SciMedCentral
JSM Environmental Science & Ecology

Research Article

A Case Study of Rural Kenyan Water Quality: Evaluating Lead and Bacterial Exposures for Children on the Nyakach Plateau

Jenny M. Rowlands[1] **and Erica D. Bruce**[2]*

[1]*Masters of Public Health, B.S. Environmental Science, Baylor University, USA*
[2]*Environmental Engineering and Toxicology, Baylor University, USA*

Abstract

Water quality on the Nyakach Plateau in Western Kenya is of critical importance to human health. Many of the adults and children depending on limited water supplies for drinking water on the plateau could be exposed to several xenobiotic compounds including lead as well as bacteria.

Background: The purpose was to gather preliminary water quality data in water sources on the Nyakach Plateau in Western Kenya, and develop recommendations for public health behavior interventions.

Methods: A qualitative study was conducted to determine lead and hydrogen sulfide-producing bacteria levels in springs, wells, rainwater tanks, and one pond on the Nyakach Plateau using field test kits.

Results: Thirty-two sources were identified using GPS. Twenty-one sites were tested for lead and/or bacteria. Four maps summarize data on water source type, source seasonality, lead levels (μg/L), and bacteria counts. Lead results fell between 0-8 μg/L and bacteria counts fell between 4,600-460,000 microorganisms per 80 mL of water.

Conclusions: Data shows water to be highly contaminated and to have a negative impact on human health. These findings directly impact children and adults on the Plateau, and are externally valid. Recommendations include government-level education on water quality and filtration, installation of chlorine dispensers at community water sites, and lead filters at local schools. Future work includes continued water quality testing.

***Corresponding author**

Erica D. Bruce, Environmental Engineering and Toxicology, Baylor University, One BearPlace #97266, Waco, Texas, 76798-7266, United States, Tel: 254-710-4877; Fax: 254-710-3409; Email: Erica_Bruce@baylor.edu

Submitted: 05 May, 2014

Accepted: 16 June, 2014

Published: 20 June, 2014

ISSN: 2333-7141

Keywords

- Lead
- Water quality
- Children's health

INTRODUCTION

The equator runs through Kenya, giving it a tropical climate with two wet seasons: March through May and October through December. The two dry seasons are January to March and June to September, when droughts become so severe that many water sources completely dry up. The Manual on the Right to Water and Sanitation states that "clean water, together with hygienic sanitation is necessary to sustain human life and to ensure good health and human dignity [1]". Not only is water a human necessity, but it enables economic development and functioning of worldwide ecosystems [1]. This is the case for Kenyan residents of the Nyakach Plateau, Nyanza Province, near Kisumu Kenya who use local water sources for all of their water needs; including drinking, cooking, bathing, and washing. Besides access to water, there is concern that their water is highly polluted with bacteria and other pollutants—which was the primary focus of this research.

According to the American Academy of Pediatrics Committee on Environmental Health elevated blood lead levels (BLLs) in children are10 μ/dL, although previously they were 15μ/dL [2]. This lower level of exposure is accompanied with delayed mental and physical development and impaired learning [2]. High levels of lead exposure can also cause organ damage and irreversible brain impairment in children according to the United States Environmental Protection Agency [3]. Children are of particular concern for lead toxicity due to their small body size, rapid brain development, and frequent hand-to-mouth behavior [4]. According to the EPA [3], drinking water was not the main source of lead exposure for most children, although it did account for 14-20% of total childhood lead exposure in the United States.

Cite this article: *Rowlands JM, Bruce ED (2014) A Case Study of Rural Kenyan Water Quality: Evaluating Lead and Bacterial Exposures for Children on the Nyakach Plateau. JSM Environ Sci Ecol 2(1): 1011.*

Malnutrition was also associated with increased lead uptake in children. Malnourished children deficient in calcium, iron, and zinc absorb more lead than normal when exposed, due to lead's positive ionic charge [5]. Primary routes of lead exposure in the environment are inhalation and ingestion, and lead particulates come from paint chips of lead-based paints, byproducts of fuel combustion, and drinking water [6-9].

