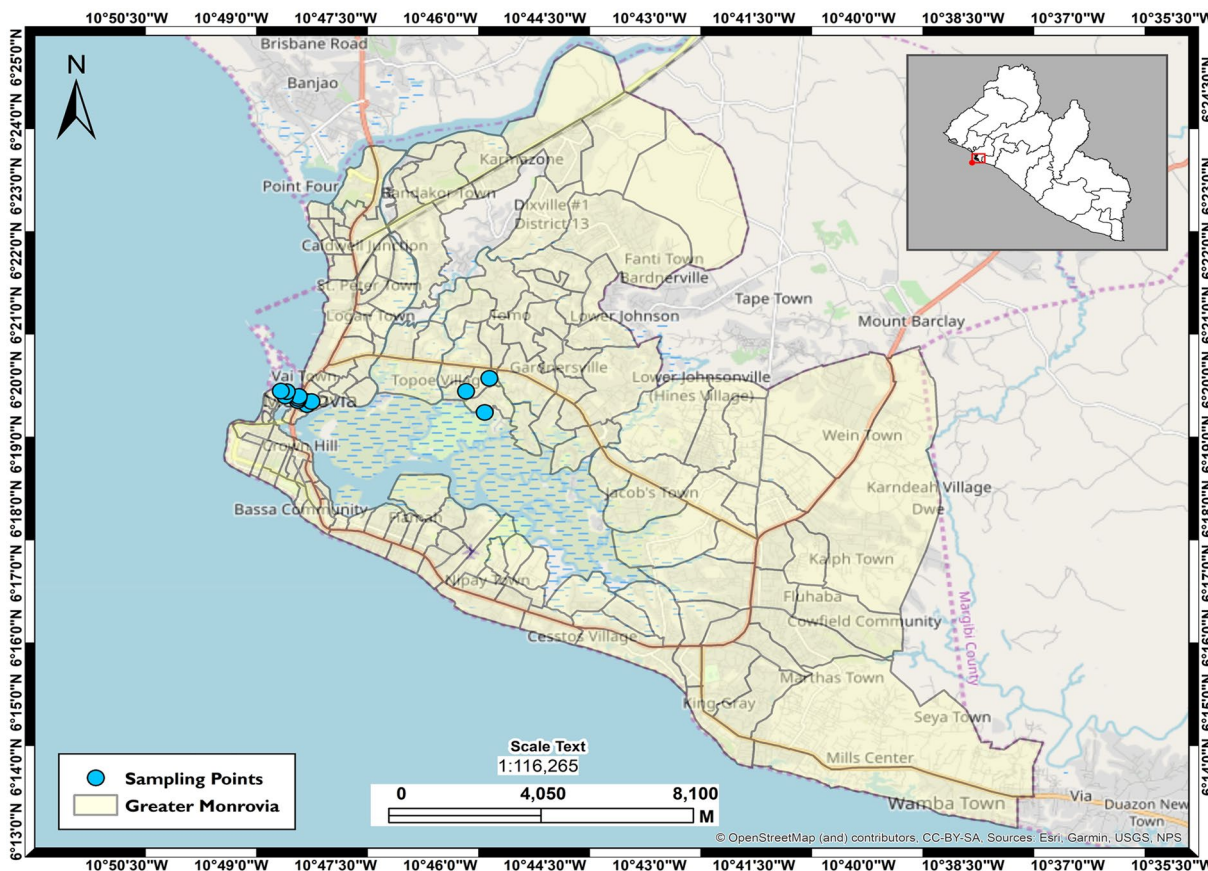


Fig. 1 Sampling points and Locations, Greater Monrovia, Liberia

**Table 1** Parameters and analytical methods

Parameter (Unit)	Analytical method	Instrument used
pH	Multi-parameter (in-situ)	pH meter
Turbidity (NTU)	Absorptometric Method (USEPA 8237)	Turbidity meter
Cadmium (ppm)	Flame Spectrophotometry	Flame atomic absorption spectrophotometer
Nitrate (ppm)	Cadmium Reduction (USEPA 8192)	Colorimeter
Iron, total (ppm)	FerroMo Method (USEPA 8365)	Colorimeter
Zinc (ppm)	Zincon Method (USEPA 8009)	Colorimeter
Nitrite (ppm)	Diazotization Method (USEPA 8507)	Colorimeter
Lead (ppm)	Flame Spectrophotometry	Flame atomic absorption spectrophotometer
Copper (ppm)	Bicinchoninate Method (USEPA 8506)	Colorimeter
Faecal Coliform	Multiple fermentation tube technique	Multiple fermentation test tube
E-coli	Multiple fermentation tube technique	Multiple fermentation test tube

presented in Tables 1, 2 and Fig. 2. A two-tailed Student *t*-test was employed to point out differences between results of dry and wet seasons.