Bacteria levels in water sources raise concern because of their association with disease. The World Health Organization states that poor water quality combined with poor sanitation infrastructure rank among the leading causes of disease in Africa [10]. Target 7C of the United Nations Millennium Development Goals addresses these concerns by "seeking to halve the number of people without sustainable access to safe drinking water and basic sanitation by 2015 [11]". Sustainable access to safe drinking water is difficult to maintain in third world rural areas such as the Nyakach Plateau, where even raw water from local sources must be treated before consumption to avoid disease [12]. Typhoid, cholera, and diarrhea are common water-borne diseases in areas with poor sanitation, water quality, and hygiene conditions. Diarrhea is the second leading cause of death for children under five years of age and "kills more young children than AIDS, malaria, and measles combined [13]". Each year1. 62 million children under age 5 die from diarrhoeal diseases, including cholera, with"88% of diarrhoeal disease… attributed to unsafe water supplies, inadequate sanitation and hygiene [14]". Therefore, if water treatment is introduced at the household level through chlorination, diarrhea episodes could be reduced by 35-39 % [14].

On the Nyakach Plateau in Western Kenya, the supply of water fluctuates throughout the year and quality is lower than many of our United States standards. The plateau is located in a rural area where water infrastructure is practically non-existent. Primary sources of water are hand dug wells, ponds, springs, and rainwater tanks, which differ greatly in water quality [15].

Overall, the goal of this project was to:

- Determine the levels of hydrogen-sulfide producing bacteria and lead in water sources on andbelow the Nyakach Plateau
- Compare bacteria and lead levels on the Plateau to Kenya and United States standards
- Discuss the health risks to those consuming the water, particularly young children
- Explore potential interventions.

METHODS

Samples were collected during the rainy season in May of 2012. Water sample collection and testing was determined by site accessibility and convenience to a central community point using GPS coordinates. Community informants were asked to list primary sources of water—wells, springs, ponds, and rivers—and the research team traveled to each site according to the most efficient use of time each day, over 9 days. A team translator, fluent in both Luo (the local language) and English led the team to water sites. Thirteen water sources were tested for lead (Pb), and nine were tested for hydrogen sulfide-producing bacteria. Global Positioning System (GPS) coordinates were gathered at every water site and logged on a Colorado 400t Handheld Garmin. GPS coordinates, elevation, and accuracy were recorded and compiled in a database of Plateau water resources. We used local for site details such as number of people the site provided water for, source seasonality, estimated depth, and uses for the water.

Supplies for the Pb test were supplied by the Hach Company [16]. The LeadTrak Fast Column Extraction Method and Pocket Colorimeter II were used to determine the amount of lead in micrograms per liter (µg/L) in 100 milliliters (mL) of water. This method involved the addition of six reagents to concentrate any possible lead in the sample. Lastly, a concentrated 10 mL sample was read using the colorimeter, best for readings in the range of 5-150 µg/L, at a wavelength of 15 nm with an error of +/-2 nm. Instructions from the LeadTrak manual were followed step by step during every sampling test. Results for thirteen sites were recorded in the field notebook.

Specific step by step instructions for the LeadTrak were as follows: a 100 mL graduated cylinder of the sample water was collected at the water site and poured into the 125-mL plastic sampling bottle. An acid preservative reagent, labeled Pb-1, was added to the 125-mL plastic sampling bottle and swirled to mix. After two minutes, a fixer solution, labeled Pb-2 was added and swirled to mix. Then a new Fast Column Extractor was placed on top of the second, empty 125-mL sampling bottle. The sample water was then poured from the first 125-mL sampling bottle into the extractor and allowed to flow into the second 125-mL bottle. Once the flow stopped, the rest of the liquid was plunged out of the absorbent pad in the bottom of the extractor with the provided plunger. This process allowed any lead in the solution to fixate in the absorbent pad. The plunger was then slowly removed and placed back in the kit. Next, the extractor was placed on top of the empty, round poly mixing bottle and 25 mL of the eluent solution, labeled Pb-3, was added to help release any of the lead that had gathered in the pad. Once the Pb-3 began to drip from the extractor, the pad was plunged again until it had been fully compressed. After removing the plunger and discarding the extractor, Pb-4, a neutralizer solution was added to the poly mixing bottle. After being swirled to mix, one Pb-5 Indicator Powder Pillow was added to the sample and swirled to mix again. After two minutes, a 10-mL sample cell was filled to the 10-mL line with the prepared sample. Once prepared, the Pocket Colorimeter II was powered on, two minutes allowed to passed, and the prepared sample placed inside the cell holder. The sample was covered with the instrument cap and 'zero-ed' using the ZERO/SCROLL button. The sample cell was removed, and three drops of a decolorizer solution added. The sample cell was capped and inverted to mix thoroughly, and then placed back in the colorimeter with the cap fitted tightly. READ/ENTER was pressed and results were presented on the screen in µg/L of lead.

Bacteria levels were tested at nine sites using the PathoScreen Field Kit, supplied by Hach Company [16]. PathoScreen Medium was used because it is ideal for monitoring drinking water systems in tropical climates of developing countries and remote field locations. The PathoScreen kit was designed specifically to detect hydrogen sulfide-producing microorganisms including

Salmonella, Citrobacter, Proteus, Edwardsiella, and some species of Klebsiella, which are all commonly found in polluted water. Before testing a sample, each sample cell was sterilized with a 10% bleach solution and rinsed three times with the sample water. Post-sterilization, a test was conducted by filling the sterilized sample cell with 20 mL of sample water and a PathoScreen Medium powder pillow. In order to narrow the range of bacteria counts, titrations were carried out using 1:10, 1:100, 1:1,000, 1:10,000, and 1:100,000 dilutions, beginning with 1 part sample water and nine parts sterile water. Tests were evaluated 24-48 hours later for changes in color from yellow to black, or formation of small black precipitates in the vial. Results were recorded in the field notebook.

RESULTS

Thirty-two water sources were identified using GPS, as seen in (Figure 1). Eighteen tanks were identified, with each site having one to four tanks each. Tank capacities ranged from 100-10,000 liters, with the majority holding 1,500 or 2,300 liters. Water tanks are denoted on the map with a pink T. Seven natural springs, denoted as a light blue droplet, were also identified on the Plateau. One pond was tested for bacteria and lead, and is represented by an orange circle with diagonal black lines. Five hand dug wells were located, three of which were tested for both lead and bacteria, and one other tested only for lead. They are denoted by a yellow ring shape on the map. The green square is the central community location—a reference point for daily activity.

Figure 2 Types of Water Sources, Nyakach Plateau, Nyanza Province, Kenya, 2012. Water tanks are denoted on the map with a pink T. Natural springs are shown as a light blue droplet. One pond was located and is marked by an orange circle with diagonal black lines. Hand dug wells are the yellow ring shape on the map, and the green square is a reference point for daily activity in the community

Figure 2 is a map of water seasonality per population served on the Plateau. Twenty-three of the thirty-two water sites were classified and confirmed as seasonal or non-seasonal during data collection. De identifying data was gathered on how many people were served by each specific tank, spring, well, or pond. The nine other sites are not shown on the map because of unconfirmed seasonality.

Figure 2 Water Seasonality per Population Served on Nyakach Plateau, Nyanza Province, Kenya, 2012. The yellow circle denotes a seasonal site, and the blue circle denotes a non-seasonal site. The population surrounding each site is displayed in this map through a progression of blue color around each water location and overlaid on satellite imagery of the Nyakach Plateau. The lighter the blue, the smaller the population served by the water site and the darker the blue, the larger the population served by the water site

Figure 3 shows the eleven sites that were tested for lead with a reading greater than zero. Ten sites had results between 0.5 and 8 µg/L. Sites 011 and 012had results of 0 µg/L. Site 008 had a lead reading of 7.75 µg/L, but is not shown on the map because of missing GPS coordinates. (Table 1) shows lead levels per site.

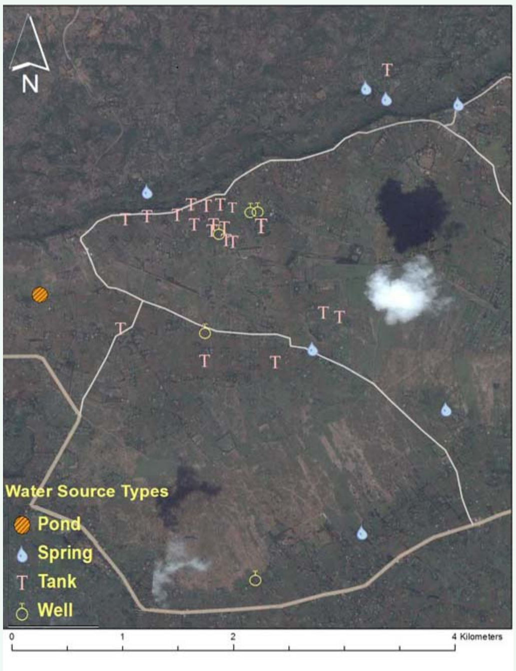

Figure 1 Types of Water Sources, Nyakach Plateau, Nyanza Province, Kenya, 2012. Water tanks are denoted on the map with a pink T. Natural springs are shown as a light blue droplet. One pond was located and is marked by an orange circle with diagonal black lines. Hand dug wells are the yellow ring shape on the map.