The values of pH ranged from 6.01 to 8.17 during the dry season and 5.96–6.64 during the wet season. The pH values recorded in the study for both seasons (dry and wet) were generally within the WHO permissible limits of 6.0–9.0 and showed no significant variation ( $p$  value = 0.06). Notable exceptions, however, were W5 and W6 (both in Clara Town), which recorded levels of 5.96 and 5.97 respectively. The results obtained in the current study were largely in agreement with an investigation conducted in 2006 by Sarfraz et al. (2006) in Rajanpur District, Pakistan; which reported pH

values between 6.9 and 7.6 for samples collected from portable groundwater sources in the study area.

Turbidity values ranged from 0.86 to 8.17 NTU during the dry season and 1.1–6.36 NTU during the wet season. The highest turbidity value was recorded in a flood-prone community, Clara Town (W6), while the lowest value was recorded in the control community of Chocolate city (W2). Generally, mean turbidity levels were higher during the wet season (5.01 NTU) and showed a significant difference ( $p$  value = 0.00) compared to the dry season (3.16 NTU). The World Health Organization recommends an ideal turbidity value to be less than 1 NTU for effective disinfection, but the results in this study showed that only W2 (Chocolate city) recorded turbidity within this limit. All other samples fell

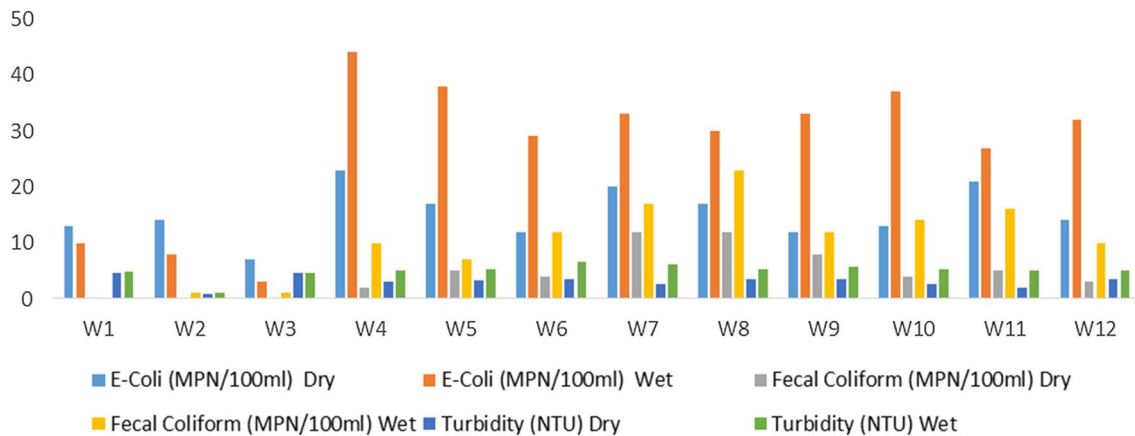
**Table 2** Water quality results from hand-dug wells in the Mesurado Peninsula-Liberia, 2018