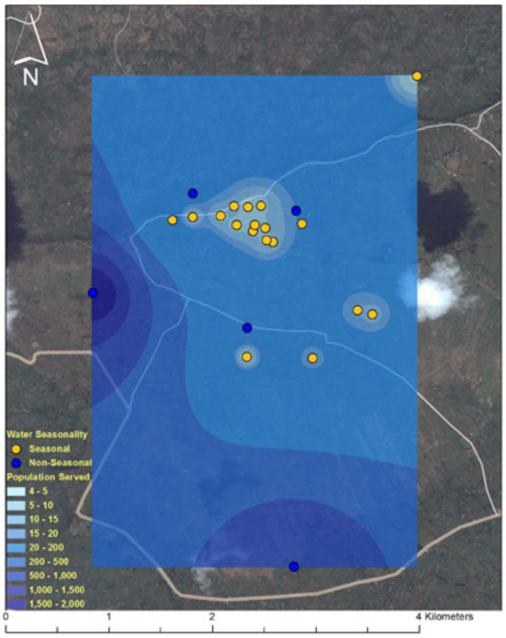

Figure 2 Water Seasonality per Population Served on Nyakach Plateau, Nyanza Province, Kenya, 2012. The yellow circle denotes a seasonal site, and the blue circle denotes a non-seasonal site. The population surrounding each site is displayed in this map through a progression of blue color around each water location and overlaid on satellite imagery of the Nyakach Plateau. The lighter the blue, the smaller the population served by the water site and the darker the blue, the larger the population served by the water site.

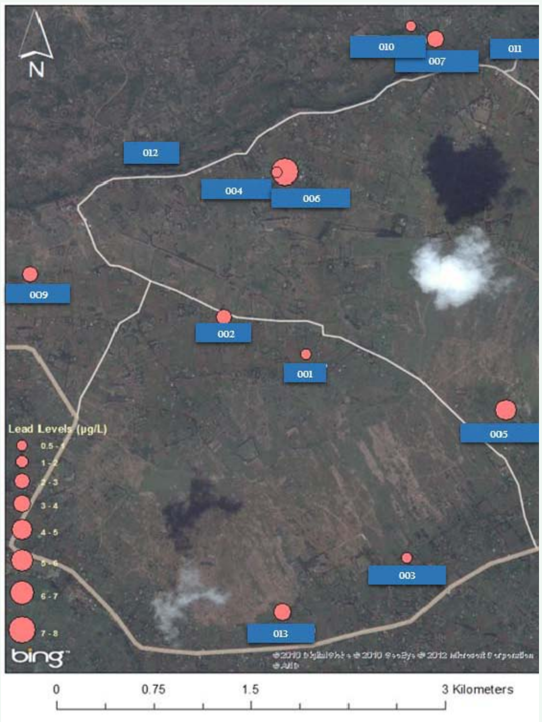

Figure 3 Lead Levels (µg/L) in Water Sources on Nyakach Plateau, Nyanza Province, Kenya, 2012. Lead levels in water sources, are shown by a graduated circle of varying diameter magnitudes. The smaller the circle's diameter, the lower the lead level in units of micrograms per liter (µg/L), andthe larger the circle's diameter, the higher the lead level in µg/L.

Table 1: Lead levels per water site, Nyakach Plateau, Kenya, 2012.

Lead Levels per Water Site (µg/L)	
WATER SITE	**LEAD LEVEL (µg/L)**
001	1
002	3
003	0.5
004	8
005	4.33
006	1
007	4
008 (NOT ON MAP)	7.75
009	3
010	1
011	0
012	0
013	4

Figure 3 Lead Levels (µg/L) in Water Sources on Nyakach Plateau, Nyanza Province, Kenya, 2012. Lead levels in water sources, are shown by a graduated circle of varying diameter magnitudes. The smaller the circle's diameter, the lower the lead level in units of micrograms per liter (µg/L), and the larger the circle's diameter, the higher the lead level in µg/L

Figure 4 shows hydrogen sulfide-producing bacteria levels in eight water sources on the Plateau. Bacteria levels were tested in dilutions of 1:10, 1:100, 1:1000, 1:10,000, and 1:100,000. Using the most probably number method found in the PathoScreen procedures (see Table 3), bacteria counts at each site were calculated. Table 2 shows individual bacteria counts per water site. The smallest circle symbol (sites 012 and 001) represents 4,600 microorganisms of bacteria per 80 mL of sample water. The second largest circle (sites 004 and 006) represents 4,601-80,000 per 80 mL of sample. The third largest circle (site 007) denotes 80,000-260,000 microorganisms per 80 mL. The largest circle (sites 002, 009 and 010) denotes 260,001-460,000 microorganisms per 80 mL of sample water. Site 008 had a bacteria count of 66,000, but is not on the map due to missed GPS coordinates.

Figure 4 Hydrogen-Sulfide Producing Bacteria Levels in Water Sources on Nyakach Plateau, Nyanza Province, Kenya, 2012. Bacteria counts are shown on the map through a graduated yellow circle. Diameter magnitude corresponds to increasing most probably number (MPN) of bacteria per 80 mL of sample water. The smaller the circle's diameter, the lower the bacteria MPN count, and the larger the circle's diameter, the larger the bacteria MPN count per site.

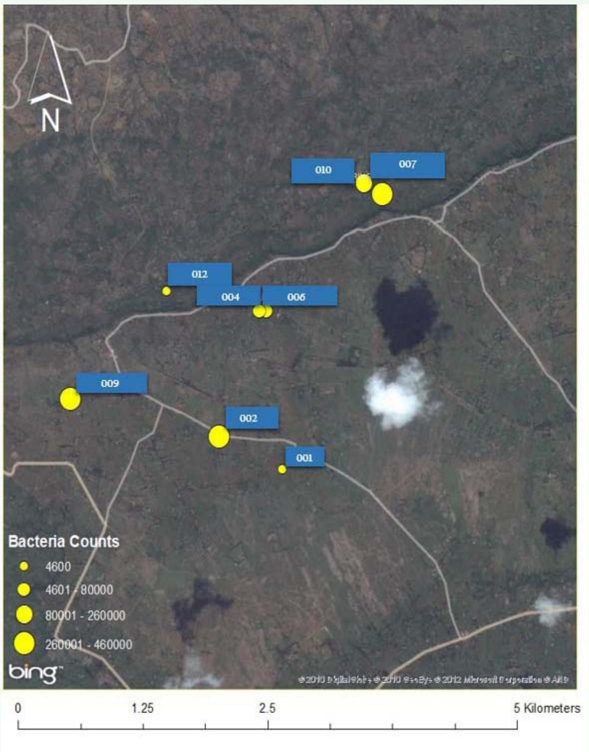

Figure 4 Hydrogen-Sulfide Producing Bacteria Levels in Water Sources on Nyakach Plateau, Nyanza Province, Kenya, 2012. Bacteria counts are shown on the map through a graduated yellow circle. Diameter magnitude corresponds to increasing most probably number (MPN) of bacteria per 80 mL of sample water. The smaller the circle's diameter, the lower the bacteria MPN count, and the larger the circle's diameter, the larger the bacteria MPN count per site.

Table 2: Four-tube most probable number (MPN)* for undiluted, 20-mL samples using 95% confidence limits (Hach Company 2011).

Positive Tubes	MPN/80 mL
0	< 1.1
1	1.1
2	2.6
3	4.6
4	8.0

Table 3: Bacteria counts per water site, Nyakach Plateau, Kenya, 2012.

Bacteria Levels per site	
WATER SITE	**BACTERIA LEVEL**
001	4,600
002	460,000
004	80,000
006	80,000
007	460,000
009	460,000
010	260,000
012	4,600
008 (NOT ON MAP)	66,000

DISCUSSION

Water sources

Water seasonality is an issue on the Nyakach Plateau, as well as in other parts of Kenya and East Africa. Rainy seasons draw run-off from higher elevations where it gathers in wells, springs, and ponds. This run-off brings dirt, debris, trash, and sewage from the surrounding areas and pollutes community water. During dry seasons, water and contaminants dry up, and are then reintroduced once the rains return. Nearly every hand dug well and spring lacked proper coverage and had no barrier of any type surrounding it. The presence of any concrete or rock barrier would assist in keeping livestock out and diverting run-off from entering the drinking water.