Well code (Location)	Dry season				Wet season			
	pH	Phosphate	Nitrate	Nitrite	pH	Phosphate	Nitrate	Nitrite
W1 (Chocolate City)	6.41	6.48 <sup>a</sup>	0.20	0.10	6.21	6.55 <sup>a</sup>	0.11	0.10
W2 (Chocolate City)	6.72	7.43 <sup>a</sup>	0.10	0.10	6.64	7.40 <sup>a</sup>	0.09	0.10
W3 (Chocolate City)	6.38	5.32 <sup>a</sup>	0.50	0.08	6.40	3.36 <sup>a</sup>	4.57	0.07
W4 (Clara Town)	6.36	3.32 <sup>a</sup>	0.00	0.01	6.20	4.67 <sup>a</sup>	7.16	0.17
W5 (Clara Town)	6.08	3.23 <sup>a</sup>	5.50	0.13	5.96 <sup>a</sup>	4.40 <sup>a</sup>	6.21	0.13
W6 (Clara Town)	6.31	3.11 <sup>a</sup>	0.30	0.07	5.97 <sup>a</sup>	4.49 <sup>a</sup>	7.01	0.11
W7 (Vai Town)	6.01	3.32 <sup>a</sup>	0.35	0.02	6.33	3.49 <sup>a</sup>	6.40	0.16
W8 (Vai Town)	6.26	3.02 <sup>a</sup>	0.53	0.02	6.29	3.17 <sup>a</sup>	0.27	0.15
W9 (Vai Town)	6.07	3.32 <sup>a</sup>	0.40	0.04	6.08	4.07 <sup>a</sup>	6.09	0.13
W10 (West Point)	8.17	3.32 <sup>a</sup>	0.50	0.07	6.30	4.22 <sup>a</sup>	7.20	0.08
W11 (West Point)	8.01	4.02 <sup>a</sup>	0.60	0.07	6.22	4.18 <sup>a</sup>	6.77	0.08
W12 (West Point)	7.98	3.10 <sup>a</sup>	0.49	0.07	6.30	4.07 <sup>a</sup>	6.11	0.12
WHO Standard	6.0–9.0	0.30	50.00	3.00	6.00–9.00	0.30	50.00	3.00
Mean value	6.73	4.08	0.45	0.07	6.24	4.51	4.83	0.12
Standard Dev	0.82	1.49	1.49	0.04	0.19	1.25	2.90	0.03
<i>T</i> -test ( <i>P</i> -value)	0.06	0.46	0.00	0.00	0.06	0.46	0.00	0.00

<sup>a</sup>Outside permissible limits (WHO 2011)



## Results of Turbidity (NTU) and Coliform Counts (MPN/100 mL)



**Fig. 2** Results of turbidity and coliform counts from hand-dug wells in the Mesurado Peninsula-Liberia, 2018

above the WHO limit for both dry and wet seasons. There was a high-pitched departure from the standard as all the samples showed a high average value of 4.09 NTU. These high values could be attributed to the runoff of wastewater into these unprotected hand-dug wells during the flood events. Notwithstanding, the mean turbidity values recorded in the current study appeared to be lower than those reported in the literature for other regions after flood events. For example, in Pakistan, Saeed and Attaullah (2013) investigated the Impact of Extreme Floods on Groundwater Quality. They reported that the area of Charsadda had turbidity values varying from 11 to 16 NTU at main sources, 15–19 NTU at intermediate points and 18–22 NTU at consumer's ends after the flood event and similar for Nowshera area with values fluctuating from 13 to 16 NTU at main sources, 17–20 NTU at intermediate points and 19–25 NTU at consumer's ends of the flood-affected areas.

Nitrate values in the current study ranged from 0.00 to 5.50 ppm during the dry season and 0.09–7.20 ppm during the wet season. Nitrate values recorded in the entire study fell below the WHO guideline value of 50 ppm (WHO 2011). Nitrate values were generally higher during the wet season and varied significantly ( $p$  value = 0.00) from values of the dry season. The increase in nitrate levels from dry to the wet season may be attributed to the poor sanitation system, improper disposal of human wastes (open urination and defecation) and open septic tanks within proximity to the hand-dug wells in the study area. According to Self and Waskom (2008), a high level of nitrate ions may have an adverse effect on the health of pregnant women.

Nitrite values during the investigation ranged from 0.01 to 0.13 ppm during the dry season and 0.07–0.17 ppm during the wet season. Nitrite values recorded in the entire study fell below the WHO guideline value of 3 ppm (WHO 2011).

However, the wet season reported higher mean nitrite value (0.11 ppm) than the dry season (0.07 ppm) and there was a significant variation between the wet and the dry season ( $p$  value = 0.00).