On the Plateau, only five out of the thirty-two water sites visited were confirmed as non-seasonal sources to sustain thousands living in the immediate area. Water is available at these five sites all year round, including the drought season. Water source 009 is one of the non-seasonal sites and serves an estimated 2,000 people during the dry season. It is connected to a fish pond, meaning that the waste products of the fish are also being consumed by the people. Sources 002, 004, 012 and 013 are the other non-seasonal sources. Source 002 is an unprotected well covered with sticks that serve300-500 people during the drought. Source 004 is also an unprotected, polluted site covered with sticks. This well water is used for cooking, cleaning and washing clothes, but not for drinking. A nearby tank provides drinking water for at least fifteen people. Source 012is a natural water source that feeds into a small river and pond nearby. Source 013 serves 1,000 people during the dry season, but was found to contain Culex larvae. A researcher of IPE Division, Kenya tested for Culex larvae, which carry elephantitis. Two cases were observed during our 14-day visit.

Plateau residents rely on non-seasonal sites for their water needs during droughts, which revealed the need for water tanks. In order to improve water security, a non-profit organization provided 25 tanks between 2010 and 2012. Figure 2 shows the location of the tanks, which cluster in the upper middle section of the map. They do provide water during the drought, but are classified as seasonal because they dry up before the drought is over. Water fills the tank by channeling rain water into the metal gutters lining the front section of the roof into the top of the tank.

Lead

Lead found in the water is a concern for human health, specifically that of children. A blood lead level of 10 μg/L or greater signifies a high risk of cognitive impairment, and levels close to the minimum risk level are still cause concern [2]. Unlike other particulates, lead cannot be removed from water through common filtration methods like boiling the water or adding a chemical.

As for the water sources, the highest lead level tested was 8 μg/L at source 004.The average lead found in all thirteen lead tests was 2.89 μg/L. According to (Figure 3), there is no clear regional pattern of lead levels. Although only one tank was tested, it had the second lowest lead level out of all the wells, springs, and pond. Any readings of lead are significant when compared to United States standards of a maximum contaminant level goal of 0 parts per billion [17]. No published Kenyan standards for leads in water were found. Lead has a high solubility, making it difficult to keep it from seeping into water sources when present. The softer and more acidic the water is, the more soluble lead becomes. The primary source of lead in the United States is residential plumbing, because pre-1930s pipes were made using lead soldering and with other lead-containing fixtures [18]. However, on this rural Plateau where these water samples were taken, there is practically no infrastructure for water piping. Thus, there must be another source of lead, from the soil, cooking dishes, or utensils with lead-based paint.

Bacteria

Bacteria test results were positive in dilutions from 1:1,000 to 1:100,000, meaning the water sources are highly polluted. Each source had three or four dilutions tested, with a positive results being black precipitates formed in the sample cell. The number of positive sample cells was matched to a MPN listed in Table 3. The MPN was multiplied by the highest positive test dilution to determine the estimated bacteria count per 80 mL of sample water. Positive tests showed the presence of hydrogen-sulfide producing bacteria specifically—Edwardsiella, Citrobacter, Salmonella, Proteus, and/or Klebsiella. Most microorganisms found in the drinking water originate from contamination by human or animal feces. Edwardsiella causes gastro-intestinal infection that can lead to a “typhoid-like” illness [19]. The bacteria *Salmonella* typhi causes typhoid fever with symptoms of fever, weakness, and rash, that is spread through contamination of water used for drinking or food preparation [20]. Klebsiella, normally associated with healthcare-related infections, is spread among people as a result of poor hygiene. It is linked with pneumonia, bloodstream infections, and meningitis [21]. Therefore, it is not surprising that typhoid fever and infectious diseases plague the third-world, where high quality water is often inaccessible and inconsistent.