Phosphate levels ranged from 3.02 to 74.3 ppm during the dry season and 3.17–7.40 ppm during the wet season. Mean phosphate levels were higher during the wet season (4.51 ppm) compared to the dry season (4.08 ppm) with no significant differences ( $p$  value = 0.46) observed. The results showed phosphate levels were far above the WHO permissible limit of 0.3 ppm for all samples in the study.

Copper levels in the study ranged from 0.00 to 0.01 ppm during the dry season and 0.00–0.05 ppm during the wet season. There was a significant variation ( $p$  value = 0.00) observed in copper levels across both seasons and the values recorded for all of the wells fell well below the WHO guideline value of 3 ppm (WHO 2011).

Zinc levels ranged from 0.90 to 4.19 ppm during the dry season and 0.80–7.09 ppm during the wet season. Mean zinc levels recorded in the study were higher during the wet season (3.13 ppm) compared to the dry season (2.25 ppm) but showed no significant variation ( $p$  value = 0.25). All the wells in the study recorded zinc values within the permissible limit of 5.0 ppm (WHO 2011) except W10, W11 and W12 (all situated in West Point) which recorded higher than permissible levels during the wet season. According to Smith et al. (1986) high zinc levels in water can produce symptoms of nausea, vomiting, and diarrhea, sometimes accompanied by bleeding and abdominal cramps. Mean zinc levels were higher during the wet season (3.13 ppm) compared to the dry season (2.25 ppm). The variation of zinc levels from the dry to the wet season may be attributed to the presence of heavy human influences in terms of oil spillage, transportation, improper wastewater discharge, and

inappropriate septic systems. In the study area, domestic dwellings are connected to on-site treatment systems (such as septic tanks) rather than to main sewerage. Improper waste management practices such as open dumping or burial of wastes may further explain the higher than acceptable levels of zinc recorded in all three wells in the West Point community during the rainy season. High flood levels may have leached metallic wastes into groundwater or simply transported the wastes into the open wells during flood events. Other authors from different regions around the world share this assertion. For example, Lu et al. (2018) investigated trace metal contamination in groundwater of a highly urbanizing area of Shenyang New District, Northeast China. Their results showed that the level of zinc in groundwater near the landfill site was twice the recommended WHO limits and thus not suitable for domestic use (Table 3).

The lead remained undetected in all of the wells during the dry season but was detected more than the permissible limits of 0.01 ppm (WHO 2011) in all except three wells (situated in Chocolate city) during the wet season. The result showed a significant variation ( $p$  value = 0.00) in the lead values between both wet and dry seasons. The variation of lead level from dry to wet seasons may be attributed to leakage from the base of refuse sites around the study area which were transported into the hand-dug wells during the flood events. This result appears to agree with Fatta et al. (1999) investigation on landfill leachate and its impact on the groundwater quality of the greater area, Athens, Greece. Pollutant concentrations in groundwater were investigated and lead was found in high levels above the maximum desirable limits of WHO in water samples due to washing away

of pollutants into the water sources. The groundwater near the landfill site was characterized as not potable and not suitable for domestic uses. Cadmium also remained undetected in all of the wells during the dry season but detected over the 0.003 ppm permissible limits (WHO 2011) in five wells from the flood-prone communities (Clara Town and Vai Town) during the wet season. Furthermore, there was a significant variation between results from the both seasons (dry and wet). This appears to suggest that the levels of lead and cadmium recorded in the aforementioned wells, during the wet season, are associated with flood events.

In addition to the Physico-chemical parameters discussed, the study also considered two microbiological parameters (E-coli and fecal coliform) in the hand-dug wells. E-coli appeared in all of the wells analyzed across both seasons with significant differences being recorded ( $p$  value = 0.01). Fecal coliform was recorded in all, but three samples (W1, W2, W3) during the dry season and in all, but one sample (W1) during the rainy season. The result from the student t-test showed significant differences ( $p$  value = 0.03) in the results of fecal coliform between both seasons. The presence of fecal coliform bacteria in aquatic environments indicates that the water has been contaminated with the fecal material of humans or other animals. At the time this occurred, pathogens or disease-producing bacteria or viruses, which can also exist in fecal material, might have contaminated the source water. Some water-borne pathogenic diseases include typhoid fever, viral, and bacterial gastroenteritis and hepatitis A. The presence of fecal contamination is an indicator that a potential health risk exists for individuals exposed to this water. The results obtained in the current study are

**Table 3** Water quality results from hand-dug wells in the Mesurado Peninsula-Liberia, 2018 (Cont'd)

Well Code (Location)	Dry season				Wet season			
	Cu	Zn	Pb	Cd	Cu	Zn	Pb	Cd
W1 (Chocolate City)	0.01	0.91	ND	ND	0.01	0.85	ND	ND
W2 (Chocolate City)	0.01	0.98	ND	ND	ND	0.80	ND	ND
W3 (Chocolate City)	ND	0.90	ND	ND	ND	0.87	ND	ND
W4 (Clara Town)	ND	0.98	ND	ND	0.03	1.16	0.09 <sup>a</sup>	0.02 <sup>a</sup>
W5 (Clara Town)	ND	1.07	ND	ND	0.01	2.05	0.16 <sup>a</sup>	0.01 <sup>a</sup>
W6 (Clara Town)	ND	1.02	ND	ND	0.03	2.71	0.13 <sup>a</sup>	ND
W7 (Vai Town)	ND	1.90	ND	ND	0.02	3.11	0.12 <sup>a</sup>	0.03 <sup>a</sup>
W8 (Vai Town)	ND	3.59	ND	ND	0.01	4.18	0.10 <sup>a</sup>	0.02 <sup>a</sup>
W9 (Vai Town)	ND	3.48	ND	ND	0.01	3.55	0.15 <sup>a</sup>	0.03 <sup>a</sup>
W10 (West Point)	ND	3.90	ND	ND	0.05	6.12 <sup>a</sup>	0.09 <sup>a</sup>	ND
W11 (West Point)	ND	4.09	ND	ND	0.04	7.09 <sup>a</sup>	0.07 <sup>a</sup>	ND
W12 (West Point)	ND	4.19	ND	ND	0.05	5.09 <sup>a</sup>	0.13 <sup>a</sup>	ND
WHO Standard	3.00	5.00	0.01	0.003	3.00	5.00	0.01	0.003
Mean value	0.01	2.25	ND	ND	0.03	3.12	0.12	0.02
Stdv	0.00	1.45	0.00	0.00	0.02	2.15	0.06	0.01
T-test ( $P$ -value)	0.00	0.25	0.00	0.02	0.00	0.25	0.00	0.02

<sup>a</sup>Outside permissible limits (WHO 2011)

in agreement with findings from other flood-prone regions around the world. For example, Mile et al. (2012) studied the bacteriological contamination of well water in flood-prone communities in Makurdi Town, Benue State, Nigeria. The authors found that all of the wells were highly contaminated with bacteria and were all above the WHO recommended values of 0 MPN/100 ml. Saeed and Attaullah (2013) investigated the impact of extreme floods on groundwater in flood-prone regions in Pakistan. The results of their investigation showed that flooding and increased precipitation in the study area increased the occurrences of total coliform bacteria in water and the recorded levels of total bacteria counts were far above the World Health Organization recommended values. These findings support earlier assertions that flooding adversely affects the microbial quality of water and has a far-reaching consequence on human health.

## Conclusion

This study assessed the impact of the flood on water quality within a total of twelve (12) hand-dug wells in four communities in the Cape Mesurado peninsula of Liberia. Levels of the assessed water quality parameters were generally higher in the flood-prone communities (Clara Town, Vai Town, and West Point) compared to the control community (Chocolate city). There was an increasing trend observed in pollution levels from dry to wet season and all of the water samples analyzed fell short of the World Health Organization (WHO) standards for safe drinking water; suggesting that water samples from these sources are unfit for human consumption. Based on the findings of the research, it can be concluded that flood adversely affected water quality in the study communities with an even more pronounced consequence in the flood-prone communities of Clara Town, Vai Town, and West Point.

On the premise of the findings of this study, it is recommended that the public be warned against consuming water from all of the test sources and proactive measures are adopted in the flood-prone communities to avoid contamination from municipal solid wastes and other refuse before flooding. There is an intense need for the provision of safe and affordable drinking water for people affected by floods as water quality becomes more unreliable when hit by floods. Additionally, the design of the hand-dug wells should be improved to prevent flooded water of a specific nature and contaminants from introducing organic matters, and other chemical substances into the wells. The current study assessed a limited number of parameters and sample size. Future studies should be tailored towards an improved sample size and more parameters to address a wide range of contaminants from different waste streams. The authors

further recommend that regular studies of the quantitative environmental aspects of severe flooding be conducted across different months of the wet season.