Other bacteria, *E. coli*. naturally occurs in third-world water where water quality standards are absent or go unenforced. Standards in the United States require that no more than 5.0%of samples, meaning only 1 in 40 samples can be positive during a round of water testing. USEPA standards state that the maximum contaminant level goal for total coliforms (including fecal and E. coli coliforms) in drinking water is zero [17]. Safe drinking water is accessible to 99% of U.S. citizens. Only "54% of Kenyans have no access to safe water supply and therefore, it is a big challenge to ensure affordable and safe drinking water, especially at point of use (household level) [22]".Therefore, interventions must be implemented to decrease this percentage.

CONCLUSIONS

Government level intervention

Moderate lead levels and high bacteria counts in the tested water sources show the need for holistic water quality interventions. According to a 2008/2009 Demographic Health Survey conducted in Kenya, "approximately 45% of Kenyans are practicing household water treatment methods—mainly boiling and chlorination [22]. At the government level, the MPHS should continue to promote education about water quality and the practical water filtration methods of boiling, chlorine addition, or use of a sari cloth. The MPHS states that 49% of Kenyans lack access to basic sanitation facilities, which is a specific target of the MDG 7 [23]. Thus, their mission is "to ensure water safety at the source, during transportation, treatment, storage, and point of use [23]"Funding from the MPHS could allow for the placement of chlorine dispensers at community sources in rural areas of Kenya, where water infrastructure is extremely limited. Other goals include improvement of water surveillance and testing from the current 10% to 30%, increasing partnerships with other divisions concerning water safety, and responding within two days of waterborne disease outbreaks [24]. Improved sanitation through implementation of latrines hygiene education are essential for meeting these water quality goals and reducing the transfer of disease. National, government-level interventions appear to have the greatest impact through implementation of the Sanitation and Hygiene Policy, continued research on hand-washing behaviors, and creation of a centralized sanitation database.

Non-governmental level intervention

Non-governmental organizations can also improve water quality. Innovations for Poverty Action (IPA) are specifically scaling up a chlorine dispenser program that has proven quite successful since its implementation in 2010. In 2 years, approximately 420,000 Kenyans have been reached by 2,000 chlorine dispensers. Each dispenser is mounted on a metal pole and cemented into the ground near a community water source. Inside the dispenser is a container of chlorine, dispensed in 3 mL doses, to be added prior to filling with water. After 30 minutes, the water is purified to drinking standards, regardless of the container's cleanliness. This program is cost-effective to install ($80) and each chlorine dispenser ($2) lasts for about a month. The Nyakach Plateau would be an ideal location for this program, and could be followed by an ecological study on usage and health outcomes. Potentially, one community would receive the chlorine dispensers, and a second community would receive an educational flyer on the importance of filtering and purifying their water before consumption. These efforts would target and potentially decrease the prevalence and incidence rates of diarrhea, typhoid, and cholera.

ZeroWater™ intervention

The introduction of ZeroWater™ filters in Plateau schools is proposed to address the lead issue for children in the community. The school would be the main focus forfilter placement since children are more at risk for lead uptake and toxicity [4]. ZeroWater™ filters are the only water purifier on the market that removes lead and chromium from water, through an ion exchange, multi-layer carbon, and oxidation-reduction alloy process. The amount of water each filter would purify depends on the total dissolved solids (TDS) in the raw water. The greater the TDS count, the shorter the lifespan of the filter. Ideally, school leadership would be trained on how to use and maintain the water bottle(s) and filters (4.5 gallon capacity), and how to keep track of used filters for recycling purposes. Practically, filters could be sponsored through an outside organization to help ensure program sustainability [25].

Limitations

This research was limited by both the geography and environment in which the data was gathered. Each water site required hiking through marshland in the heat of the day at an altitude of 5,000 feet. The rough terrain limited our efforts to gather data from a larger number of locations, although we were able to gather GPS coordinates and data from thirty-two sites. A local translator led us efficiently from site to site allowing the team to gatherample baseline data on which to form future efforts to improve the water quality for the Plateau community.

The sophistication of field instruments was also a limitation to this baseline research project. It was nearly impossible to have sterile conditions for water testing, because water samples were tested outdoors. The team lacked conditions and transportation needed to set up a sterile laboratory environment with incubators for bacteria testing. However, the water test kits were created specifically for field usage and came in hard plastic containers ideal for transport. Sealed purified water bottles and a dilution of bleach solution were used to clean the water sample instruments and vials between uses. With conditions and short time period taken into account, the team conducted a large number of water tests in the most scientific and reliable way possible.