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## References

- Burrell, B. C., Davar, K. S., & Hughes, R. (2007). Review of flood management considering the impacts of climate change. *Water International*, 32(3), 342–359.
- Fatta, D., Papadopoulos, A., & Loizidou, M. (1999). *A study on the landfill leachate and its impact on the groundwater quality of the greater area* (21st ed., pp. 175–190). Athens: Kluwer Academic Publishers.
- Hanaa, M., Eweida, A., Farag, A., (2000). Heavy metals in drinking water and their environmental impact on human health. International Conference on Environmental Hazards Mitigation, Cairo University, Egypt, 542–556.
- Haque, A., Sumaiya, S., & Rahman, M. (2016). Flow distribution and sediment transport mechanism in the estuarine systems of Ganges-Brahmaputra-Meghna delta. *International Journal of Environmental Science and Development*, 7(1), 22–30. <https://doi.org/10.7763/IJESD.2016.V7.735>.
- International Federation of Red Cross and Red Crescent Societies. (2016). Emergency Plan of Action Liberia: Margibi County Floods. <https://reliefweb.int/sites/reliefweb.int/files/resources/MDRLR002%5B1%5D.pdf>. Accessed 7 Nov 2018.
- IPCC. (2007). Climate change 2007: Synthesis report. In Core Writing Team, R. K. Pachauri & A. Reisinger (Eds.), *Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change*. IPCC, Geneva, Switzerland, 104 p.
- Junk W.J., Bayley P.B., and Sparks R.E. (1989). The flood pulse concept in river floodplain systems in Dodge, D.P. (Ed.) Proceedings of the International Large River Symposium, Can Journal Fish Aquatic Science Spec. Publ., 06, 0–27.
- LISGIS. (2008). *Government of the Republic of Liberia 2008 National Population and Housing Census: preliminary results*. Liberia: Monrovia.
- Living with Risk (2002). A global review of disaster reduction initiatives, Geneva Switzerland
- Lu, Y., Zang, X., Yao, H., Zhang, S., Sun, S., Liu, F. (2018). Assessment of trace metal contamination in groundwater in a highly urbanizing area of Shenzhou New District, Northeast China. *Frontiers of Earth Science*, 12(3), 569–582.
- Mile, I. I., Jande, J. A., & Dagba, B. I. (2012). Bacteriological Contamination of Well Water in Makurdi Town, Banue State Nigeria. *Pakistan Journal of Biological Sciences*, 15(21), 1048–1051.
- Nott, J. (2006). *Extreme Events: A Physical Reconstruction and Risk Assessment New York*. Cambridge: Cambridge University Press.
- Petterson, D. R. (2014). Liberia. In *Encyclopaedia Britannica*. Available at: <https://www.britannica.com/EBchecked/topic/339254/Liberia>. Accessed 7 Nov 2018.
- Prowse, T. D., Peters, D., Beltaos, S., Pietroniro, A., Romolo, L., Töyrä, J., et al. (2002). Restoring Ice-am floodwater to a drying delta Ecosystem. *Water International*, 27, 58–69.

- Saeed T. U., Attaullah H. (2013). Impacts of floods on water quality. *British Journal of Environment and Climate Change*
- Sarfraz, M., Dosedall, L. M., & Keddie, B. A. (2006). Diamondback moth–host plant Interactions. *Implications for pest management, Crop Protection*, 25(7), 625.
- Smith, T., Grigera-Naon, J. J., Broster, W. H., & Siviter, J. W. (1986). The use of barley straw as a feed. *Animal Feed Science and Technology*, 14(1–2), 23–39.
- Takeuchi, K. (2002). Floods and society: a never- ending evolutionary relation Flood Defence, Proceedings of the Second International Symposium on River Flood Defence, Beijing, China. New York, USA Science Press New York Ltd. New York 1(0) 5–22
- World Health Organization. (2011). *Guidelines for drinking-water quality* (4th ed.). World Health Organization. <https://apps.who.int/iris/handle/10665/44584>.