FUTURE WORK

Gathering more water quality data and GPS readings would greatly add to this research. Extensive documentation of the blood lead levels of children under 14, their main source of water, and the location of their home would also benefit this project. More data would allow for greater definition of correlations and links between the amount of lead in water and the children's BLLs, ultimately leading to improved public health and quality of life.

ACKNOWLEDGEMENTS

The authors would like to thank Chris Breed, who aided in the creation of the four GIS figures in the results section.

REFERENCES

1. Centre on Housing Right and Evictions, American Association for the Advancement of Science, Swiss Agency for Development and Cooperation, United Nations Human Settlements Programme. Manual on the Right to Water and Sanitation. 2007.
2. American Academy of Pediatrics Committee on Environmental Health. Screening for elevated blood lead levels. Pediatrics. 1998; 101: 1072-1078.
3. United States Environmental Protection Agency. Office of Prevention, Pesticides, and Toxic Substances. Environmental fact sheet: Lead leaching from submersible well pumps (EPA747-F-94-001). 1994.
4. Lin-Fu JS. Vulnerability of children to lead exposure and toxicity. N Engl J Med. 1973; 289: 1289-1293.
5. Goyer RA. Lead toxicity: Current concerns. Environ Health Concerns. 1993; 100: 177-187.
6. Maas RP, Patch SC, Morgan DM, Pandolfo TJ. Reducing lead exposure from drinking water: Recent history and current status. Public Health Rep. 2005; 120: 316-321.
7. Raab GM, Laxen DPH, Fulton M. Lead from dust and water as exposure sources for children. Environ Geochem Health. 1987; 9: 80-85.
8. Sherlock JC, Ashby D, Delves HT, Forbes GI, Moore MR, Patterson WJ, et al. Reduction in exposure to lead from drinking water and its effect on blood lead concentrations. Hum Exp Toxicol. 1984; 3: 383-392.
9. Thomas JF, Elwood PC, Welsby E, St Leger AS. Relationship of blood leads in women and children to domestic water lead. Nature. 1979; 282: 712-713.
10. World Health Organization. World health report 2002: Reducing risks, promoting healthy life.
11. United Nations Millennium Development Goals: Millennium Development Goal 7.3. 2010.
12. Murray K, du Preez M, Kuhn AL, van Niekerk H. Water Research Commission: A pilot study to demonstrate implementation of the national microbial monitoring programme.
13. United Nations Children's Fund and World Health Organization. Diarrhoea: Why children are still dying and what can be done. 2009.
14. World Health Organization. Water, sanitation and hygiene links to health: Facts and Figures – updated November 2004.
15. Parker AH, Youlten R, Dillon M, Nussbaumer T, Carter RC, Tyrrel SF, and Webster J. An assessment of microbiological water quality of six water source categories in north-east Uganda. J Water Health. 2010; 8: 550-560.
16. Hach Company. PathoScreen field kit: Test procedure. Loveland, Colorado; 2011.
17. United States Environmental Protection Agency. Drinking water contaminants: National primary drinking water regulations. 2009.
18. Miranda ML, Kim D, Hull AP, Paul CJ, Galeano MAO. Changes in blood lead levels associated with use of chloramines in water treatment systems. Environ Health Perspect. 2007; 155: 221-225.
19. Clarridge JE, Musher DM, Fainstein V, Wallace RJ Jr. Extraintestinal human infection caused by Edwardsiella tarda. J Clin Microbiol. 1980; 11: 511-514.
20. Centers for Disease Control and Prevention. National center for emerging and zoonotic infectious diseases: Typhoid fever. 2010a.
21. Centers for Disease Control and Prevention: Healthcare-associated infections: Klebsiella pneumonia in health care settings. 2010b.
22. United Nations Children's Fund, World Health Organization: National household water treatment and safe storage strategies and integrated household environmental health interventions. 2011.
23. Ministry of Public Health and Sanitation in the Republic of Kenya: Sanitation and Hygiene Promotion. 2011b.
24. Ministry of Public Health and Sanitation in the Republic of Kenya: Water Safety and Quality Control. 2011a.
25. Zero Technologies, LLC. 2009.

Cite this article

Rowlands JM, Bruce ED (2014) A Case Study of Rural Kenyan Water Quality: Evaluating Lead and Bacterial Exposures for Children on the Nyakach Plateau. JSM Environ Sci Ecol 2(1): 1011.